REPORT

OF THE

STATE GEOLOGIST

ON THE

MINERAL INDUSTRIES AND GEOLOGY

OF

VERMONT

1919-1920

TWELFTH OF THIS SERIES

GEORGE H. PERKINS

State Geologist and Professor of Geology
University of Vermont

BURLINGTON, VT.:
FREE PRESS PRINTING Co.
1921.

STAFF OF THE VERMONT GEOLOGICAL SURVEY, 1919-1920.

GEORGE H. PERKINS, *State Geologist, Director.*
Professor of Geology, University of Vermont.
ELBRIDGE C. JACOBS, *Assistant.*
Professor of Mineralogy, University of Vermont.
CHARLES H. RICHARDSON, *Assistant.*
Professor of Mineralogy, Syracuse University.
CLARENCE E. GORDON, *Assistant.*
Professor of Geology, Massachusetts Agricultural College.
NELSON C. DALE, *Assistant.*
Professor of Geology, Hamilton College.
J. W. MERRITT, *Assistant*, 1920.
Sapulpa Refining Company, Oklahoma.
ROLF A. SCHROEDER, *Assistant*, 1920.
U. S. Engineers Office, Chattanooga, Tenn.
D. B. GRIFFIN, *Field Assistant.*

CONTENTS.

LIST OF PLATES.

LIST OF FIGURES.

STATE OF VERMONT.

OFFICE OF STATE GEOLOGIST.

BURLINGTON, January 3, 1921.

To His Excellency, Percival W. Clement, Governor of Vermont:

Sir:—In accordance with Section 405 of the General Laws I herewith respectfully present my Report for the years 1919-1920 as State Geologist, this being the twelfth biennial report of the present series.

The introduction following sufficiently indicates the scope and character of the work accomplished during the last two years.

It is a matter of satisfaction that through the continued appropriation of the last Legislature, the work of accurate mapping of the State has been carried forward successfully in cooperation with the Federal Survey and that a considerable addition to previous surveys has been made so that it will not be long before half of Vermont is fully mapped and the maps made available to citizens of the State.

Respectfully submitted,

GEORGE H. PERKINS,

State Geologist.

INTRODUCTION.

The work of the Vermont Geological Survey which was begun in 1898 has been continuously carried on since that time. Eleven Reports have been already published and the work, of which these have contained accounts of more or less completeness, has been followed in the same manner during 1919-1920, but in additional portions of the State.

Before the beginning of the present Survey very little was accomplished by way of exploration and study of the rock beds of different parts of Vermont since the close of the old Survey in 1861. At that time a large Report in two quarto volumes on "Vermont Geology" was published by the State, copies of which I suppose are found in most of our town libraries. This Report, by Dr. Edward Hitchcock and several Assistants, has long been out of print and very much of it out of date according to modern geological ideas, though the volumes do contain much that will always be valuable for reference and historically as well.

Between 1861 and 1898 no volumes were published.

The work of the older geologists was for many reasons, chief of which were lack of time and funds, both of which were exceedingly limited, little more than that of hasty reconnaissance. This was all that was possible under the circumstances.

Such investigation as would properly be considered reconnaissance must always be first in the examination of any region, for it is obviously preliminary to more detailed work, but so far as possible it has been the policy of the present Survey to follow the preliminary examination of any part of the State by more careful and thorough investigation as it is only this latter that is of practical value, at least in most cases. Nearly all of the papers presented in the following pages are of this sort and must be a part of the permanent record of Vermont geology.

As has been stated elsewhere, it is the intention of the Geologist to include in these Reports everything available that seemed to him worthy to form a part of the final record of the geology of Vermont and also to enlist in the geological investigation of the State the services of competent geologists from other states. Anyone looking over a file of past Reports can judge how successfully this plan has been carried out.

In the present volume will be found several most excellent and valuable papers treating very thoroughly of different phases of our geology. No more than a brief summary of the contents of the pages which follow is necessary, but so much as this may be helpful in calling attention to the scope of what is to be found.

The first paper, "Structural and Metamorphic Geology of the Hanover District of New Hampshire," by Dr. J. W. Merritt, although it might readily be questioned because of its title and regarded out of place in a work on Vermont geology, has its justification in the fact that more than half of the Hanover District is in Vermont and the whole area is really continuous with this State, so far as geology is concerned. The paper will be found to be a very thorough investigation of the rocks of the region discussed and an important addition to the geology of the State.

Mr. Schroeder gives a brief account, which supplements his paper in the Report preceding this, of the Geology of Essex County. This is very welcome because little has been done in this section of the State and therefore information as to this is desirable.

In the previous Report, Professor Dale gave a preliminary statement of his work in the western part of Vermont. In the paper on "The Areal and Structural Geology of a Portion of the Western Flank of the Green Mountain Range," a much fuller report on the area studied is presented. Portions of the Burlington and Middlebury Quadrangles are studied with especial reference to metamorphic rocks.

For many years Professor Richardson has studied the rocks of eastern Vermont and has gone over a considerable number of the eastern townships, beginning at the Canadian border and continuing south until in the present Report he discusses the "Geology and Mineralogy of Braintree." In this work Professor Richardson was assisted by Mr. C. K. Cabeen. In course of his work in Vermont, Professor Richardson has studied the geological conditions in more than fiftten townships and added greatly to what was previously known of the geology of eastern Vermont, as will be readily seen by anyone who examines his papers in former Reports of this series.

The Geologist gives a "Detailed Study of the Trenton Beds of Grand Isle," which paper is a report of a careful study of the limestones of Trenton age on the island.

The value of this article is greatly increased by a report on the fossils collected by Dr. R. Ruedemann, who has identified the various forms which have thus far been found in the beds named.

In the sixth paper, Professor Jacobs continues his work reported in several previous volumes, on "Progress in Talc Production" in Vermont, to which are added some statements of general talc production.

The seventh paper by Professor Clarence E. Gordon is an exceedingly full and thorough account of his "Studies in the Geology of Western Vermont." During the past twenty years several geologists have written on parts of this region, notably Drs. Brainerd and Seely, and the present paper will be found by geologists a very important supplement to all former work, as it is also far more complete.

Professor Jacobs, in the next paper, gives a very interesting and valuable account of "The Geology of Lake Willoughby."

The final paper is a "Report on the Mineral Resources" of the State by the Geologist and he has included in this some discussion of the granite areas of Vermont and the relation of granite to other rocks of the region.

The Geologist wishes to say that, as in all Reports, he does not in any way hold himself responsible for opinions and statements which are given in the various papers. Each author is given the fullest liberty to express whatever ideas he may wish and for these he alone is responsible.

STRUCTURAL AND METAMORPHIC GEOLOGY OF THE HANOVER DISTRICT OF NEW HAMPSHIRE.[1]

JOHN WESLEY MERRITT.

TABLE OF CONTENTS.

[1] A thesis submitted to the Graduate School of the University of Wisconsin in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

INTRODUCTION.

PREVIOUS WORK.

The first field work done in this region was by the first State Geological Survey, established in 1839. The final reports of this work were published by the Geologist, Dr. C. T. Jackson, in 1841 to 1845. In 1868 the State Legislature provided for the re-establishment of the State Survey and provided an annual appropriation for a period of ten years. C. H. Hitchcock was appointed State Geologist. Annual progress reports were published. In 1878 the last five volumes, comprising the final work, were published under the caption "The Geology of New Hampshire." These were accompanied by an atlas. Subsequent to the publication of the Geology of New Hampshire, Hitchcock has published several papers touching upon the geology of this region, the last

PLATE I.

Topographic Map of the Hanover Quadrangle.

of which appeared in the Report of the Vermont State Geologist for 1911-1912.

Besides the reports mentioned above, two chapters mentioning rocks in this district appear in the U. S. Geological Survey Bulletin 150.[1]

FIELD WORK BY THE WRITER.

The writer began field work at Hanover in September, 1912, and continued it through the school months until June 1, 1916. The work was carried on, for the most part, without reference to previous writings and with little attention to earlier reports, until the areal geology was practically complete, because it was desired that the writer be not prejudiced by structural or lithological descriptions of earlier workers here. Field work was based upon a topographic map later to be described. A fairly complete collection of the rocks of the Hanover district was made by the writer and added to specimens previously collected by Hitchcock and Goldthwait. Thin sections representative of the rocks of the region were prepared. One section, at least, was made of each rock group, and several sections from such groups as were in doubt as to origin, or whose mineralogy was especially interesting. Many specimens and sections are present in this Dartmouth Collection which are not described in detail in this paper.

THE BASE MAP.

The base map upon which the areal geology of this region is placed was compiled from the following sources by Dr. Goldthwait: U. S. Geological Survey topographic sheets for the Hanover and Strafford quadrangles; topographic maps of small areas around Hanover, surveyed by the Thayer School of Civil Engineering; and topographic survey work carried on by Dr. Goldthwait himself. The topographic map is shown as Pl. I.

SCOPE AND PROBLEMS OF THIS PAPER.

Original basis of field work and subsequent limitations. During field work in the Hanover district it was the writer's intention to prepare a complete geologic report covering the areal and structural geology of the entire "Hanover Circle" and, if possible, for the purposes of stratigraphy, to correlate in some way the rocks of the "circle" with those outside of the region whose ages are known. It is hoped that this work may be completed at some future date. It seemed best, however, to limit this paper to a study of the granite and the closely overlying rocks in order to determine their origin, character, and the kind and extent of metamorphism. The primary attempt to obtain some quantitative values of the endomorphic effects of the granite upon the intruded formations was not successful because of the variable

---

[1] J. P. Iddings: No. 138. Epidote-Mica-Gneiss. (From Lebanon, Grafton County, New Hampshire.) U. S. Geol. Survey Bull. 150. 1898.
W. S. Bayley: No. 141. Garnetiferous Hornblende Schist. (From Hanover, Grafton County, New Hampshire.) U. S. Geol. Survey Bull. 150. 1898.

character of the mineral content of the different strata of the latter. The different rocks were studied carefully in the field to learn their general relations, and the quantitative mineralogical analyses were made to determine their present form, the kind and approximate amount of metamorphism, and their ultimate origin.

Previous variety of theories. Various theories of the origin of the rocks have been held by Hitchcock and others in the papers already mentioned. Even the Lebanon Granite was at first thought to be a gneiss or a schist of possible sedimentary origin, the next overlying schist being put with the granite as a darker part of the same formation. And the age of this granite was first placed by Hitchcock as greatest of any of the rocks of the region. Later he came to recognize its igneous origin and ascribed to it a laccolitic form. He then gave it an age younger than any of the surrounding rocks. In one of his later papers he states that the granite is overlain by a mica schist which shows the metamorphic effect of the granite for half a mile or more from the contact.

Need of more organized and detailed study. No quantitative chemical or mineralogical study of any of these rocks has been made, so far as the writer knows, up to the date of this writing. Nor has a complete discussion of the origin of the overlying schists or of the hornblende schist of Dartmouth Park been published, other than, in the latter case, a rather summary statement without arguments pro or con that the hornblende schist is probably of igneous origin.

Ultimate purpose of this paper. It has become the purpose of the writer, therefore, to supplement his field work by quantitative mineralogical study of the specimens collected from each of the formations in question, in order to assemble all available evidence, both field and laboratory, that may be of service in clearing up the problem of the origin of these schists and their metamorphic and other relations.

THE USE OF DIAGRAMS.

Triangular diagrams. In order to show graphically the mineralogical relations between different rocks of the region and to compare these rocks with average types from other localities, the triangular diagram has been used. These diagrams show the percentage values of three groups of constituent minerals. Plates IV, V, XIII. The distance from the base of the triangle to the point plotted marks the per cent. of that group of minerals shown on the apex toward which the measure is made. A straight line passed from that apex through the point plotted to the base of the triangle marks a complete series of analyses whose proportions of the other two mineral groups are the same as that of the first mineral plotted, but which represent all possible variations in the third group of constituents. Where some constituents

fall outside the groups included at the three corners of the triangle, that percentage missing is represented by the altitude of the small triangle so formed within the main triangle. In the case of such a triangle of unplotted ingredients, the percentage of each ingredient plotted is shown by the distance from the base to the side of the small triangle parallel with that base.

Straight line diagrams. For the purpose of showing variation of composition in a set of specimens taken along lines crossing the granite and extending out into the overlying rocks across the strike, a modified form of straight line diagram is used. This shows the variation along the line upon which the samples were taken of each of the more prominent ingredients, the diagram being so arranged that minerals from the same specimen are plotted one above another.

Source of comparative analyses. Where mineral analyses of rocks other than those analyzed by the writer were needed to place upon the triangular diagrams for comparative purposes the figures were obtained from norms given by Clarke.[1] Mineral analyses of sedimentary rocks are obtained by recalculation of chemical analyses given by the same author. The recalculations were carried on as far as possible in such a way as to derive such minerals as might be expected from the metamorphism of those sediments by dynamic processes. Page references for these analyses and for the norms given by Clarke may be found with the descriptions accompanying the diagrams.

ACKNOWLEDGMENTS.

During the course of his field work, and in the preparation of maps and assembling of the rock collection the writer was aided in no small amount by Dr. Goldthwait, and much gratitude is due him for his help and for his advice concerning this study. The writer is indebted to Dr. Leith, under whose guidance this paper was prepared, for his help and suggestions pertaining to field work, laboratory work, and the preparation of the paper. In his laboratory work in preparation for the writing of this paper innumerable comments and suggestions were offered by Professors A. N. Winchell, Edward Steidtmann and W. J. Mead, which the writer is glad to acknowledge with thanks.

LOCATION AND AREA.

The Hanover Circle. The topographic and geologic map, Pl. II, is drawn to cover a circle, with a diameter of 10 miles, the center of which is found at the center of the Dartmouth College campus. About half the area of the circle lies in Vermont, and the remainder in New Hampshire.

Area specifically studied. Although the whole circle has been covered by field investigations and a complete areal geological map of the region prepared, the area studied in preparation for

[1] Frank Wigglesworth Clarke: Data of Geochemistry. U. S. Geological Survey Bulletin 616. 1916.

this paper comprises but a part of the New Hampshire half of the circle. It is made up of an ellipse of granite, the overlying dark colored mica schist, and parts of the next two formations, a light sandy schist, and a clay-rock formation with interbedded strata of sandy schists or quartzites. The parts of the last two formations mainly concerned in this study lie on the west side of the granite, where the clay rock has been replaced by hornblende schist. The ellipse of granite is 5.8 miles long, 2.7 miles wide in its widest place, and has an area of about 6 square miles. The dark colored mica schist, next overlying the granite, varies in width from ½ mile to 1½ miles, and has an area of nearly 6 square miles.

TOPOGRAPHY AND DRAINAGE.

Drainage. The region is drained by the Connecticut river and its tributaries, the White, Mascoma, and Ompompanoosuc rivers. The Connecticut river flows southward across the center of the circle, entering at an altitude of 367 feet above the sea[1] and leaving at an altitude of 325 feet.

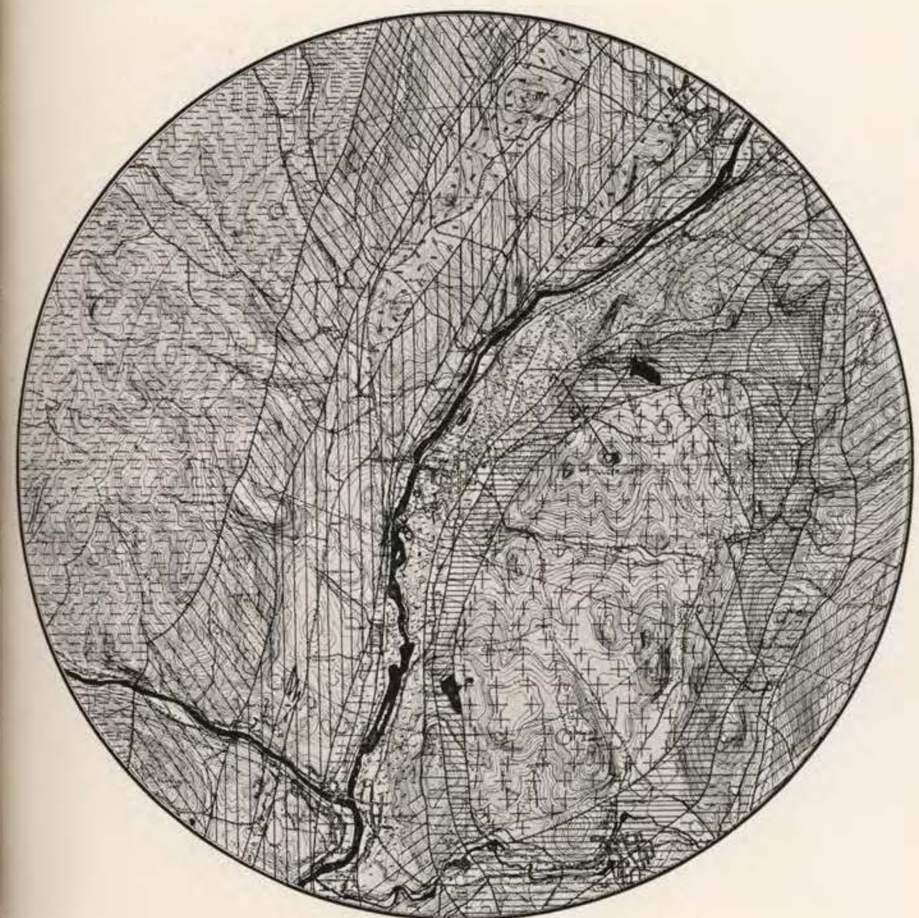
Relief. The lowest point in the region is at river level where the Connecticut leaves the circle, just south of White River Junction, Vermont. The highest point is the summit of Happy Hill, altitude 1,800 feet above tide.

Relation of topography and drainage to geology. A glance at the topographic map, Pl. I, will show the marked tendency for regularity of form and arrangement of hills and valleys. If this study is carried over to a comparison of the areal geology with the topography, a close relation between these two will be seen. In the region of the sedimentary rocks the hills are elongated, usually, in the line of the strike of the rocks, and the streams flow either parallel with the strike or else, where necessary for escape, directly across it. The Connecticut River, for instance, flows neither in a straight line nor in a very irregular course, but makes a wide curve which corresponds rather closely to the curve of the sediments wrapped around the granite ellipse, as though the river, in cutting downward, had slipped off the slope of the dome on the dip of the rocks. The White River, in the circle, cuts directly across the strike of the sediments, as do also the Mascoma and Ompompanoosuc rivers, but a short distance west of the circle the course of the White River swings back in a line roughly parallel with the strike of the sediments. Creeks tributary to the White, Mascoma, and Ompompanoosuc rivers usually enter these rivers flowing in a direction parallel with the strike of the sedimentary rocks. Within the area of the granite there is no such regularity of stream pattern. On the whole, it may be said that the streams of the Hanover circle make a trellis pattern, except where the granite is exposed at the surface.

On the Vermont side the high hills are made up mainly of

[1] C. H. Hitchcock: Geology of the Hanover, New Hampshire, quadrangle. Sixth Report of the State Geologist of Vermont. 1908, pp. 139, 140.

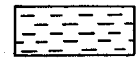
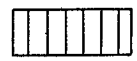
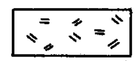
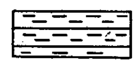
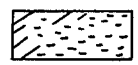
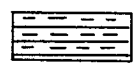
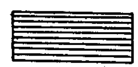
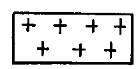
PLATE II.



Areal Geology of the Hanover Quadrangle.

sandy schists and slates, with occasional hills of basic igneous rocks. The Vermont side of the Connecticut River valley is underlain by calciferous chlorite schist, with the gorge itself cut down against quartzite in many places. In New Hampshire the high hills are sandy schists or granite, with the dark mica schist next above the granite forming a lowland or trench running entirely around the granite, except where it merges into the Mascoma or Connecticut valleys. The Connecticut River valley in New Hampshire is underlain by slate, some sandy schist, and the hornblende schist.

GEOLOGICAL STRUCTURE SHOWN IN PLATE II, HANOVER QUADRANGLE.

	Sandy schist.
	Slate and phyllite.
	Slate and phyllite.
	Chlorite schist.
	Basic intrusives.
	Quartzite conglomerate.
	Hornblende schist in clay rock group.
	Clay rock group without hornblende schist.
	Light gray to yellow sandy schist.
	Lower mica schist.
	Lebanon granite.

AREAL GEOLOGY.

Sedimentary rocks. Overlying the granite, in ascending order, are the following rocks: (1) lower gray mica schist; (2) light gray to yellow sandy schist, containing squeezed quartzite pebbles near its base; (3) slate and phyllite, with interlayered quartzite and mica schist beds (changing in places to hornblende schist with interbedded micaceous quartzites); (4) quartzite conglomerate; (5) slate and phyllite, with sandy layers; (6) calciferous chlorite schist; (7) slate and phyllite with sandy layers, grading upward into (8) sandy schist with occasional beds of slate or phyllite.

Intrusive rocks. Intruded into these sediments, especially into the calciferous chlorite schist and the underlying sediments, are numerous dikes and sills of basic igneous rocks, from a few inches to hundreds of feet in thickness. They vary from fine grained diabase dikes to coarse grained and sometimes porphyritic masses of diorite. The main intrusive mass, of course, is the granite laccolith, which intrudes into or underneath the oldest sediment of the series listed above. In the granite itself are found dikes of aplite, usually not over a few inches thick. Not many of these dikes have been found, and those which do appear are not very well defined. Some small, fine grained trap dikes, rarely over a few inches thick, cut the sediments which lie close to the granite.

GENERAL STRUCTURE AND METAMORPHISM.

Structure. The granite has been intruded into the sediments in such a way as to form a dome, elliptical in shape, with its longest axis lying northeast and southwest. The sediments dip away in all directions from the center of this dome. To the east and west are synclines, the one on the east rising again on the west slope of an area of similar granite five or six miles distant. Bedding is often ill defined and difficult to locate, because the rocks have been rendered so schistose that traces of bedding have been largely destroyed. Wherever bedding has been found clearly enough shown, the dip varies within wide limits. In one place the lower gray mica schist dips toward the granite. Here, on the hill slope directly east of the lower rapids below the Wilder dam, the reversal is due probably to slumping in of this rock during the intrusion of the granite.

The only fault found which could be traced any distance is on the Vermont half of the circle.

Stratigraphic relations. It is difficult to say, considering the highly metamorphosed condition in which they are now found, whether the sediments on the New Hampshire side of the circle follow one another in conformable series or not. The only conglomerate found in this half of the circle is near the bottom of the light gray or yellow sandy schist next overlying the lower gray mica schist just above the granite. This is not a distinct conglomerate bed, but rather consists of squeezed quartzite pebbles which may have had a diameter of three or four inches or less before flattening, held in a matrix of sand. No marked discordance of dip or strike between the lower gray mica schist and this light gray sandy schist has been noted.

Metamorphism. The sand and clay rocks of the region have been metamorphosed to micaceous sandy schists, slates, phyllites, and, locally, to hornblende schists, sometimes with the development of garnets.

The dikes and sills have, for the most part, been intruded late in the period of folding or after the folding was complete, because they show, with few exceptions, no tendency to take the form of schists or gneisses, and the exceptions themselves show usually only slight effect of dynamic metamorphism.

The granite has a gneissic texture which, with a well developed rock cleavage, lies roughly parallel with the plane of contact between the granite and the overlying mica schist.

AGE OF THE SEDIMENTS.

No evidence of the age of these sediments has yet been found. Hitchcock and others have made attempts at classifying them on a lithological basis. Hitchcock[1] says: "As to age, it" (chlorite group) "may be partly Cambrian and partly Ordovician; at least the geologists of Canada and Massachusetts give these references to the same rocks within their limits, the latter not using the term Cambrian for them."

The nearest place along the general strike of the rocks of this region where fossils have been found is at Littleton, New Hampshire, about forty miles northeast of Hanover. Here fossils have been found by Lahee[2] and identified as of Devonian age. Unfortunately, up to this time no attempt has been made to trace the rocks of the Hanover circle and vicinity northward along their strike to determine, if possible, their relation to those of the area at Littleton. It is hoped that later work may be carried on in this direction.

DESCRIPTION OF THE ROCKS.

THE LEBANON GRANITE.

Distribution. The Lebanon granite is found exposed in an ellipse on the east half of the Hanover circle, and in a single dike at the summit of Balch hill, 1½ miles northeast of Hanover. The ellipse is about 5.8 miles long, its longest axis lying northeast and southwest. Its greatest width 2.7 miles and its area about 6 square miles. At no place is the full width of the dike exposed, so the thickness cannot be given accurately. It probably does not exceed 40 feet in width. The ends of the dike are also covered, the only exposure being on the top of the hill, in the notch.

Previous descriptions. This rock was first described by Hitchcock[3] as a "protogene gneiss" and several areas in New Hampshire and Vermont, the rocks of which resembled each other, were grouped together and given the name Bethlehem

[1] C. H. Hitchcock: Geology of the Hanover, New Hampshire, quadrangle. Sixth Report of the State Geologist of Vermont, 1908, pp. 144, 145.

[2] Frederic H. Lahee: American Journal of Science, Vol. XXXVI, September, 1913, pp. 247-250.

[3] C. H. Hitchcock: Geology of New Hampshire, Vol. II, 1878.

gneiss. Later he revised his opinion, making this rock the youngest instead of the oldest of the Hanover region. His latest map, however, shows the area under the name "protogene." Of this granite in his latest paper fully describing it he says: "Now it seems clearly to be a batholite with a foliation somewhat concentric and the upper part and the adjacent Coös schist altered by contact, and the thermal influences working outward from the interior heated mass. Certain portions of it contain inclusions or fragments of the adjacent mica schist, which fact proves, first, the igneous character of the interior, and, secondly, its age later than the schists included within it."[1]

Acording to Hawes,[2] this granite was supposed to be protogene gneiss, the characteristic minerals of which were "chlorite, talc, rotten mica, and other decomposition products."

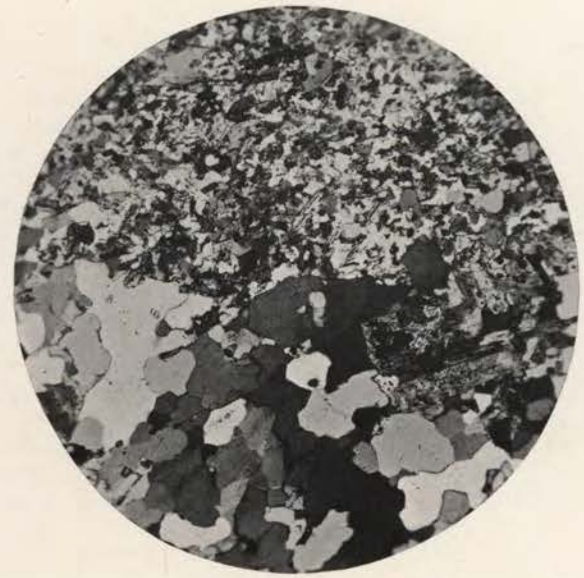
Iddings,[3] who has studied samples of this granite from the quarries near the southern end of the area, calls it an "epidote-mica gneiss, according to present classification. It consists of relatively large, irregular crystals of microcline, with small grains of quartz in aggregates equalling the feldspar in bulk, besides brown biotite in aggregates of small plates, variable amounts of colorless muscovite, and much epidote in aggregations of microscopic crystals. Subordinate minerals, occurring in relatively small amounts, are apatite, allanite, zircon, possibly sphene, and occasionally green mica or chlorite and, rarely, calcite. The rock is quite fresh and undecomposed, judging from the condition of the brown biotite. The epidote is grouped in aggregates with quartz and sometimes with muscovite, or it is scattered in various sized crystals and grains through the microcline, but there are no remains or other evidence of any ferromagnesian mineral, more or less altered, from which it could have been in part derived. It appears to be a primate constituent. . . . ." He mentions also the absence of magnetite and the minute quantities of minor constituents.

Mineralogy. The mineralogy of the granite is well described by Iddings in the quotation given above, though he has made no attempt at quantitative mineralogical analysis other than to note in a rough way the comparative bulk of quartz and feldspars.

The microcline is found in crystals of irregular shape with a diameter in cross section of as much as 1.5 mm.; though the average size of the larger crystals will run considerably lower, and a large number of grains of microcline will be found from 0.1 mm. up. Other feldspars rarely exceed 0.25 mm. in diameter, and the quartz grains are about the same size. The grains of quartz and feldspar in the schist inclusions are all much smaller

[1]C. H. Hitchcock: Geology of the Hanover, New Hampshire, quadrangle. Sixth Report of the State Geologist of Vermont, 1908, p. 165.
[2]G. W. Hawes: Mineralogy and Lithology of New Hampshire. Geology of New Hampshire, Pt. 4, 1878, p. 201.
[3]J. P. Iddings: No. 138. Epidote-Mica-Gneiss. (From Lebanon, Grafton County, New Hampshire.) U. S. Geol. Survey Bull. 150, 1898.

PLATE III.



Photomicrograph of Lebanon granite and a schist inclusion in contact, illustrating the difference in texture between the two, and the difference in size of mineral particles. The schist inclusion is the finer grained portion. Crossed nicols. X 26. Spec. 2401 a.

than the average for the same minerals in the granite. This difference may be seen in photomicrograph Pl. III. Epidote and other minor minerals in the granite rarely exceed 0.02 mm. in diameter. The micas are in plates or bundles of plates with a length of 0.25 mm. or more. Tourmaline, where found, is in needles arranged radially.

Iddings describes epidote as an original mineral, but the distribution of this mineral seems very irregular, and the writer has found epidote in numerous veins and stringers in the granite and in the overlying schist. The percentage of epidote is very low in the aplite and in the granite dike, and in sample 2401a, taken well within the granite area, and high in samples from Sta. 8, Sta. 6, and Sta. 1, relatively close to the border. It is also abundant in the schists overlying the granite.

The granite and overlying rocks have been analyzed mineralogically by the Rosiwal method, first getting the mineral quantities volumetrically, and then reducing to terms of mass. Then, except for the granite, quantitative mineral analyses were changed to chemical analyses. Following are tables of mineralogical analyses of the Lebanon granite. 9516 is the dike. 1301 is aplite.

Specimen No.	Sta. 8	Sta. 6	Sta. 1	9616	9619	1301a	2401a
Quartz	40.2	39.7	23.6	31.0	36.9	35.6	38.2
Orthoclase	33.6	33.0	4.8	23.8	21.8	...	5.0
Microcline	1.7	10.1	50.5	32.1	31.6	61.6	48.6
Albite	3.3	...	...	...	...	...	...
Andesine	...	...	...	...	...	...	0.4
Muscovite	...	8.3	9.7	6.1	6.0	...	3.5
Biotite	6.9	6.8	3.8	6.1	1.5	0.4	1.9
Epidote	14.4	4.5	6.0	...	1.9	0.1	0.3
Chlorite	...	...	1.2	0.9	...	...	...
Calcite	...	...	0.4	...	0.2	2.1	2.0
Tourmaline	...	...	...	...	0.1	...	...

Sta. 8 was taken from a point not far from the granite contact with the overlying schist. Its relation to the granite and to the schist may be seen in the triangular diagram, Pl. IV. As may be seen from this diagram, the average of the analyses of the Lebanon granite falls rather close to the average of several granites whose compositions are given by Clarke.

The mineral constituents of different thin sections of the Lebanon granite, especially the minor minerals, vary considerably in quantity, though this variation is no more than should be expected in a series of single petrographic analyses of different chips of the same rock.

Schist inclusions. The granite contains inclusions, not mentioned by Iddings, which have a mineralogy closely resembling that of the lower mica schist next overlying the granite. The following tables show the chemical and mineralogical analyses of specimens of these inclusions taken from a quarry on the Mount Support road, about 1½ miles southeast of Hanover.

Specimen No.	2401a	2401b	2401d
Quartz	55.3	55.2	40.3
Orthoclase	17.5	23.3	25.7
Albite	...	7.1	...
Andesine	...	...	2.9
Muscovite	1.5	1.1	1.5
Biotite	13.0	7.9	15.0
Epidote	3.0	0.6	12.0
Chlorite	6.7	0.4	2.6
Calcite	3.0	4.2	...
SiO_2	75.3	78.8	71.1
Al_2O_3	7.6	7.5	11.8
Fe_2O_3	1.1	0.5	2.3
FeO	1.8	1.1	2.1
MgO	3.9	1.0	2.7
CaO	2.5	2.5	3.2
Na_2O	0.4	1.1	0.7
K_2O	4.4	4.7	5.8
H_2O	1.6	0.5	1.1
TiO_2	0.3	0.2	0.4
CO_2	1.3	1.8	...

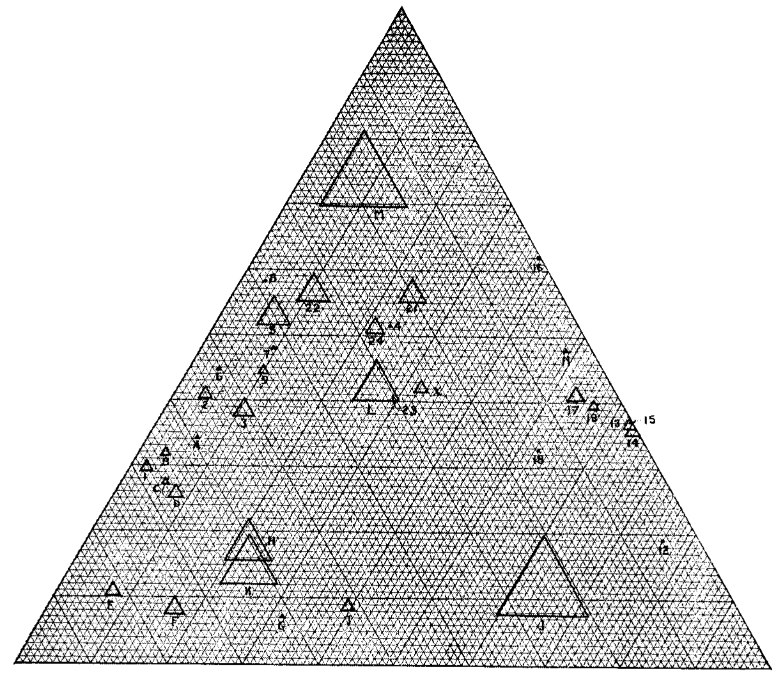
A comparison of the mineralogical composition of the schist inclusions with the schist next overlying the granite and also with the Lebanon granite and with other igneous rocks may be seen in the triangular diagram, Pl. IV. In the photomicrograph, Pl. III, the difference in texture between the granite and the schist inclusions is clearly shown.

Texture. The Lebanon granite is of medium to fairly coarse grain. The texture tends to be gneissic, more especially toward the border. Iddings calls the rock a gneiss instead of a granite, though Hitchcock notes its porphyritic character near the center. The groups of mica minerals are so arranged that they are roughly parallel with the plane of contact between the granite and the overlying schist. There is a distinct rock cleavage parallel also with this plane of contact, so that the granite appears to dip away from the center of the ellipse.

Origin of gneissic texture. The arrangement of the minerals so as to give a gneissic texture described above may be caused, according to Trueman,[1] by "(1) rotation of minerals in a still fluid magma, by (2) development of abnormal elongated mineral forms during crystallization, by (3) parallel growth of minerals with normal form development, or by (4) granulation, slicing, or gliding." Harker[2] says that "for the production of a primary gneissic banding in plutonic rocks two conditions are requisite—*viz.,* a heterogeneous constitution and a sufficient differential deformation while the mass is still fluid. The heterogeneity may

[1] J. D. Trueman: The Origin of Foliated Crystalline Rocks. Jour. of Geol., Vol. XX, 1912, p. 241.
[2] Alfred Harker: The Natural History of Igneous Rocks. The Macmillan Company, New York, 1909, p. 341.

PLATE IV.



Triangular diagram comparing mineral composition of Lebanon granite with that of average granite and averages of lower mica schist.

ANALYSES OF LEBANON GRANITE.

01—Spec. 9619
02— " 9616
03— " 1301a
04— " 2401a
05— " Sta. 1
06— " Sta. 6
08— " Sta. 8
A—Average of 01-08 inclusive

AVERAGE ANALYSES FOR COMPARISON

B—Average of granites. Bull. U. S. G. S. 616, p. 437.
9—Average of CD group of lower mica schist.
19—Average of AB group of lower mica schist.
X—Average of AB and CD groups of lower mica schist.

arise either from differentiation or from admixture." Iddings[1] passes the subject with the following brief sentence: "Streaked or banded texture is occasionally developed pyrogenetically, sometimes as schlieren, sometimes through shearing and metamorphism." Dale[2] ascribes this parallel arrangement of mica in streaks to "flow structure."

This gneissic character is a common border condition in granites of the New England region and elsewhere. As indicated by the above variety of theories, the origin of this texture is by no means decided.

Since the granite is gneissic mainly at its borders, it is safe to assume that the cause effecting this texture was not equally active at the center and at the periphery. From this it may be concluded that the texture was developed before the whole mass became solid. If caused by rotation of crystals in a still fluid magma, or by "flow," one would expect the micas to be more in streaks than in elongated bunches. While some of the minerals, such as micas, may be abnormally elongated, the writer does not believe that this alone can explain the texture found at the borders of the Lebanon granite. Except in the bunching of the micas, there is no marked parallel arrangement of the minerals. The micas, of course, are not as abundant in the granite as in the schist. There is no granulation or slicing to be seen in any of these sections. The granite is too uniform in composition to be thought of as forming a gneiss at its borders by admixture or by differentiation.

The writer ventures to offer the following suggestion as a simple explanation of gneissic texture in the Lebanon granite. When a substance is liquid and pressure is exerted at one point it is distributed equally throughout the mass. When it is solid, the application of a force from one direction would cause differential pressures and tend to develop, in the case of rocks, recrystallization and formation of minerals with longer axes normal to the direction of the force. Shearing may or may not accompany the process of recrystallization. Now, if the substance ranges from liquid to semi-solid state, it is reasonable to assume that, when pressure is exerted, say, from the side of the liquid, a point may be found between the most liquid and the most solid part where slight differential pressure may begin to exert itself. Here, then, will form the first gneissic arrangement of minerals. From here outward into the more solid part of the mass the gneissic character will increase.

Form and mode of occurrence. The Lebanon granite is intruded underneath or into a schist and probably has a laccolitic form. The contact of the granite with the schist is hidden in most

---

[1] J. P. Iddings: Igneous Rocks. John Wiley & Sons, New York, 1909, Vol. I, p. 355.

[2] T. N. Dale: Commercial Granites of Massachusetts, New Hampshire and Rhode Island. U. S. Geol. Survey Bull. 354, 1908, pp. 18, 19.

places by vegetation, soil, and glacial débris, and the line of this contact can be only approximated in the work of mapping, though in most places this approximated location should be quite close.

The granite was intruded at sufficient depth to allow it to be cooled slowly and at a uniform rate, for the rock is relatively coarse grained and the crystals are only slightly larger in the center of the area than at the periphery. It is possible, however, that the section through the granite, as exposed in the present erosion surface, is really more or less peripheral and may be cut rather close to the original upper surface of the laccolith for, scattered through the granite from border to center are many small inclusions of schist. These inclusions vary from less than an inch to three or four inches in diameter and should have been dissolved were they entombed within the granite at any great distance from the outside.

A dike of granite, cutting the schist at the summit of Balch Hill, is as coarse grained as the main mass of granite in the laccolith.

There is a distinct jointing in the Lebanon granite roughly parallel with the gneissic texture and also with the contact plane of the granite with the overlying schist. There is another set of joints approximately at right angles with the plane of the first set. The strike of the two sets is not far from the same. The sheets developed by the first set of joints vary up to ten feet or more in thickness.

The possible causes for sheeting in granite are ennumerated by Dale[1] as follows:

"1. To expansion caused by solar heat after the exposure of the granite by erosion.

"2. To contraction in the cooling of the granite while it was still under its load of sedimentary beds, the sheets being therefore approximately parallel to the original contact surface of the intrusive.

"3. To expansive stress or tensile strain brought about by the diminution of the compressive stress in consequence of the removal of the overlying material.

"4. To concentric weathering due to original texture or mineral composition. This action would be chiefly chemical and would be aided by vertical joints and by any superficial cracks due to expansion and contraction under changes of temperature.

"5. To compressive strain akin to that which has operated in the folding of sedimentary beds."

In discussing these various possibilities, Dale argues that 1 and 5 are the most effective. The jointing of the Lebanon granite is no exception to the type generally found in the granites of this region. It is possible that the effect of the solar heat may

[1] T. N. Dale: Commercial Granites of Massachusetts, New Hampshire and Rhode Island. U. S. Geol. Survey Bull. 354, 1908, p. 27.

have had something to do in the case of minor sheeting, but taken as a whole, the sheeting planes are parallel with the original upper surface of the granite and bear no marked relation to the present erosion surface. It seems probable that the causes mentioned under heading 2 or 3 were most effective in the formation of this sheeting.

Origin. The Lebanon granite, as first described by Hitchcock and Hawes, was called "protogene gneiss" and was said to be the oldest rock in the region. Later its igneous origin was recognized by Hitchcock and it was described as a laccolith intruded into or underneath rocks of greater age. Hitchcock then described it as a rock mass gneissic at its borders and porphyritic near its center. It is difficult to ascertain from his writings just how closely the granite gneiss is separated from the overlying mica schist, but it seems from a study of his map in the Report of the Vermont State Geologist, 1907-1908, p. 160, that the boundaries of the granite conform fairly closely with those by the writer shown on the map accompanying this paper.

That the Lebanon granite is of igneous origin may be seen almost by a glance at the hand specimen of the less gneissic phase of the rock, where its mineralogy and texture may most easily be seen. In the triangular diagram, Pl. IV, showing mineral composition it is seen to fall close to the composition of the average of a group of granites whose analyses are given by Clarke. The relative proportions of quartz and feldspar of the original magma are probably best shown by the aplite dike whose analysis is plotted on the same diagram, or by the granite dike plotted here also. The igneous origin of the granite is shown also by the fact that it is found as a dike cutting the schists.

Metamorphism. It is evident from the gneissic specimens of the granite, especially those collected near the boundaries of the granite, that this rock has suffered a certain amount of metamorphism subsequent to intrusion and before complete cooling.

During the course of this study it became evident that the granite has been affected by the rocks into which it has worked its way, though sufficient analyses to make a complete study of this effect are not at present available. The granite doubtless absorbed some of the ingredients of the intruded rock so that, on Pl. XI, it is to be seen that specimens along the section line CD, as samples approach the boundary of the granite, tend toward the composition of the average of the lower mica schist. Note here specimens from Sta. 8, Sta. 6, and Sta. 1, respectively, working inward from the schist. From Sta. 6 to Sta. 8 the granite changes mainly by the addition of iron and magnesium minerals, chiefly epidote, which is a common ingredient of the schist on this side of the granite area. From Sta. 1 to Sta. 6 the granite changes chiefly by the addition of quartz, of which mineral the former seems to contain but a small amount. As is to be expected, the dike rocks, aplite and granite, are lower in iron and magnesium minerals than the main body of the granite, especially where such substances might have been acquired by a limited amount of stoping.

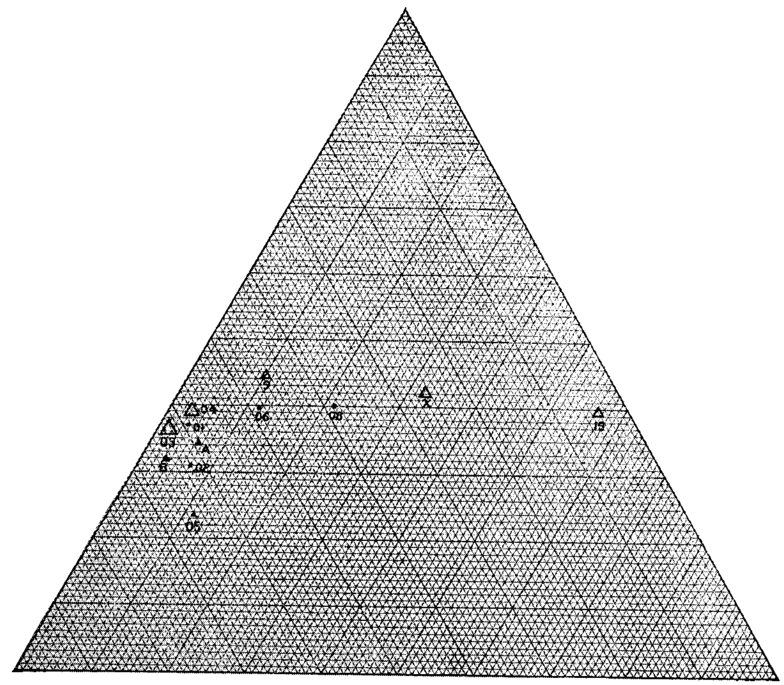
Summary. The Lebanon granite, which is younger than the schists, has entered in the form of a laccolith. During the intrusion the granite probably absorbed enough of the intruded schist to change the chemical nature of the outer part of the intrusive. Some of the magma was forced out into the overlying schist in the form of a dike, and small pieces of the schist were torn from the walls and included within the granite. During the intrusion, or at least before cooling was complete, the granite was rendered gneissic toward the outside of the laccolith, probably by differential pressure due to the application of the forces of the intrusion or other forces to the semi-solid part of the granite near the periphery. Subsequent to the cooling of the granite no great amount of metamorphism took place.

THE LOWER MICA SCHIST.

Distribution. The Lebanon granite is intruded into or underneath this schist, doming it up. Erosion has removed the top of this dome, so that now the older schist appears areally to be wrapped around the granite in a concentric band, varying from ½ mile to 1½ miles in width. The approximate area of this rock exposed within the circle is 6 square miles. The variation in width of the outcrop may be due to one or more of the following factors: (1) The narrowest part is along the west side of the granite ellipse, where the dip appears to be steepest. (2) The schist may have been originally lenticular in shape. (3) The next overlying rock has squeezed pebbles of quartzite near its base, which are found most of the way around the dome. This may be a basal conglomerate, and, if so, may mark an unconformity, and this might account for the removal of part of the lower schist by erosion before the deposition of the next formation. (4) The granite may be intruded into instead of underneath the lower mica schist, so that the former appears at a higher horizon in the schist on the west side of the ellipse than on the east side. (5) The schist may have been thickened by repeated folding.

Lithology. The group of rocks known as the lower mica schist, which extends upward from the granite contact to the base of the formation described as the light gray or yellow sandy schist, is made up mainly of rather coarse grained medium to dark gray or greenish mica schist layers interbedded with which are sediments of various other types. These interbedded sediments, on the east side of the granite area, as seen in the specimens taken along the line CD, are mainly quartzites and fine grained sericite schists. Along the west side of the granite area

PLATE V.



Triangular diagram comparing mineral composition of the lower mica schist with that of the schist inclusions, that of the average Lebanon granite, and with the mineral composition (norms) of average igneous rocks and average shales and sandstones.

the interbedded sediments are quartzites, quartz-mica schists, and clay rocks with some hornblende schists. The main rock, from which the formation gets its descriptive name, is so coarse grained, and in places resembles so closely lithologically the rock one would expect to find derived from the intense shearing of an igneous rock that it was called by the writer and others working with it in the field a "border zone" rock, surrounding the Lebanon granite. It was thought, because of the hornblende in parts of it along the west side of the granite, and because of other ferro-magnesian minerals found in it, to be either a more basic rock related to the granite, but intruded and metamorphosed previous to the intrusion of the granite, or else a border zone phase of the granite metamorphosed during the intrusion of the main portion of the granite. During the field study of this formation there was no small difficulty encountered in explaining the field relations of the so-called "border zone" rock and the interbedded quartzites and sericite schists. It was only while making quantitative mineral analyses of thin sections of the typical "border zone" rock that the probability of a sedimentary origin was impressed upon the writer, and the mineralogical evidence checks so well with the field relations of this rock that the sedimentary origin of this portion of the group seems conclusive.

Since there was no doubt of the origin of the quartzites and sericite schists, either in the field or in laboratory study, these rocks, together with the clay-rocks included in the lower mica schist group, have been left out of the tables of analyses given and only those analyses tabulated and plotted which represent rocks which in the hand specimen and in the field would be called "border zone" rock.

Mineralogy. Following are tables of mineral and chemical analyses of the older mica schist, omitting quartzite, and sericite and hornblende schist layers interbedded. The first table shows the mica schist samples taken along the line CD on the southeast side of the ellipse. The second shows analyses of the mica schist samples taken along the line AB on the northwest side of the ellipse. There is a marked difference between the ratio of the different groups of minerals in these two sets of analyses, as may be noted from triangular diagram, Pl. V.

SAMPLES TAKEN ALONG LINE CD.

Specimen No.	9512	9514	9515	9517	9518	9519	9520	9521
Quartz	28.2	40.3	37.7	51.7	51.5	44.7	47.9	58.2
Orthoclase	...	...	...	...	...	1.8	9.7	3.4
Microcline	31.6	27.7	29.2	1.4	...	1.8	0.7	...
Albite	...	...	...	14.1	0.3	11.1	...	11.9
Andesine	4.5	4.1	7.0	...	...	...	4.5	...
Muscovite	31.6	22.4	13.7	9.4	38.4	36.3	27.3	22.9
Biotite	...	0.5	5.2	5.4	...	2.9	7.9	1.9
Hornblende	...	...	...	...	...	...	...	...
Epidote	...	0.3	1.8	13.7	...	0.5	0.7	0.8
Chlorite	...	...	...	4.3	...	...	0.5	0.8

Specimen No.	9512	9514	9515	9517	9518	9519	9520	9521
Calcite	...	0.2	...	...	4.3	...	0.9	...
Garnet	...	...	...	...	...	...	...	...
Rutile	...	...	...	...	...	...	...	...
Zircon	...	0.2	0.5	...	...	...	...	...
Tourmaline	...	...	...	...	...	...	...	...
Titanite	1.8	0.5	2.3	...	...	...	...	...
Pyrite	1.8	2.7	2.7	...	5.4	...	...	...
SiO_2	66.1	60.4	69.9	75.1	69.2	72.4	72.9	80.2
Al_2O_3	19.3	14.9	14.2	11.5	14.9	18.9	15.2	12.3
Fe_2O_3	...	0.1	0.5	2.0	...	0.1	0.5	0.2
FeO	...	0.1	0.7	0.8	...	0.4	1.1	0.2
MgO	...	0.1	0.6	2.2	...	0.3	1.1	0.5
CaO	1.0	0.7	2.0	3.4	2.4	0.3	1.1	2.0
Na_2O	0.3	0.2	0.6	1.8	tr.	1.3	0.6	1.5
K_2O	9.0	7.3	7.0	1.8	4.5	5.2	5.7	3.5
H_2O	1.3	1.0	0.4	1.5	1.7	1.7	1.6	1.2
TiO_2	1.7	0.4	1.0	0.1	...	0.1	0.2	tr.
ZrO_2	...	0.1	0.3	...	...	...	...	...
FeS_2	1.8	2.7	2.7	...	5.4	...	...	...
CO_2	...	0.1	...	...	1.9	...	0.4	...

SAMPLES TAKEN ALONG THE LINE AB.

Specimen No.	9607	9608	9609	9610	9613	9614	9615	9618
Quartz	47.6	19.0	36.2	35.3	37.4	62.0	40.2	32.9
Orthoclase	...	5.0	...	...	...	...	3.5	10.0
Microcline	...	...	...	...	...	...	1.3	4.5
Albite	...	...	...	...	...	...	...	...
Andesine	3.5	...	...	...	...	...	...	...
Muscovite	...	...	...	...	...	...	...	...
Biotite	29.2	24.3	35.8	1.4	2.0	3.8	12.4	10.8
Hornblende	...	21.3	8.6	52.2	16.8	11.8	12.7	31.1
Epidote	17.6	21.0	17.2	5.0	27.4	18.8	24.8	10.7
Chlorite	...	5.4	...	...	15.7	...	...	...
Calcite	...	...	...	...	...	...	2.4	...
Magnetite	...	...	...	...	...	...	1.0	...
Garnet	1.4	...	...	...	...	...	...	...
Rutile	...	...	1.7	...	...	...	...	...
Zircon	...	...	...	...	...	...	...	...
Tourmaline	...	...	...	1.1	0.7	0.8	...	...
Titanite	0.7	3.0	0.5	1.6	...	...	...	...
Pyrite	...	1.0	...	3.3	...	2.8	1.7	...
SiO_2	67.4	51.2	60.3	72.3	61.5	76.2	62.9	64.6
Al_2O_3	10.0	12.9	10.6	6.9	11.7	6.5	10.0	10.0
Fe_2O_3	4.3	3.8	4.5	3.6	4.4	0.9	5.1	3.7
FeO	4.1	5.5	5.9	5.6	2.1	1.8	3.3	4.7
MgO	3.4	7.2	5.2	6.1	7.8	1.8	3.0	4.9
CaO	4.7	8.5	5.3	8.0	8.5	8.3	8.7	6.3
Na_2O	1.2	3.8	1.3	0.8	0.3	0.3	0.6	0.9
K_2O	2.6	3.2	3.3	0.5	0.3	0.4	2.0	3.8
H_2O	1.3	2.3	1.7	0.8	2.8	0.7	1.1	1.0
TiO_2	1.0	1.8	2.2	0.6	0.5	0.1	0.2	0.3
FeS_2	...	1.0	...	3.3	...	2.8	1.7	...
CO_2	...	...	...	...	...	...	1.1	...
B_2O_3	...	...	...	0.1	0.1	0.1	...	...

LOWER MICA SCHIST ANALYSES.

1—Spec. 9512
2— " 9514
3— " 9515
4— " 9517
5— " 9518
6— " 9519
7— " 9520
8— " 9521
9—Average of 1-8 inclusive

11—Spec. 9607
12— " 9608
13— " 9609
14— " 9610
15— " 9611
16— " 9614
17— " 9615
18— " 9618
19—Average of 11-18 inclusive
X—Average of 1-19 inclusive

ANALYSES OF SCHIST INCLUSIONS IN LEBANON GRANITE.

21—Spec. 2401a
22— " 2401b
23— " 2401d
24—Average of 21-23 inclusive

AVERAGE ANALYSES FOR COMPARISON.

A—Average of Lebanon granite.
B—Average granites, U. S. G. S. Bull. 616, p. 437.
C—Quartz diorite, U. S. G. S. Bull. 616, p. 454. (B).
D—Quartz monzonite, U. S. G. S. Bull. 616, p. 452. (B).
E—Andesite, U. S. G. S. Bull. 616, p. 455. (A).
F—Diorite, U. S. G. S. Bull. 616, p. 457. (B).
G—Quartz basalt, U. S. G. S. Bull. 616, p. 458. (C).
H—Diabase, U. S. G. S. Bull. 616, p. 461. (A).
I—Gabbro, U. S. G. S. Bull. 616, p. 463. (C).
J—Gabbro, U. S. G. S. Bull. 616, p. 469. (I).
K—Clarke's average igneous rock, U. S. G. S. Bull. 616, p. 419.
L—Average shale, computed from analyses, U. S. G. S. Bull. 616, p. 546.
M—Average sandstone, computed from analyses, U. S. G. S. Bull. 616, p. 541.

In the group of analyses of specimens taken along the line CD feldspar and muscovite are abundant, while biotite, hornblende, and epidote are relatively low or lacking entirely. In the group AB the feldspars are lacking in most of the analyses and muscovite in all of them, while hornblende, biotite, and epidote run high. The quartz ratio will be about the same in both groups.

Quartz grains in these rocks seldom exceed 0.25 mm. in diameter, and will average nearer 0.1 mm. A few microcline crystals were found with diameters as great as 1.5 mm.; but the average was about the same as that of the quartz. The remaining feldspars will run about the same size as the quartz grains, or smaller. The micas are arranged in bunches parallel with the rock cleavage. Often they are found in streaks. Hornblende, when it occurs, is found in similar parallel arrangement. Its diameter will run on the average, from about 0.02 to 0.04 mm. with the longer dimension two to four times as great. Epidote crystals are very small, as in the granite, though often arranged in large clusters. Zircon crystals are never found of greater length than 0.02 mm. Titanite appears in diamond shaped crystals from 0.01 to 0.05 mm. in diameter.

Many of the microcline crystals are well filled with inclusions of tiny needles and plates of sericite and chlorite, while in others grains of quartz are included. These included quartz grains do not occur in excess of 0.01 mm. or 0.02 mm. in diameter. The plagioclase feldspar shows inclusions to a lesser degree. The feldspars and quartz sometimes show undulatory extinction. Sometimes the hornblende crystals have pleochroic halos. Some of the zircon crystals appear to be well rounded and even etched or frosted in some cases, while others show clear and distinct interfacial and crystal angles. The biotite shows the effect of the weather and is often partly or wholly altered to chlorite. The titanite, also is weathered, and sometimes is decayed away entirely, leaving diamond-shaped holes in the section. There is a marked tendency for the zircon and titanite to be segregated in bands with the mica.

Occurrence. In the field or in the laboratory there is scant remainder of any sign of bedding to be seen in the "border zone" rock proper. True, there is a trace of lamination in some specimens which might be said to represent traces of bedding, but they might equally be said to have been formed during the development of the rock schistosity by the rearrangement of the minerals newly formed. But when the lower mica schist group as a whole is studied in the field, with its interstratified quartzites, traces of strike and dip of bedding planes may be found. The same is true also of certain interstratified clay rocks, which contain numerous laminations of more sandy materials, giving by this means the attitude of the beds. If the beds of quartzite be studied as units the key to the structure of the lower mica schist group may be obtained.

Origin. (*Evidence of field characteristics.*) Inasmuch as these beds of quartzite, sericite schist, and other rocks closely parallel the periphery of the granite, and are themselves mutually parallel, it would seem more probable from field evidence that these beds form a part of a group of sediments interstratified with each other than that they are beds of sedimentary rocks separated widely by intrusive masses of the so-called "border zone" rock. If the latter were the case, it would be expected that the igneous rock would in some place be found cutting across the bedding of the known sedimentary rocks and in places it would be expected also that the sedimentary rock would be broken up and included

within the rock that was thought to be igneous. Such occurrences have not been found. On the other hand, within the so-called "border zone" rock there are no such evidences of sedimentation as ripple marks, formation of conglomerates, etc. But the probable original nature of the rock and the effects of metamorphism would prevent or destroy such evidences.

(*Evidence of mineralogical composition.*) Quantitative mineralogical evidence also points toward sedimentary origin as the more probable interpretation. On triangular diagram, Pl. V, all specimens of the "border zone" rock are shown, and for purposes of comparison there are also plotted various kinds of igneous rocks. In choosing examples of igneous rock types for purposes of comparison, those types of a group are chosen which have the highest percentage of quartz shown in the norm. Thus, it is seen, the advantage of the doubt is given to a possible interpretation of igneous origin. Also, for purposes of comparison, the averages of the lower mica schist (exclusive of rocks known to be sedimentary) in the group AB and in the group CD are plotted, also the average of both groups. Besides this, there may be found plotted the composition of an average of several shales and of several sandstones given by Clarke. It will be noted, that the CD group falls on one side of the triangle because of the low content of iron and magnesian minerals. The AB group stands relatively high in iron and magnesian minerals and is found on the other side of the triangle. The average of the two groups lies strikingly close to the average analysis of shale, about in the center of the triangle. The nearest rocks of an igneous nature approaching the mineralogical composition of the rocks of the CD group are granites and allied rocks. In one case, specimen No. 9512, the rock in question has a mineral composition closely resembling the average granite. In this case, from a purely mineralogical point of view, the origin of the rock analyzed may be said to be at least in doubt, if not actually igneous. And it is not to be argued here that the occurrence of granite dikes within the schist is impossible, for such is known to be the case in at least one instance (on Balch hill). On the other hand, where such a dike is known, it is relatively coarse grained and is free from the development of schistosity—especially of the nature and to the degree of that found in specimen 9512. Hence, if this specimen be of igneous origin, it was introduced into the schist at a date earlier than that of the main granite mass. In all other cases the rocks of this group, while they fall on the same side of the triangle as the granites, show by their place in the triangle that they contain a much higher percentage of quartz. This percentage of quartz is usually far greater than would be expected in any common type of acid igneous rock. Such a superabundance of quartz may be taken as indicative, at least, of sedimentary origin. Of the rocks found along the section line AB the same thing may in general be said. The rocks of this group are relatively higher in iron and magnesian minerals than the rocks of the CD group. The igneous rocks more closely resembling the rocks of the AB group are the basic igneous rocks, but here, also, the igneous rocks fall far short of the amount of quartz necessary to form by dynamic metamorphism schists resembling mineralogically those of the AB group, even when basic igneous rocks with the highest available amount of quartz are chosen for the comparison. It should be added, in the case of the CD group, that where abnormal igneous rocks with high enough percentage of quartz to be comparable to these schists are chosen, they are deficient in the iron and magnesian minerals.

(*Evidence of rounded mineral grains.*) Such evidence as rounded grains of minerals remaining from the original sedimentary rock are sometimes seen and added to other proofs of origin. Grains of quartz may remain which have not been sufficiently recrystallized to destroy their original rounded outlines.

Better still, grains of heavy residuals, such as zircons, when well rounded, have been used as a proof of the sedimentary origin of the rock enclosing them. In the case of this "border zone" rock little if any rounding of quartz grains is discernible, and such as was seen was not well enough developed to serve as criteria of any considerable value. In using rounding of grains of heavy residuals one is usually cautioned to search for them in the coarser parts of the rocks with the quartz grains rather than in the clay laminæ. It has been the writer's experience, however, to find most of the heavy residuals in these schists grouped in bands of sericite and not with the quartz or feldspar grains. In this rock, however, the residuals are all smaller than 0.03 mm. in length and will average less than 0.01 mm. Some of these very small grains of zircon show rounding and etched or frosted surfaces, while others, even in the same section, have crystal faces and angles well defined and distinct. The writer questions the usability of such criteria as evidence of wear during sedimentation if it takes place under water, though it is not impossible that the etching and rounding may have been due to action of the weather in breaking down the original crystalline rock from which they came.

(*Evidence of the segregation of certain minerals in bands.*) Zircons are found in abundance in some of the "border zone" rocks, and several grains are found in each of many of the thin sections. They are exceptionally abundant in some of the more sericitic phases of this group of rocks. Here they are found in layers or bands of sericite rather than in the other parts of the rock with the quartz and feldspar grains. In this connection, the presence of titanite segregated with the sericite should also be mentioned. If a sedimentary rock made up of rather sandy shale, *i. e.*, shale relatively low in kaolin and high in finely ground

PLATE VI.

Photomicrograph of mica schist showing zircon crystals segregated in bands of sericite. The zircons are the small opaque or semi-opaque crystals whose long axes lie roughly parallel with the cleavage of the mica. Spec. 9506. Ordinary light. X 54.

PLATE VII.

Photomicrograph of a mica schist showing titanite crystals segregated in a band of sericite. The titanite crystals are the dark, semi-opaque, diamond-shaped crystals in the gray band of mica.
Spec. 9512. Ordinary light. X 54.

quartz should be subjected to anamorphism of the dynamic type one would expect the laminæ of kaolin with absorbed potash to form sericite. It is not necessary nor is it logical to think that this argillaceous material would be carried far from its original position during recrystallization, especially when this change takes place because of pressures which affect the rock as a whole. Consequently it may be thought that the sericite bands represent the contorted laminae of the original rock, were it sedimentary. If this be so, what is more reasonable than to look for the very small grains of the heavy residuals in the sericite bands which were clay laminæ in the original sedimentary rock? Plate VI shows the grouping of zircons in the sericite schist bands. It has been found that titanic acid is found in sedimentary rocks closely associated with the clay material. If this be the case, and if in the metamorphic rock the sericite bands represent original laminæ of clay, it would follow that the titanium might take crystal form in the sericite bands. This has been found to be the case, as illustrated by photomicrograph, Pl. VII. And it may be stated in addition that these titanite crystals are not found elsewhere in the sections except in this close association with the mica.

Of course, it might be argued that the crystallization of the titanite was induced in the neighborhood of the sericite from solutions passing by and carrying the titanic acid. But it remains to be proved whence this material came and why it should be precipitated at just this place and not elsewhere. Also it is by no means certain, if the elements of the rock were all original, just how far they would travel in the process of recrystallization. A study of recrystallization induced by dynamic metamorphism seems to support rather the belief that materials are not moved far during this process. It may be seen in certain rocks that the minerals formed, especially garnets, etc., have taken their constituents from the immediate vicinity. For instance, surrounding magnetite crystals may be noted areas low in iron, while a little farther away may be seen an abundance of biotite and other ferromagnesian minerals. And in the formation of these minerals, substances not needed are left where they occur, and are not carried out even a short distance to form other minerals near by which might well use this left over substance. Photomicrographs, Pls. VIII and IX, show crystals of garnet and of hornblende formed around small grains of quartz which were left in their original place in the former rock.

(*Evidence of chemical composition.*) As shown by the triangular diagrams of Leith and Mead[1] the value of chemical criteria for the determination of the origin of the metamorphic rocks is doubtful, for they show that certain metamorphic rocks known to have originated from igneous rocks have all the characteristics that would be ascribed to rocks of sedimentary origin,

[1] C. K. Leith and W. J. Mead: Metamorphic Geology. Henry Holt & Co., New York, 1916, pp. 228-240.

and some metamorphosed sediments show all the characteristics of igneous rocks. If sediments and igneous rocks could be said to remain unchanged chemically after the time of their origin and previous to the introduction of new metamorphic conditions, and if they could be said likewise to retain all their chemical characters during metamorphism, chemical criteria might have a much more positive value. Unfortunately the above two sources of error offer themselves here, for in the chemical processes of nature no such control is or can be exercised as in the chemical laboratory. Consequently, in listing chemical evidences of origin, no great weight will be placed upon them either one way or another. This evidence is added more for the purpose of completeness than for any usefulness in making determination of origin.

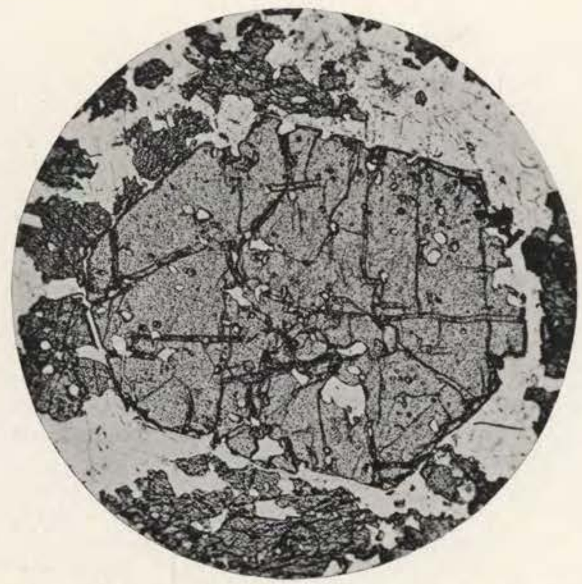
From the tables on pages 18 and 19 it will be seen that the silica-alumina ratio is high and in seven out of eight of the analyses, potash is far in excess of soda, but in only two instances does the magnesia equal the amount of lime. The tables on page 25, for the specimens from the line AB, give a silica-alumina ratio not so high as that just cited for the analyses on CD. In four out of eight analyses potash is in excess of soda but not so markedly as in the previous groups of analyses. In no instance does the magnesia equal lime in amount. If the evidence based upon chemical analyses is as usable as some claim for it, the above would indicate that the balance stands in favor of sedimentary origin, though proof would not be considered decisive.

Relations to adjacent formations. The lower mica schist is intruded and underlain by the Lebanon granite and underlies the light gray to yellow sandy schist.

Whether or not the lower gray mica schist is overlain conformably by the light gray to yellow sandy schist cannot be definitely determined. No striking discordance of dip or strike at contact has been found though the lower mica schist is quite variable in width of outcrop and the sandy schist contains pebbles near its base, indicating unconformity. On the other hand, the pebbles contained in the sandy schist, scattered as they often are through a sand matrix, do not indicate a distinct conglomerate, and the irregularity in width of the lower mica schist may be due rather to intrusional than to erosional conditions.

Metamorphism. There is no doubt that during the intrusion of the granite into this lower mica schist, water vapors and other mineralizers passed out from the granite into the schist. The presence of tourmaline in several of the sections is indicative of hydrothermal activity. Small veins of tourmaline-bearing pegmatite occur, also, in the schist not far from the granite contact. Probably much of the sericitization of the potash feldspars took place at this time. It is not at all certain whether quartz was introduced from the granite, for, even if the quartz grains were enlarged, which cannot be proved from the thin sections, the

PLATE VIII.

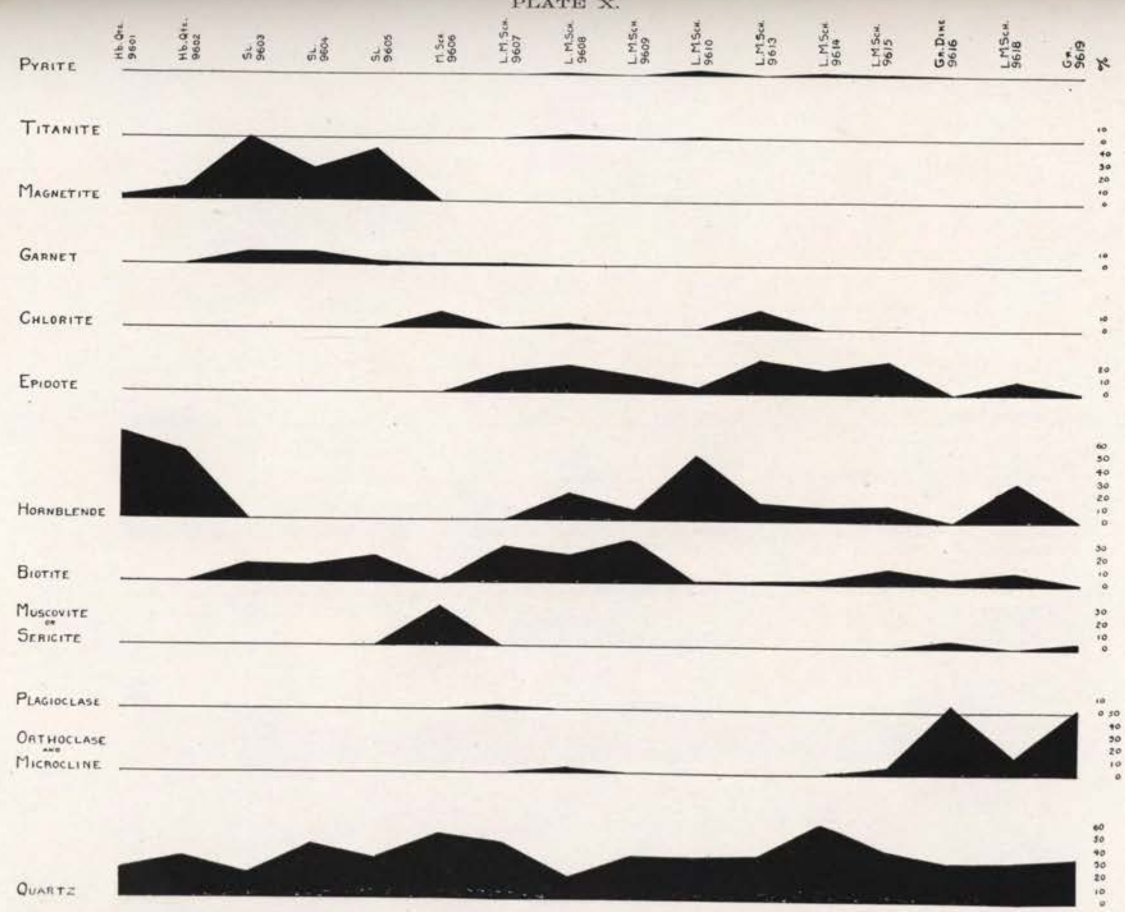


Photomicrograph of garnetiferous hornblende schist showing garnet crystal with quartz inclusions. Magnetite, quartz and hornblende comprise the rest of the field.
Spec. 1208-5 a. Ordinary light. X 26.

PLATE IX.

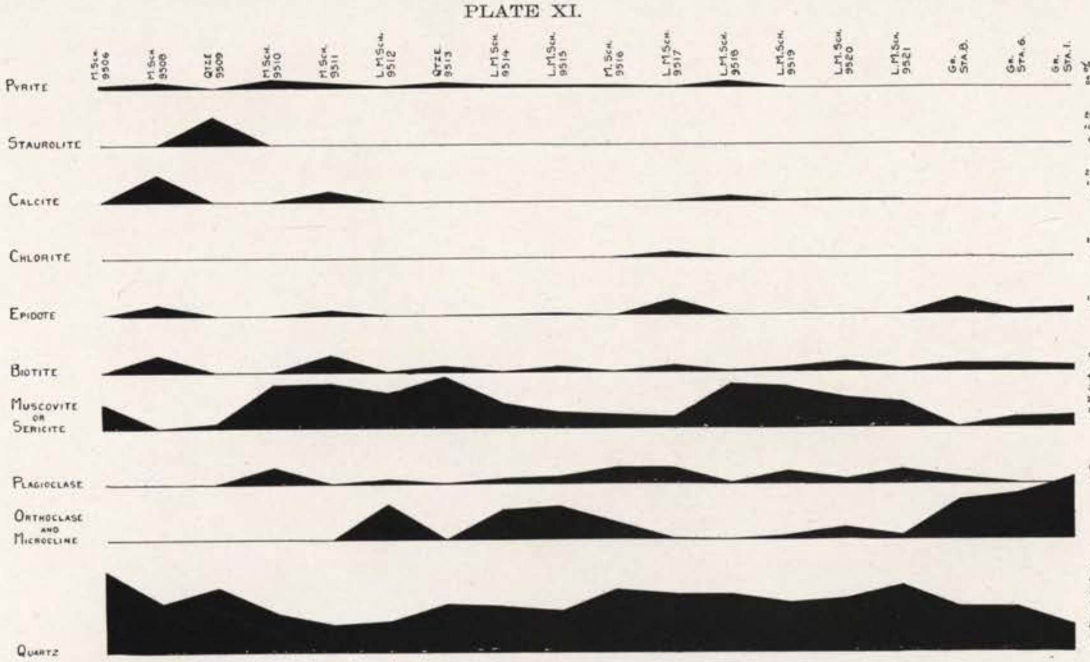
Photomicrograph of hornblende schist in which the hornblende crystals are "feathery" with inclusions of quartz.
Spec. 1208-3. Ordinary light. X 26.

PLATE X.



Straight line Diagram of Analyses of Specimens along line A-B.

PLATE XI.



Straight line Diagram of Analyses of Specimens along line C-D.

enlargement might have taken place before the intrusion of the granite. Unfortunately, also, there is no uniformity of composition to this schist, as may be seen from the diagrams, Pls. X and XI. The interbedding of sediments of different mineralogical and chemical character makes a quantitative comparison of the mineralogy at different distances from the granite worse than useless. Though evidences of the metamorphic effect of the granite upon the lower mica schist may be found in every section, the actual amount of metamorphism and the distance from the granite at which the metamorphic effects cease to become important cannot be determined. It is probable that the rock had been metamorphosed to its present schistose state before the intrusion of the granite, for other rocks of the region, be they near the granite or other intrusives, or far away, have reached the same state of metamorphism. Also, the inclusions of mica schist within the granite, which were torn off from the walls by the in-flowing granite, are schistose, and the mineralogical character of these inclusions is essentially the same as that of the lower mica schist. Having reached this state of metamorphism before the entrance of the granite, these schists were already in a condition more stable under metamorphic conditions, and were therefore resistant to the change attempted by the intrusive. Little alteration, therefore, other than sericitization of some of the feldspars and the carrying in of small amounts of such substances as tourmaline was brought about.

Summary. As indicated by field relations, by structural and textural and by chemical and mineralogical evidences, it would seem that the lower mica schist group was formerly a group of argillaceous to sandy sediments which was subjected to intense dynamic metamorphism, causing the development of a rock of essentially the same form and composition as now found, which was later intruded by the Lebanon granite and subjected to slight further changes such as the introduction of hydrothermal minerals and the sericitization of the feldspars.

LIGHT GRAY TO YELLOW SANDY SCHIST.

Distribution. This schist overlies the lower mica schist and, therefore, appears areally as a band outside the latter, surrounding the granite. It varies in width from 1/8 to 1/2 mile.

Lithology. This rock is mainly a relatively soft, sandy schist with occasional darker bands of more argillaceous material. Near its contact with the lower mica schist are found scattered through the sandy material numerous flattened pebbles of pink to gray quartzite.

Origin. There is nothing about the rock that would indicate any origin other than sedimentary. Bedding is distinct in places. The rock is composed essentially of quartz sand and mica. It has a conglomerate phase.

Relation to adjacent formations. The relation of this formation to that beneath has been discussed. It grades upward into the next higher formation by increase in argillaceous and decrease in siliceous material.

Metamorphism. That this rock has been under intense pressure is shown by the fact that hard quartzite pebbles originally as much as three or four inches through have been flattened to half that thickness. Mica has been developed in the rock by the same processes.

CLAY ROCK GROUP.

Distribution. This rock, overlying the sandy schist last described, forms another band around the granite and the underlying sediments. This band may vary in width from ½ mile upward.

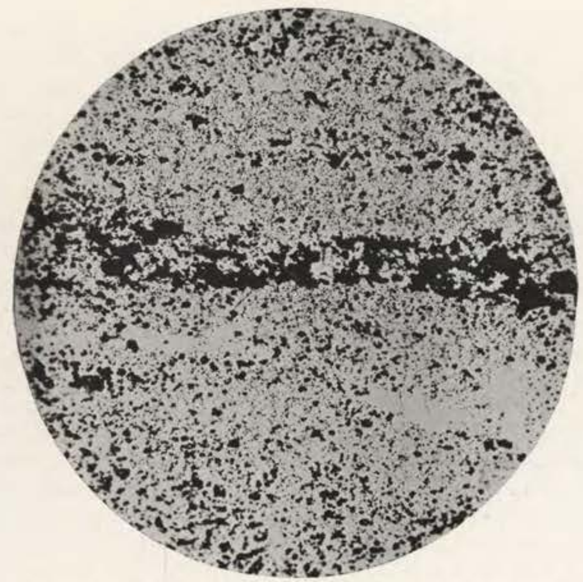
Lithology. Surrounding the granite ellipse, except on the west side, this group appears to be composed of slate and phyllite, with interstratified beds of quartzite or quartz-mica schist. The clay rocks of this group, where found as such, are slates or argillites. The most prominent mineral seen in the hand specimens of these clay rocks is a porphyritic mica, though sometimes small, well formed garnets appear. The quartzite and quartz-mica schists consist essentially of quartz and muscovite or sericite, occasionally biotite, some feldspar, and sometimes hornblende. In fact, the quartzose rocks often grade into hornblende schist by the loss of quartz and addition of hornblende. Magnetite is common to all the rocks of this group in greater or lesser amount. There is one bed of quartz-magnetite rock about six inches thick, lying between layers of hornblende schist. The rock consists of rough bands of magnetite between bands made up dominantly of quartz. The percentages of quartz and magnetite are 62.9 and 37.1 respectively. No other minerals were found in the thin section. The banding is illustrated in photomicrograph, Pl. XII. Slates and phyllites are, however, the normal thing for this group, and their origin is not in doubt. It is the hornblende schist, or amphibolite, that replaces the clay rock on the west side of the granite area, that forms the interesting problem here.

Mineral and chemical composition. In writing about the garnetiferous hornblende schist of Dartmouth park Bayley[1] says: "Under the microscope the rock is discovered to be composed of numerous hornblende prisms and large plates of brown biotite, crystals of garnet, and grains of magnetite, in a colorless matrix which between crossed nicols is resolved into an aggregate of quartz and plagioclase.

"The hornblende is usually elongated parallel with the *c* axis. Occasionally a cross section with the characteristic prismatic cleavage is observed, but not frequently. While the majority of the

[1] W. S. Bayley: No. 141. Garnetiferous Hornblende Schist. (From Hanover, Grafton County, New Hampshire.) U. S. Geological Survey Bull. 150, 1898, pp. 362-365.

PLATE XII.



Photomicrograph of quartz-magnetite rock, showing a band of magnetite. Spec. 1208-5 b. Ordinary light. X 26.

prisms are arranged with their longer directions approximately parallel, many of the larger crystals lie in a direction inclined to this, thus interfering with the perfection of the rock's schistosity. . . . .

"The biotite is not found in all sections, though it occurs in greater or lesser quantity in most of them. It is in large flakes with a distinct cleavage and a reddish brown and yellow pleochroism. . . . .

"The garnets appear in thin section as light pink, perfectly isotropic bodies, that include a few grains of quartz and some magnetite. Although completely idiomorphic, they are plainly formed after the hornblende and biotite, as may be seen by the examination of their contacts with these minerals.

"The magnetite occurs as small, irregular masses and grains scattered through the colorless groundmass and as comparatively large crystals with an octahedral habit. . . . .

"The matrix in which these constituents lie is a hypidiomorphic granular aggregate of triclinic feldspar and quartz. The latter mineral is more abundant. It occurs in irregular grains of a larger size than the feldspar grains. . . . .

"The feldspar of the matrix is mainly plagioclase; a few grains resembling microcline. The feldspars, like the quartz, are in irregular grains which show little or no effects of pressure."

The above description of the micromineralogy of the hornblende schist will answer well for the results of the writer's study of thin sections of the same rocks.

As with the granite and with the lower mica schist, the writer has made a quantitative mineralogical analysis of specimens from the various bands of the hornblende schist, and he has reduced these analyses to terms of oxides. Tables of these analyses follow:

ANALYSES OF HORNBLENDE SCHISTS FROM DARTMOUTH PARK.

Specimen No.	1208-1	1208-3	1208-4	1208-5a	1208-5c	1208-6	1208-7b
Quartz	10.6	26.0	31.4	32.4	9.7	33.9	10.6
Orthoclase	...	...	...	...	...	...	...
Microcline	0.6	...	...	...	0.6	...	...
Albite	...	...	...	...	...	...	...
Andesine	...	5.3	24.5	7.4	0.6	3.9	1.6
Biotite	...	...	...	...	...	...	4.8
Hornblende	85.0	67.5	36.2	59.0	74.2	53.9	73.8
Epidote	3.5	0.4	...	...	...	...	...
Chlorite	...	...	...	...	0.9	...	6.4
Calcite	...	...	...	...	2.5	...	...
Magnetite	...	0.8	7.9	1.2	3.4	2.5	2.8
Garnet	...	...	...	...	8.7	5.2	...
SiO_2	51.6	60.5	62.3	63.9	48.0	63.0	49.2
Al_2O_3	9.4	8.3	10.6	8.0	9.6	7.5	9.8
Fe_2O_3	5.3	4.6	7.5	4.1	10.4	7.3	6.3
FeO	8.7	7.2	6.2	6.4	8.7	6.3	9.1

Specimen No.	1208-1	1208-3	1208-4	1208-5a	1208-5c	1208-6	1208-7b
MgO	9.9	7.9	4.3	6.9	8.9	6.3	11.3
CaO	11.3	9.0	7.0	8.1	10.7	7.1	9.2
Na_2O	1.3	1.3	2.0	1.3	1.1	1.1	1.4
K_2O	0.8	1.0	0.3	0.5	0.7	0.4	1.1
H_2O	1.4	0.9	0.5	0.8	1.1	0.7	2.0
CO_2	...	...	...	...	1.1	...	...

In the above rock sections very little quartz was found that could be called vein quartz, but practically all, if not all, that was included in the analyses given above, was intermingled more or less intimately with other mineral grains.

Quartz grains in this rock average about 0.15 mm. in diameter, and few of them attain a diameter of less than 0.40 mm. Feldspar grains are still smaller. Hornblende needles range in width from less than the smaller quartz grains up to the width of the wider ones, and are usually elongated to dimensions double or more that of their width. The biotite flakes are usually no longer than the hornblende crystals. Epidote grains are small, as in the granite, and in the lower mica schist. Garnets average between 0.25 and 0.5 mm. across, though some of them are found much larger.

Bayley claims that much of the banding in this rock is due to minute veins of quartz in the schist. The writer has not been able to find small veins in the sections which he has studied. Except for this fact, the description of Bayley agrees with the mineralogy of the hornblende schist of Dartmouth Park as examined by the writer for this study.

Occurrence. The clay-rock group occurs as a series of argillaceous beds interstratified with arenaceous beds. These have been metamorphosed to slates and phyllites interbedded with sandy schists and quartzites. Along the west side of the area this formation has been largely replaced by hornblende schist.

The hornblende schists which are studied in detail in thin sections are located in Dartmouth Park, a small hill lying within the village of Hanover and occupying an area a little over ¼ mile long by almost as broad. Here the rocks strike northeasterly and dip from 45° to 80° northwesterly. Beginning at the west side of the park there is the following descending succession of rocks: hornblende schist; micaceous quartz schist with no hornblende; hornblende schist; micaceous quartz schist with minor amounts of hornblende in large, irregularly scattered crystals; garnetiferous hornblende schist; a thin band of rock made up entirely of quartz and magnetite; quartz-mica schist; hornblende schist; micaceous quartz schist; and hornblende schist.

The strike of the rocks in the park is quite uniform. The hornblende schist is not known to cut across the bedding of the quartz schists. Sometimes the contact between the hornblende schist and the mica schist is sharp and at other times one seems to grade into the other. Banding of the light and dark minerals in the hornblende schist coincides with the strike of the sandy

sediments. This, at the same time, coincides roughly with the schistosity of the hornblende and mica schists.

Similar series are found on Oak Hill 1½ miles northeast of the park, and in Spencer's pasture 1½ miles southwest, in the latter place even the small magnetite band being duplicated. The hornblende schist in other parts of the same general region seems to have similar field relations, as indicated by the quotation from Hitchcock's paper in the Vermont State Geologist's Report for 1908, in which he describes other hornblende schists with the same interstratified relation with schists and even limestones.

Origin. The problem of the origin of the hornblende schists has been a source of much study from the beginning, but no attempt to gather all evidences of origin for the purpose of a detailed study has been made. Hitchcock,[1] in speaking of the amphibolite areas of the Hanover quadrangle says: "No one can examine the rocks of the Connecticut valley with care without discovering the problem of the hornblende schists. What are they? Are they altered sediments or original igneous masses? . . . . At Dartmouth Park the outcrops are numerous. . . . . The schistose structure is everywhere as pronounced as that of the schist known as altered sediments, in fact, some of the layers of the park are believed to be sediments. . . . . Mount Finish is a single large mass along its course of the rock. As represented upon Section 4, the mountain is not a uniform mass of hornblende, it is more or less intercalated with mica schists with northerly dips. . . . . . . At the north end of Mount Finish area upon the west bank of the Connecticut, there is a narrow belt of white granular limestone interstratified with the hornblende and mica schists."

In discussing the origin of the hornblende schist of Dartmouth Park Hitchcock[2] says that the rock occurs in "bunches, varying in size from a peck measure to a mass ten miles long. . . . . . On the northwest side of the principal range, the schist comes successively in contact with mica schist, hydromica schist, argillite, and chlorite schist, all of which have been altered through heat into vitrified and indurated rocks, usually richer in silica than when unaltered. On the southeast the adjacent rock is invariably mica schist, somewhat indurated. . . . . The present attitude of the igneous hornblende is like a laccolith where the cap has been worn away."

Bayley[3] discusses the origin of the hornblende schist in the following words: "The study of the thin sections throws but little light on the problem of the origin of the schist. The garnets, the biotite, and the hornblende are probably secondary, *i. e.*, they are not original secretions from a molten magma. Whether the components of the matrix are also secondary or not cannot be

[1] C. H. Hitchcock: Geology of Hanover, New Hampshire, Quadrangle. Sixth Report of the State Geologist of Vermont, 1908, pp. 161-163.
[2] C. H. Hitchcock: Bull. Geol. Soc. Amer. Vol. VII, p. 511.
[3] W. S. Bayley: No. 141. Garnetiferous Hornblende Schist. U. S. Geol. Survey Bull. 150, 1898, pp. 362-365.

told. It is impossible to discover, therefore, from a study of the specimens in the collection whether the rock from which the schist was derived was originally a quartz-diorite, a diabase, or a gabbro. From its mineralogical composition it may quite safely be inferred that it was originally one of these three types. A chemical analysis of a series of carefully selected specimens of the rock would probably show that it was originally igneous, and it might determine the type of igneous rock to which it belonged. . . . . Whatever may have been the original nature of the rock, it is now a hornblende schist, since it consists largely of hornblende and quartz. The structure of the rock from which it was derived has been completely lost in the changes which it has suffered in passing to its present condition."

Evidences for origin of these schists will be grouped here, as in the case of the lower mica schist, with the hope that a conclusion may be reached regarding which origin is at least the more probable.

(*Evidence of field characteristics.*) The hornblende schist belts occupy places between bands of other rock that are filled elsewhere in the group by clay-rock bands. Usually where hornblende schist is found, clay rock is either entirely lacking or nearly so. Where the hornblende schist is found it lies in layers parallel with the strike and dip of the known sediments associated with it. Physical signs of sedimentation are almost if not entirely lacking in the hornblende schist itself. Rocks in contact with the hornblende schist do not show even marginal alteration by contact metamorphism. Neither are the known sediments cut across by the hornblende schist belts. The latter closely follow, however, the strike of the beds of the known sediments. The only field evidence by which it might be said that the hornblende schists were intrusive is the mere presence of this rock between beds of sedimentary rock. Sometimes the quartzitic and hornblende layers grade into each other, and at other times their line of contact is quite marked. This gradation between the hornblende rock and the quartzite would not be probable were the hornblende rock intrusive into the quartzite, especially in such narrow dikes or sills as would be the case here. The hornblende schist layers are seldom over 40 or 50 feet thick here and often the quartzite may be found to contain layers of hornblende rock less than half an inch in thickness, though usually these layers are found to be poorer in hornblende than the larger bodies of that rock.

(*Evidence of mineralogical composition.*) The igneous rocks most closely related to these hornblende schists in mineral composition are shown on the triangular diagram, Pl. XIII. The examples plotted here are chosen from the groups given by Clarke, and specimens of igneous rocks chosen were those highest in quartz, giving the possibility of igneous origin for these schists the advantage, if any is to be given either side. Along with the rocks just mentioned the diagram shows also an average shale

and an average sandstone, compiled from groups of typical shales and sandstones given by the same author. Three analyses of clay rocks from this same group (clay-rock group) are also plotted. It will be seen from this diagram that the hornblende schists, like the lower mica schists, are quite widely separated in composition, although they all fall within one-third of the triangle. Also, the nearest igneous rocks comparable in composition are much lower in quartz than most of the hornblende schists of the area and considerably lower than the average of the group. Compare, now, with the analyses of the hornblende schists those of the three clay rocks taken from the section line AB. Except for the presence of feldspar, these rocks fall very close to the hornblende schists in their position on the diagram.

Another fact of value in making determination of the origin of the hornblende schists is the great variation in mineral content of the different layers of hornblende rock. It would be expected, were the rock intrusive, that the different layers, intruded at such close-spaced intervals, would be brought from the same source and, if so, that their composition would be relatively constant. In this connection, note the uniformity of composition of the different specimens of Lebanon granite, Pl. IV, even though collected from widely separated localities, and compare it with the analyses of the hornblende schists of Dartmouth Park plotted on diagram, Pl. XIII.

HORNBLENDE SCHISTS.

31—Spec. 1208-1
32— " 1208-2
33— " 1208-4
34— " 1208-5a
35— " 1208-5c
36— " 1208-6
37— " 1208-7b
38—Average of 31-37 inclusive

CLAY ROCKS

41—Spec. 9603
42— " 9604
43— " 9605

AVERAGE ANALYSES FOR COMPARISON.

A—Average Lebanon granite.
B—Average granites, U. S. G. S. Bull. 616, p. 437.
C—Quartz diorite, U. S. G. S. Bull. 616, p. 454 (B).
D—Quartz monzonite, U. S. G. S. Bull. 616, p. 452 (B).
E—Andesite, U. S. G. S. Bull. 616, p. 455 (A).
F—Diorite, U. S. G. S. Bull. 616, p. 457 (B).
G—Quartz basalt, U. S. G. S. Bull. 616, p. 458 (C).
H—Diabase, U. S. G. S. Bull. 616, p. 461 (A).
I—Gabbro, U. S. G. S. Bull. 616, p. 463 (C).
J—Gabbro, U. S. G. S. Bull. 616, p. 469 (I).
K—Clarke's average igneous rock, U. S. G. S. Bull. 616, p. 419.
L—Average shale, computed from analyses, U. S. G. S. Bull. 616, p. 546.
M—Average sandstone, computed from analyses, U. S. G. S. Bull. 616, p. 541.

(*Evidence of rounded mineral grains.*) Unfortunately, heavy residuals were not noted in these sections. Many quartz grains are found which show rounding, but they are not sufficiently rounded to be strong evidence of sedimentary origin.

(*Evidence of chemical composition.*) From analyses on page 33 it will be noted that the silica-alumina ratio is high, but potash never exceeds soda and magnesia only once exceeds lime.

(*Conclusion from the above evidences.*) There is little reason to believe, unless the chemical analyses be used as proof, that these hornblende schists were other than sedimentary in origin. (And the chemical evidence is not by any means conclusively against it.) The belief in sedimentary origin is supported by field evidences and by a mineralogical study of the hand specimens and thin sections.

Metamorphism. The stippled part of the clay-rock area lying west of the granite on the map, Pl. II, shows the region in which the hornblende schist predominates. Just why this portion of the clay rock should suffer this more intensive change is not known. It may be that the original composition of the sediments here differed from that at other localities, or it may be that the granite approaches the clay rock more closely underneath at this point. Such irregular development of hornblende schist is not uncommon elsewhere, and very frequently there is no adequate and conclusive reason to be deducted from the field relations. Possibly it is a product of both contact and dynamic metamorphism.

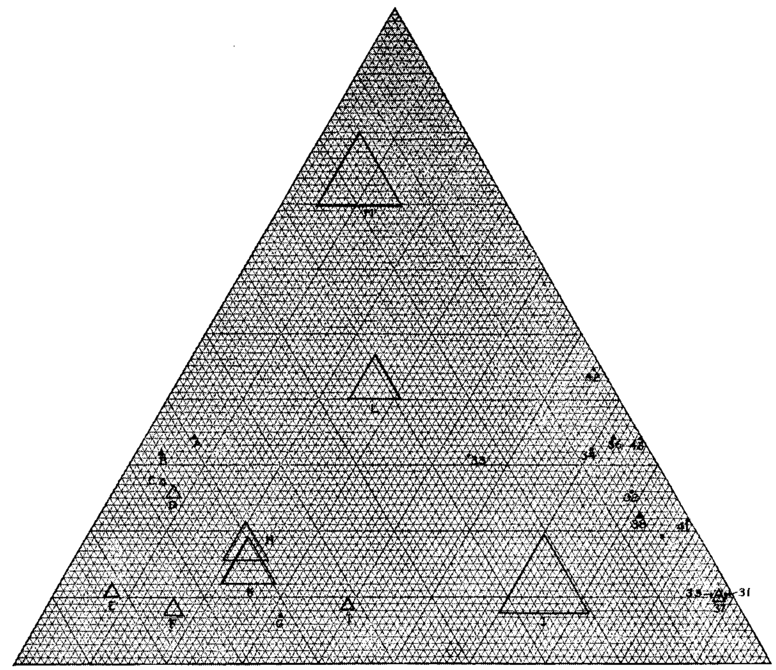
Summary. The field relations and the mineralogical composition and texture indicate that the hornblende schist of the clay-rock group, as well as the rest of the rocks of this group, originated as a series of interbedded argillaceous and arenaceous sediments which were subjected to dynamic metamorphic influences before the intrusion of the granite, and, possibly, to igneous metamorphism during the intrusion of the granite, forming, in one part of the region, a hornblende schist in place of clay rocks found elsewhere.

Subsequent to these changes little has taken place save removal of some of the rocks by erosion.

GENERAL DISCUSSION OF METAMORPHISM OF THE HANOVER REGION.

Thus far the metamorphism of different formations has been described and discussed for the individual formation. It remains now to look at the general aspects of the metamorphic problem and to study the relations of the two types of metamorphism and the application of metamorphic conditions here to the problem of metamorphism in general.

PLATE XIII.



Triangular diagram comparing mineral composition of the hornblende schists with clay rocks of the same group and with norms of average igneous and sedimentary rocks.

EFFECTIVENESS OF DYNAMIC METAMORPHISM.

Original composition. As has been shown by the triangular diagrams, the original composition of the schists whose origin is in question, if sedimentary, probably varied from a high silica, high alumina shale to a shale lower in silica, much lower in alumina, but higher in iron and magnesium. The chemical and mineral composition of most shales is by no means simple. And yet the mineral composition of schists is usually relatively simple. In a word, during the formation of a schist, there is a tendency to form a simple group of platy minerals.

Mineral convergence. Mineral convergence, or the tendency to form by recrystallization a new and simpler group of minerals, usually the platy minerals, is particularly noticeable in rocks which have undergone intense dynamic metamorphism.

Of these platy minerals, sericite, biotite and hornblende make up an important proportion of the schists analyzed for this study. In the case of the mica schists, sericite, or biotite and hornblende make up on an average nearly a third of the rock mass. The proportion of hornblende in the hornblende schists averages nearly 65 per cent. Quartz, some feldspars, and occasionally garnet, make up most of the remaining percentage.

The presence of an unusually high percentage of quartz indicates a failure of these metamorphic processes in producing a rock made up entirely of platy minerals. In the case of the hornblende schist most of the alumina, and some of the quartz were used, with iron, magnesium and other compounds to make the hornblende. But in this process not all of the quartz was so used. When not used, it was left behind in place, and photomicrograph, Pl. IX, shows feathery hornblende formed around such remaining grains of quartz.

It is such remnants of quartz and other original minerals, and especially the heavy residuals, that offer themselves either by the exhibition of rounded edges obtained by wear during sedimentation, or by the mere presence in excess of the amount usually found in the more common types of igneous rocks, as evidences of sedimentary origin.

The fact that there has been such a marked tendency, during the formation of these schists by dynamic metamorphism, to form few platy minerals leads to the suggestion that there may be also a tendency toward simplification of chemical composition during the same processes.

Chemical convergence. That such a convergence takes place has been shown by analyses mentioned by Leith and Mead for impure quartzites that have gone over along shear zones to sericite to the actual exclusion of most of the quartz. In their work on chemical convergence they have shown that this may be so marked at times as to make chemical criteria, such as are suggested for the origin of metamorphic rocks, if not useless, at least far from conclusive.

But examples of complete or nearly complete loss of everything except the platy minerals are chosen from shear zones, or portions of larger formations more affected by metamorphism than the main mass, while metamorphosed formations such as these schists show as a whole only the tendency and not complete convergence. This suggests that, where such complete convergence is found, especially favorable conditions must have obtained to bring it about.

Since this convergence means loss of excess material not used for the formation of the platy minerals, and this removal cannot be brought about without a suitable transporting agent, active and effective in proportion to the amount of work to be done, the following may be said to be factors which determine the completeness of the convergence: (1) the intensity of the forces acting, (2) the time allowed for the reactions, (3) the mass to be affected, (4) the type of compounds to be removed, and (5) the presence of the transporting agent and its ability to get about and do the work. The presence of quartz grains in the newly formed hornblende, garnet, and feldspar, testifies to the failure of these solutions in their work of removal of excess material.

Conclusion. It is evident, then, that Le Chatlier's[1] principle applies to mineralogical as well as to chemical composition of rocks undergoing dynamic metamorphism. Rocks containing compounds stable under atmospheric condition have in this region been subjected to dynamic metamorphism, and the mineral composition has gradually changed toward that of the more platy minerals, for the formation of which the necessary elements were present, and which are found to be stable under the new conditions.

EFFECTIVENESS OF CONTACT METAMORPHISM.

Effect of the presence of the granite on the metamorphic problem. We know from a study of the rocks of the Hanover region that dynamic metamorphism has been the most active factor in the formation of these crystalline rocks, for they are thoroughly metamorphosed whether they be near or far from igneous contact. We know also that the presence of such a large body of granite, cooled under deep-seated conditions, means contact metamorphism, and this assumption is supported by the presence of hydrothermally formed minerals in the overlying schists and by the sericitization of the feldspars of the schists. It now remains for us to determine the relative effectiveness of each and to ascertain their time relations.

[1] When chemical or physical equilibrium exists, and one of the factors upon which it depends is altered, a change is produced which opposes the first alteration. In other words, the system seeks some new form of equilibrium at which it will be stable under the new conditions.

Differentiation of types. (Mineral groups.) Of the metamorphic minerals found in these rocks certain may be formed by either dynamic or contact metamorphism, and certain are only the result of hydrothermal action accompanying the latter. Sericite, biotite, garnet, and hornblende found in these schists may be formed under either condition of metamorphism. Some other factors than that of their mere presence must be found, therefore, if these minerals are to be used in any way to identify the type of metamorphism effective in this case. The presence of tourmaline in the schists, on the other hand, is direct evidence of hydrothermal action.

One might expect that those minerals which are found distributed widely with little reference to the position of the intrusives would be caused by the dynamic metamorphism. But the converse does not necessarily follow, for a localization of certain minerals may mean merely local differences in the original character of the sediments.

(The hornblende problem.) The localization of the hornblende schist, therefore, becomes a problem in this metamorphic study. Is it due to the original differences in composition of the clay rock which it replaces, or is its presence an evidence of the nearness of the intrusive? It is possible that either may have been the cause of this local occurrence, and it is not improbable that both were. The problem would be impossible of solution were this the only occurrence of such localization. Such local arrangement is found elsewhere in many places, however, and field relations at many of those places throw some light of suggestion on the problem here. In many places, such as the Lake Superior region, the local occurrence of hornblende schist is very frequently found in the vicinity of intrusive rocks. This place relation is suggestive in the Hanover district, as elsewhere, but cannot be used as conclusive evidence until much more work is done on this problem wherever this close relation is found.

The hornblende crystals in the Hanover schists are roughly parallel in arrangement, but not so nearly parallel in arrangement as one usually looks for in the case of dynamic metamorphism alone. This is another suggestion of the effect of contact metamorphism.

Time relations. Evidences already stated to show that dynamic preceded contact metamorphism are: (1) the intrusive rocks show little or no effect of dynamic metamorphism, and (2) large feldspar crystals in the schists have been sericitized by hydrothermal action following the granite intrusive.

If the above interpretation of time relations is correct, the sedimentary rocks were probably well metamorphosed before the intrusion of the granite and such minerals were already formed as most effectively to resist further metamorphism by igneous action. Consequently, the actual amount of metamorphism due to the granite intrusion is much less, except possibly in the case of the hornblende schists, than that due to dynamic metamorphism.

SUMMARY.

The rocks of the Hanover, New Hampshire, district consist of schists, intruded mainly by granite, in the form of a laccolith.

The schists are sedimentary in origin because (1) they are made up of successive layers of rock, essentially parallel, and not cutting one another; (2) the layers are greatly variable in composition one from another, but having certain group characteristics; (3) quantitative mineral analyses show these schists to approach nearer the composition of sediments than that of igneous rocks; (4) segregated minerals in bands with micas point toward original mineral segregation during sedimentation.

The probable sequence of events from the time of deposition of the sedimentary rocks to the present, as far as can be read in the geology now seen, is: deposition of the sedimentary rocks, probably during Paleozoic time; dynamic metamorphism during a mountain-building epoch, during the latter part of which, or closely following which came the intrusion of the Lebanon granite. This was attended by some metamorphism of the already crystalline overlying schists. Subsequent to this group of events erosion has removed the cap of this formerly deeply buried laccolith, exposing the upper part of the granite.

A CONTRIBUTION TO THE GEOLOGY OF ESSEX COUNTY, VERMONT.

ROLF A. SCHROEDER.

INTRODUCTION.

Essex County, situated in the northeastern corner of Vermont, has received less attention from geologists than other portions of the State. This is due in part to its remoteness and in part to the absence of stratified rocks, the northern part of the county being underlain entirely by granite and schist. Our present knowledge of the geology of this region is limited to Hitchcock's pioneer work[1] of 1861, and, more recently, Dr. Richardson's report[2] which takes up certain phases of the geology of this section.

It is not the writer's purpose to submit a geologic map of Essex County, for no good base map[3] is available at present, and thus it seems more practicable to await the completion of the proposed topographic map of the United States Geological Survey before attempting any detailed geologic mapping. It was rather the meagreness of our information in this region, especially regarding the economic importance of the granites of Averill and vicinity, which has prompted the writer to spend several months during the summers of 1919 and 1920 in field work for this report.

The area covered may be roughly described as that portion of Essex County immediately adjacent to the Averill Lakes.

TOPOGRAPHY.

The Averill Lakes are situated in the towns of Averill and Norton in Essex County, just south of the international boundary, but north of the topographic divide. They are of glacial origin, their beds being composed of granite. Their waters discharge northward, finally reaching the St. Lawrence River. Big Averill

[1] Hitchcock, C. H., Geology of Vermont, 1861.

[2] Richardson, C. H., Areal and economic geology of northeastern Vermont, Biennial Report of the State Geologist of Vermont, 1905-1906.

[3] Beers' map of Essex County (published in 1878 by F. W. Beers & Co. of New York), is the best large scale map of this section. However, Averill Mountain is not shown and the dimensions of the lakes are quite incorrect.

Lake covers an area of about 1,860 acres and its elevation above sea-level is 1,968 feet.[1] Its main inlet is the outlet of Little Averill Lake. The latter lies one mile to the southwest, covers an area of about 800 acres and has an elevation of 2,093 feet above sea-level. Forest Lake lies one-half mile east of Big Averill Lake. The surrounding country is wooded and moderately mountainous with occasional bogs. The climate is healthful.

GLACIATION.

The direction of ice movement here was south-southeast. Striæ are very prominent along vertical joint faces, which strike N. 34° W. All the higher mountains have been scoured by the ice to their very summits, resulting in the typical gentle slope on the north side and nearly vertical cliffs on the south side. Good examples are Averill Mountain, Nulhegan Mountain and Little Averill Mountain,[2] whose precipitous crags and talus slope tower impressively over the inlet of Little Averill Lake.

Curiously enough certain small areas have apparently escaped the erosive action of the ice, for there are several deposits of rotten residual granite in this vicinity, which must have existed in pre-glacial time, for the normal Averill granite is hard and fresh. (See Rock Descriptions.)

Granite and schist erratics are common, but there is also an abundance of pyritic slate and sandstone (Specimen No. 7), especially in the beach gravels, the latter no doubt representing detrital Silurian rocks, which occur northward in Stanstead County, P. Q.[3]

The long axis of Big Averill Lake lies approximately in the direction of ice movement.

JOINTS.

Jointing is especially prominent in the granite and has a control on topography which is easily recognized. A number of measurements of joint directions were made and plotted on a diagram. (See figure 1.)

It will be seen that the majority of joints strike N. 40° W. Not only does the long axis of Big Averill Lake lie in this direction, but its northeastern shore is extremely straight, the configuration being largely determined by the well developed joints on that shore aided by the erosive action of the ice.

[1] Richardson, C. H., Areal and economic geology of northeastern Vermont. Biennial Report of the State Geologist, 1905-1906, p. 78.

[2] This mountain is also locally known as Little Averill Cliff, The Bluff, Turgeon Mountain, etc. It is the writer's opinion that *Little Averill Mountain* is the most fitting name. It appears on Beers' map of Essex County but carries no name.

[3] Ells, R. W., Report on the geology of a portion of the Eastern Townships. Geol. and Nat. Hist. Survey of Canada. Annual Report, 1880, Part J, p. 8.

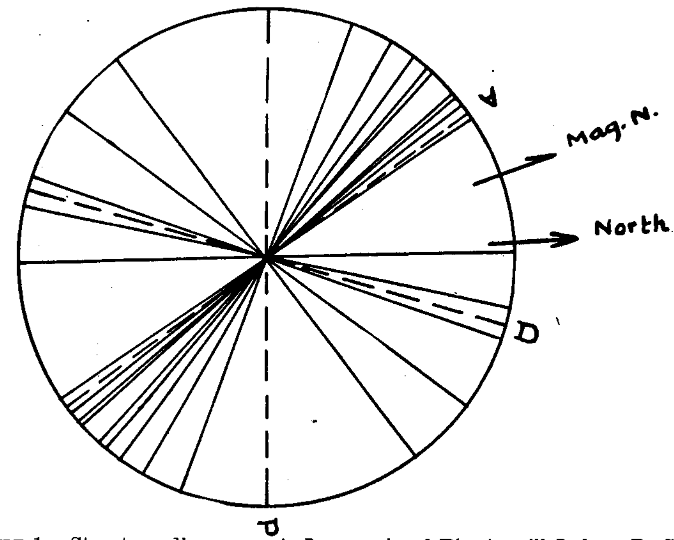


FIGURE 1. Structure diagram. A. Long axis of Big Averill Lake. D. Strike of diabase dike. P. Strike of pegmatite dike on summit of Averill Mountain.

ROCK DESCRIPTIONS.

The rocks underlying this area are for the most part granite (Specimen No. 1)[1] and schist (Specimen No. 3). The former underlies and surrounds Big Averill Lake and all but a small portion of Little Averill Lake. The southeastern half of Averill Mountain is composed of Averill granite, which is intrusive in a muscovite-biotite schist (Specimen No. 3) lying towards the north. The contact between the two rocks is well exposed on the summit of Averill Mountain, where it strikes N. 44° E., and in the bed of Averill Stream a hundred yards below the granite bridge of the Norton Mills Road. It is also visible on the southeastern shore of Little Averill Lake, and on the Canaan Road, about three miles from Averill.

PEGMATITE.

Irregular masses, small dikes and sills of pegmatite crop out at the various contacts between the granite and schist. The pegmatite is composed of large cream-colored feldspars, smoky quartz, and mica. It also contains a few black tourmalines and garnets but no beryl was found. There is not enough pegmatite, however, to make mining for feldspar or mica profitable. Moreover, the distance to the nearest market is prohibitive.

[1] The specimens referred to in this report may be viewed in the collection of the State Cabinet, Montpelier, Vt. Specimen No. 5, which is not referred to in this paper, is granite-gneiss from a cut near Lake Station on the Grand Trunk Railroad.

ROTTEN GRANITE.

Disintegrated granite or *gruss* occurs on W. E. Jones' farm on the Averill-Cold Spring road. There are two pits here where it is excavated with pick and shovel for road metal. It makes excellent roads. The rock comprises a friable mass of quartz, feldspar, kaolinite, mica and limonite. It is not transported material but Averill granite, weathered *in situ*. Similar deposits occur along the outlet of Little Averill Lake. These places were probably protected from glacial erosion by a mantle of débris deposited over them in the early stages of glaciation.

DIABASE DIKES.

Several diabase dikes (Specimen No. 4) cut the granite in a ledge just east of the post office on the north shore of the lake. They have been intruded along joint fissures and strike N. 17° E., dipping 60° N. W. The largest of the set is 18 inches thick and shows transverse columnar structure. The rock is nearly black, fine-grained, slightly porphyritic towards the center and rich in pyrite. It is probably Triassic in age.

AVERILL GRANITE.

The Averill granite (Specimens No. 1 and No. 2) is a pink, two-mica granite of medium grain with sub-porphyritic texture, the phenocrysts being microcline crystals, twinned according to the Carlsbad Law, and measuring 10 to 15 millimeters in length. The general color of the fresh normal granite is pink with small black specks. It bleaches upon exposure to the weather and becomes light grey to white. (See Specimen No. 6.) The color, as usual, is imparted to the granite by the color of the dominant feldspar, in this case, microcline.

Microscopic examination of thin sections in polarized light reveals the following constituents in descending order of abundance:

(1) White to pink, sub-transparent microcline feldspar, twinned and showing well developed lattice structure. It is fairly fresh.

(2) Colorless to light smoky quartz, transparent and quite rich in inclusions. The latter comprise cavities arranged in streaks, small elongate crystals (possibly zircon), and numerous hairlike crystallites (probably rutile). In places the quartz occurs in myrmecitic intergrowth with plagioclase, the latter being the host.

(3) Plagioclase. This feldspar is present in the form of oligoclase, but is much less abundant than the potash feldspar. Locally it incloses muscovite and quartz, the latter occurring in vermicular form in the oligoclase. It alters to kaolinite.

(4) Muscovite is quite abundant in grains up to two millimeters in diameter and in places is in parallel intergrowth with biotite.

(5) Biotite is present in about equal amounts with muscovite. It alters to chlorite and limonite, but is quite fresh in the unweathered granite.

Other minerals present are chlorite, epidote, hematite and magnetite.

Weathering of this granite involves kaolinization of the plagioclase feldspar and alteration of biotite to chlorite and limonite. Sericite may also form.

GOLD.

The possibility of the occurrence of gold in this region is a much mooted question. Considerable prospecting has been done in the hills and stream beds south of Little Averill Lake. In fact, certain men claim to have found gold in small quantities. No quartz fissure veins of any size have been noted during the reconnaissance work on this report. Quartz was seen associated with pegmatite and schist on the south end of a hill on the southeastern shore of Little Averill Lake, and on the trail from this lake to the East Branch of Nulhegan River, but this was of the usual sort generally found in pegmatite. It is said that small amounts of gold have been mined in Hereford, P. Q., eight miles east of Averill, and at another point just north of Beecher Falls, Vt. Other occurrences of gold in this region, somewhat more distant, however, are the alluvial gold prospects in Chesham Township, Compton County, P. Q.[1] and the well known placer gold territory of the Chaudiere River Valley, the "Beauce Gold District," in Beauce County, Quebec.

The occurrence of placer gold in scattered localities has naturally excited an ambition among prospectors to locate the mother lode. So far, their efforts have been futile. It is very possible that extensive systems of gold-bearing quartz veins once existed in this granite region and that they have been broken up and removed by the ice and other erosive agencies. The origin of the Meule Creek gold in Quebec is pre-glacial, according to Keele.[2]

ECONOMIC CONSIDERATIONS.

The pegmatite and rotten granite deposits are of minor significance economically. On the other hand, the huge masses of undeveloped granite deserve attention. The Averill granite is, to be sure, rather coarse for monumental purposes, but it should

[1] Mailhiot, A., Granites of the Eastern Townships of Quebec. Summary Report for 1914, Canada Geol. Survey, p. 100.

[2] Keele, Joseph, "Placer gold on Meule Creek, Quebec." Summary Report, 1911, Canada Geol. Survey, p. 303.

make an excellent building stone. No attempt has yet been made to quarry this rock on a large scale. Boulders have been split up and used locally for stone walls and bridges, and some pieces have even been cut into small monuments and bases. The unreliability of its pink color should not discourage anyone because the white stone is very handsome. Jointing would be a great aid in quarrying the granite. Good locations for a quarry would be on the steep side of Averill Mountain and along the road to Salmon Point and, in the event of granite-cutting sheds being built here, power in abundance is available in Averill Stream. There is an excellent chance for a dam across this stream below the stone bridge and north of the Norton Mills road. The nearest railway is the Grand Trunk Railroad at Norton Mills, only four miles distant over a good, level road, downhill most of the way. A quarry at Stanhope, P. Q., four miles away, owned by the Coaticook Marble and Granite Works, has afforded a first-class building stone.[1]

No doubt some day this vast deposit of granite will be exploited. The depth, of course, is unlimited and moreover the quality of the stone probably improves with depth, as is usually the case.

[1] Mailhiot, A., Granites of the Eastern Townships of Quebec, Sessional Paper No. 26, Summary Report for 1913. Geol. Survey of Canada, p. 217.

NOTES ON THE AREAL AND STRUCTURAL GEOLOGY OF A PORTION OF THE WESTERN FLANK OF THE GREEN MOUNTAIN RANGE.

NELSON C. DALE,
HAMILTON COLLEGE.

INTRODUCTION.

Through the courtesy of Dr. G. H. Perkins, the state geologist of Vermont, the writer of this paper was given the opportunity of spending a portion of the summer of 1914 in an attempt to investigate the geology of the more mountainous sections of the Middlebury and Burlington Quadrangles.

Though the work accomplished is largely of a reconnaissance character, it is hoped that further investigations may produce more detailed results.

GEOGRAPHY.

Location and Extent of Area. The area under consideration comprises a trifle more than the eastern third of the Middlebury Quadrangle and nearly the lower half of the eastern third of the Burlington Quadrangle. Practically all the work was done within the Townships of Hinesburgh, Huntington, Monkton, Starksboro, New Haven, Bristol, Lincoln, Middlebury and Ripton.

In extent, this area is about 129 square miles and of rectangular shape, being 23½ miles long in a N.-S. direction and 5 to 6 miles in an E.-W. one. The north end of the strip is about 15 miles southeast of Burlington and the south end between 4 and 5 miles east of Middlebury. The shaded area on figure 2 shows approximately the extent covered.

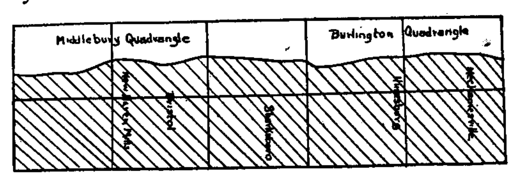


FIGURE 2. Shaded section represents parts of Middlebury and Burlington Quadrangles covered in this report.

Topography. Although this is an extremely rugged section of the State one with still a greater relief lies immediately east in the central range where the Green Mountains culminate in such masses as Lincoln Hill, Camel's Hump and Mansfield, all about 4,000 feet above the sea-level. The maximum relief of this particular region varies from 500 and 600 feet in the northern part to 2,000 feet and over at the southern.

With the exception of Hogback Mountains there is very little of the range aspect, as is found in the Appalachians proper and in other folded areas. As the observer crosses over from the Champlain Valley into the mountainous eastern part, he is confronted by a great quartzite wall over 2,000 feet in height, beyond which there is a noticeable lack of ridge topography. The one exception, that of Hogback Mountains, is the west limb of a great asymmetrical syncline and owes the fact of its isolation to its folded structure. Its lack of persistency as a ridge is doubtless due to the northerly pitch, as it dies out both geologically and topographically in the north part of the township of Starksboro.

Drainage. The principal streams draining this part of the west flank of the Green Mountain range are the La Platte River, which obtains the greater part of its water supply from Hinesburgh Pond at the extreme north edge of the region and from tributaries SE. of Hinesburgh, Lewis Creek, to which Hollow and Pond Brooks contribute, draining Lincoln Hill, Shaker and East Mountains, and the north end of Hogback, and the New Haven River, by far the largest stream in this region.

The tributaries of Lewis Creek and of the New Haven River are responsible for the greatest erosion on the west flank of this region. The New Haven River itself has been largely responsible for the deep gap between the town of Bristol and the village of Ackworth. The deepest part of this cut is below the Pinnacle, where Pleistocene glaciation may have assisted in the cutting, as the perpendicular cliff of the Pinnacle was in all probability the lee side of a glaciated ridge.

As a rule, quartzite resists erosion more than most rocks, but here there were doubtless other factors aiding the streams.

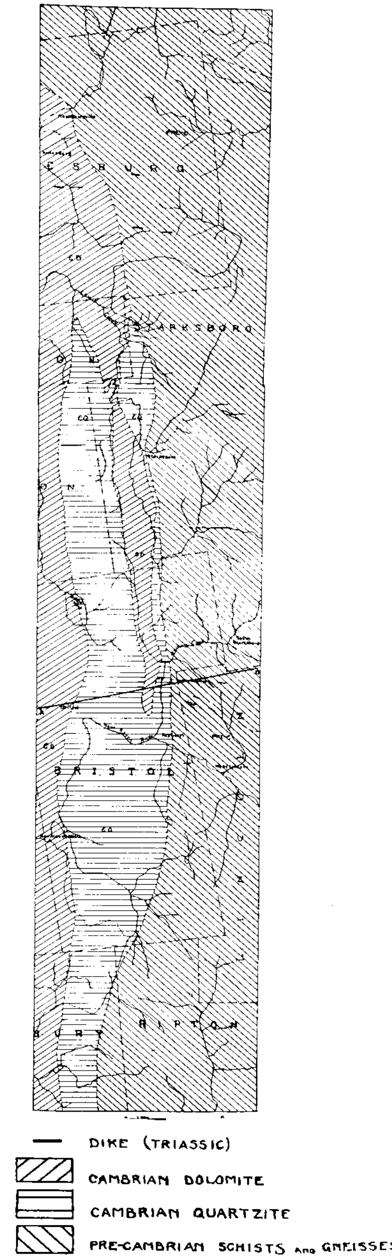
The trellis drainage of the Hogback region is a direct result of its synclinal structure, the softer and less resistant calcareous rocks of the Starksboro valley making an easy northwest-southeast drainage line with the New Haven River forming a gap drainage line normal to it.

In the more massive regions to the east digitate drainage prevails, as no large structural lines prevail there.

GENERAL AND AREAL GEOLOGY.

The essential features of the areal relations of the various rocks are shown on the areal map, Plate XIV, as determined largely by reconnaissance work. The rock types of the so-called pre-Cambrian, though very different as a whole from those of the Cambrian, may upon further investigation turn out to be

PLATE XIV.



younger than the age assigned them. Though, in large part, of sedimentary origin, reasons for which statement will be made further on, these pre-Cambrian rocks are not set apart because of any great unconformity or any structural incongruity, but simply on the basis of lithological characteristics. It is quite possible that they may be younger than the Cambrian, because there were no structural inconsistencies near the line of contact. This conformity of strike between the pre-Cambrian and Cambrian may be due to changes produced by the post-Ordovician movement in the pre-Cambrian structure so strikingly brought out at North Sherburne, Vt., and described by T. N. Dale.[1] The rocks in the southern part of the so-called pre-Cambrian, though highly metamorphic in character, were undoubtedly igneous in origin, and for that reason have been included.

Some of the schists, however, occurring among the quartzite-dolomite contact in the west, may very well be a part of the Cambrian quartzite, and at Starksboro, as figure 3 depicts it, the quartzite schist may be included with the Cambrian.

The mountainous parts of the extreme western section consist essentially of Lower Cambrian quartzite and dolomite. Though no fossils were found by the writer establishing this horizon, a Cambrian lingula was found some years ago in the Rocksville area by Henry Miles of Monkton. Other workers in this same general field to the south have also established a similar horizon for those rocks occupying analogous structural and stratigraphical positions in the Green Mountain range.

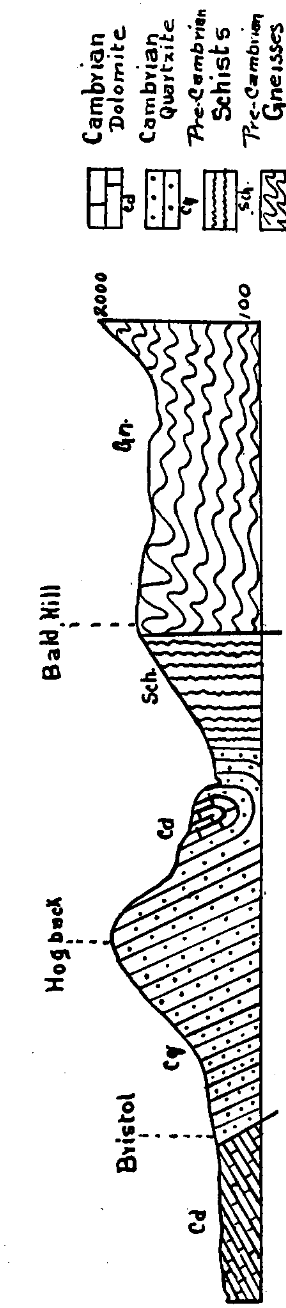


FIGURE 3. Structure section, along line A-B on areal map.

[1] The Algonkian-Cambrian Boundary East of the Green Mountain Axis in Vermont. Am. Jour. Sci., Vol. XLII, Aug., 1916.

For more than two-thirds of the entire area the quartzite and dolomite are co-extensive, but the quartzite syncline pitches northwards some four or five miles south of Hinesburgh and disappears.

From the north end of Hogback Mountains, where the quartzite disappears, the dolomite is in contact with a quartzose mica schist which may possibly have originated in an argillaceous quartz sand.

Intruding both the pre-Cambrian and the Cambrian areas are five diabasic dikes, all trending in approximately the same direction. Doubtless they belong to the Triassic age or later.

STRUCTURAL GEOLOGY.

Rock Descriptions and Relations. The characteristic rock types of the region are as follows:

Basalt (Diabase).

Dolomite.

Quartzite.

Schists:
- Quartzite Schists.
- Calcareous and Micaceous Quartzose Schist.
- Chloritic Micaceous Schist.
- Arkosic.
- Magnetiferous Chloritic Schist.
- Magnetiferous Micaceous Schist.

Gneisses:
- Arkosic.
- Granitic.

Schists and Gneisses. Those rocks which have been most thoroughly altered from their original state most naturally present the greatest problems. In the case of these schists and Arkosic gneisses there has been no attempt to make any differentiation. Where the rocks show coarse banding accompanied by complex folding and plications, or where the rocks show feeble foliation planes, the term gneiss has been used. All other finely cleaved or schistose rocks have been grouped under schists. According to this classification many of the metamorphics of the eastern third of the map are Arkosic gneisses, while those on the west side are schists. As both schists and gneisses are likely to occur in either or both areas we cannot adhere to this classification too strictly.

Quartzite Schist. Just east of the main dolomite area of Hinesburgh and of the quartzite area in the townships of Bristol and Lincoln there is a band of quartzitic schist of variable width and thickness.

In the Starksboro district, figure 3, quartzitic schists are found in contact with the Cambrian quartzites. Perhaps the best development of this quartzitic schist may be seen on the west slope of Bald Hill.

Succeeding these schists on the east is a band of micaceous (sericitic) quartzose schists, and these in turn are succeeded by light and dark banded micaceous quartzose schists, all well exposed along the Baldwin Creek Gorge between the village of South Starksboro and the junction of Baldwin and Beaver Creek, a tributary of the New Haven River.

The uniformity and continuity of these schists, as well as their adjacency to the quartzite, lead one to think that there must be a genetic relationship or possibly a progressive form of metamorphism. As it was not possible to find a gradational series through the schists from the quartzite and as there was a conspicuous absence of feldspar in the quartzites the relationship can only be applied to the number and increasing complexity of structural planes.

Within these schists occur calcareous micaceous schist bands of no great development, but indicative of sedimentation.

Chlorite Schist. Chloritic magnetiferous and non-magnetiferous schists are found in two bands, one just east of the quartzitic schist area in the lower west slope of Lincoln Hill and the other in the east slope of Lincoln Hill and north in the township of Hinesburgh, as well as on the west slope of Shaker Mountain. At the latter locality the schists carry abundant octahedra of magnetite, while the schists of Red Rock carry pyrite, which because of its alteration to limonite accounts for the coloring of the rocks at that place.

Just east of South Starksboro is another band of chloritic micaceous magnetite bearing schist which is in contact with a magnetite bearing calcareous chloritic schist. A quarter of a mile west of Starksboro the chloritic schist is found as thin bands intercalated with bands of calcareous and chloritic marble one and a half to two inches thick. According to the microscope much of this chlorite is a green muscovite. Other minerals are quartz and chlorite, while those accessory to the rock are ilmenite, leucoxene and limonite. Alignment of minerals, stretching of quartzes, and two cleavage or schistosity planes, one 45° to the other, characterize this type.

The mapping of these various schists was found to be impracticable because of the ruggedness of the area which prohibited detailed contact work in the time allotted, and such detail could not be incorporated satisfactorily on the small-scale map. In a general way, throughout most of the area these various schists occurred in bands approximately parallel with the strike of the range. Plate XII.

It is believed that the above series of schists are of sedimentary origin, for two reasons, first, because they are preponderantly siliceous, calcareous, argillaceous, or carbonaceous, and second, because they are alternating and thin bedded. These characteristics are well shown in the vicinity of Mechanicsville and Starksboro.

Arkosic Schists and Gneisses. From the northern part of the township of Hinesburgh to within two miles and a half of the southern boundary of the township of Starksboro is a well defined band of arkosic schists and gneisses consisting of strata of various thicknesses and of varying grain, but decidedly clastic. Quartz, mica and feldspar are predominantly visible. In color, the rocks may be gray, brown or lavender. As this series is all more or less metamorphosed we find rocks of a quite massive and feebly foliated character and also those strongly foliated and tremendously contorted.

No better example of the degree and complexity of folding in this region can be seen than is shown in figure 4, where, just east of Hinesburgh, is a cliff of light colored and fine grained arkose schist, the upper edge of which presents a fringe which apparently is a portion of the eastern limit of an eroded anticline.

Included within the major structure are two secondary zones along which there has been movement, one resulting in a vertical divisional plane and the other in a horizontal plane, both normal to the axial plane of the major one. A generous talus slope is already sufficient proof of the weathering and erosion possibilities in this strongly folded rock.

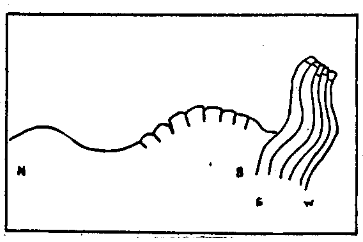


FIGURE 4. Highly folded arkosic schist at edge of cliff. East-west cliff front with north-south profile. Hinesburgh, Vt.

In this series we find diagrammatic primary and secondary cleavage planes, the former occurring in the coarser grained beds, the latter in the finer grained. Bedding planes are easily distinguished from the metamorphic divisional planes.

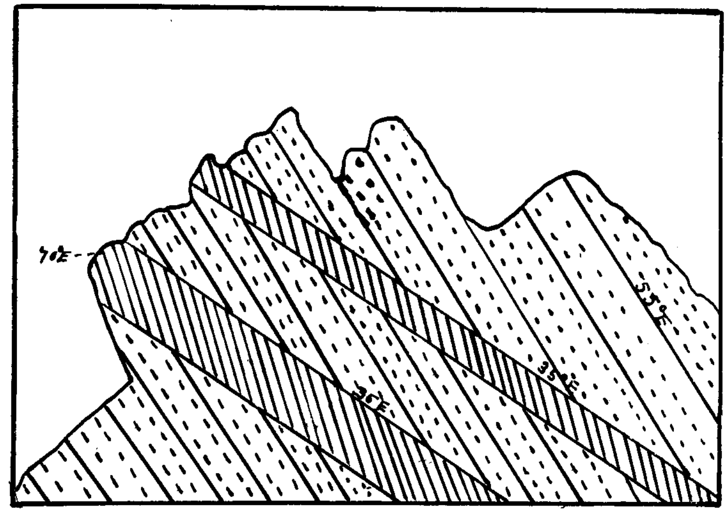


FIGURE 5. Arkosic schists and gneisses, showing bedding plane dipping 35° E., schistosity plane in arkosic gneiss dipping 55° E., and cleavage plane in arkosic schist dipping 70° E. Hinesburgh, Vt.

The most interesting of the Arkose series is a massive, lavender colored rock which outcrops midway up on the western slope of Lincoln Hill (Red Rock). Upon first appearance it bears a close resemblance to a granitic or aplitic intrusion, and is intruded by a mesh of white quartz veins which are characterized by vugs lined with quartz crystals and schist inclusions.

To the unaided eye there are abundant grains of lavender colored quartz, some of feldspar, with finely disseminated magnetite.

Under the microscope this rock has a massive structure and a granular texture of the mortar design. In descending order of abundance the essential minerals are quartz, which occur in both large and small grains, the former, embedded in a ground mass of the latter, albite, and orthoclase, while the accessory minerals are magnetite, calcite and rounded grains of zircon. Many of the quartz grains are coated and indented by other quartz grains suggestive of replacement.

The smaller quartz grains and the calcite would appear to be secondary, the former, autoclastic, and the latter, either a decomposition product of some pre-existing basic mineral or else a primary arkosic constituent.

Three miles east of Hinesburgh occurs a dark gray arkosic schist band one-half inch in thickness between a massive arkose and a plicated micaceous quartzose schist. Its position with respect to the "pseudo" aplite gives it a strong resemblance to an exomorphic contact phase of the former. Where feldspar have leached out, particularly along the cleavage planes, the rock has almost a vesicular structure.

Under the microscope this rock has a coarse schistose structure and its composition consists of sub-elliptical to angular quartz grains arranged according to the mortar design, orthoclase, albite, muscovite (sericite) and magnetite. Sericite is found enveloping the quartz grains and along the schistosity planes, while the magnetite occurs as fine granules filling the interstices or replacing the orthoclase along cleavage lines. Between 25 and 30 percent of the rock consists of magnetite.

Another variety, somewhat massive in structure, greenish-gray in color, consists of colorless, white and blue quartzes, albite, sericite, with only small amounts of the two latter minerals. The accessory minerals are chlorite, magnetite, pyrite, limonite and zircon. Enveloping the limonite areas are confused masses of a fibrous or scaly mineral, possibly talc. The mortar pattern is common to this rock as to the other arkoses, but there was a marked dove-tailing or saw-edge relationship between the smaller grains of the ground mass and the larger quartz grains.

In the feebly foliated areas of this same series just east of the occurrence of the more massive varieties the arkose exhibits the same mortar texture with the larger quartz grains exhibiting an elliptical shape and arranged with the larger axes of the grains parallel with the schistosity. The edges of the large grains are more or less saw-edge, into which the smaller grains extend, doubtless a product of granulation and recrystallization.

Other essential minerals are albite, muscovite (sericite), while calcite, ilmenite and leucoxene comprise the accessories. Calcite is found abundantly in grains either as interstitial matter or replacements of the quartz. Leucoxene is an alteration product of the ilmenite.

In the more schistose varieties which are plicated and tremendously contorted, the latter type frequently exhibits fracture cleavage. On the more weathered surfaces feldspar and quartz are visible to the unaided eye.

Microscopically, some of these rocks appear to be very strongly plicated, of fine grain, and in a few places, to show traces of their original mortar structure. Quartz, orthoclase, albite, muscovite and sericite are the essential minerals, while biotite, magnetite and enstatite form the accessories. The sericite is usually found in confused aggregations near the crests and troughs of the plications, in the fracture cleavage zone, as well as along the schistosity planes.

Magnetite occurs as bands in the mica aggregates parallel with the metamorphic divisional planes.

An excellent exposure of the arkosic series is found two miles and a quarter east of Hinesburgh, consisting of interbedded schists and gneisses, and characterized by their natural and metamorphic divisional planes, an abundance of feldspar grains and colorless, bluish and rose colored quartz pebbles and grains set in a matrix or ground mass of chloritic and green muscovitic schist.

In one of the more pebbly beds there was a large specimen, one foot by five inches in size, of dolomite surrounded by small pebbles of quartz and grains of feldspar and set in a groundmass of green muscovitic schist. In the more pebbly parts of some of the beds there are lenticular masses of chloritic or green muscovitic schist.

Quartzite. Approaching the Green Mountain range from the Champlain valley in this area, as well as in other similarly related districts to the south, one is immediately struck by the prominence of the wall-like barrier of the front range, a prominence due in large part to the fact that it consists almost entirely of quartzite, and its consequent ability to withstand erosion, as well as to the uplifted range.

The quartzite is typically exposed throughout the Hogback and South Mountain areas, comprising the front range or western flank of the Green Mountain range, extending throughout the Middlebury Sheet and disappearing near the southern edge of the Burlington Sheet, two miles and a half northeast of Monkton Ridge. The synclinal structure of the Hogback Mountain section is responsible for a thin east limb parallelling the mountain from Ackworth to a point south of South Hinesburgh. With the exception of a small bed outcropping between dolomite strata about one mile north of Hinesburgh and another one mile and a half SW. of the same village, the main quartzite mass no longer appears, due to a northerly plunging syncline.

Not all the quartzite in this area is of the massive crystalline type which characterizes the west slope of Hogback and South Mountains. Much of it, as found along the crests, the east slope of Hogback, and contacts, presents a much more highly metamorphosed condition, and so far as purity is concerned is far less siliceous near dolomite contacts, in fact when in contact with the dolomite is apt to be calcareous. It is perfectly possible to find throughout this area all gradations, from a massive quartzite to one that is highly sheared, or from the purest type of quartzite to one that is highly calcareous or magnetiferous. The more massive structures and purer types are found in the less deformed zones and away from contacts.

The stratigraphical position of the quartzite is according to the structure section, figure 3, that of the Lower Cambrian, and the same has been determined on palæontological grounds by Professor Seeley from the Dunmore Section by the discovery of Nothozoe Vermontana, from the Rockville Section by the discovery of a Cambrian lingula by Mr. Henry Miles and from the Bennington Area by Dr. Charles D. Walcott.

The relationship of the quartzite to the Cambrian dolomite in the Starksboro valley is well shown by the structure at the southeast end of Hogback Mountains where the dolomite overlies the quartzite, and in the bed of the New Haven River above Ackworth, where the structure of the quartzite is decidedly synclinal, figure 3.

Assuming that the Starksboro valley dolomite and the dolomite occurring at the western base of the Hogback Mountains is of approximately the same age, we should expect from structural inferences that the quartzite would continue beneath. As there are no discoverable contacts along the west slope and there is a marked disparity in dip between the dolomite and the quartzite, the former dipping west and the latter east within a very short distance, there is likelihood of faulting. In fact, north of Hinesburgh sheared quartzite or quartzitic schist of possible pre-Cambrian age overlies the dolomite.

At Starksboro, in a road cutting a mile east of the village, is an excellent contact exposure of the quartzite and dolomite—see figures 6 and 7. Thin beds of dolomite and quartzite may have become sheared and schistose.

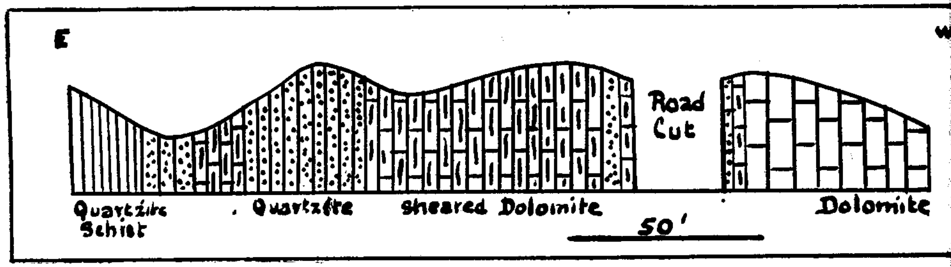


FIGURE 6. Quartzite-dolomite contact near Starksboro, Vt.

In the dolomite are curiously shaped bodies of a quartzose composition resembling pebbles of a conglomerate. As these pebbles resemble the quartzite in the adjacent beds in nearly all particulars, it was concluded that they represent a litoral phase of marine sedimentation where blocks of quartzite eroded from an adjacent quartzite cliff as a result of marine erosion and later became a part of the calcareous oozes of the sea-bottom, figure 7.

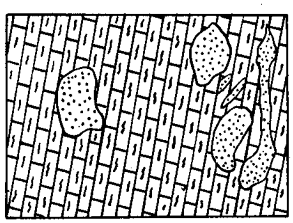


FIGURE 7. Dolomite at Starksboro, showing conglomeratic phase.

Their present distortion and metamorphism represent their later history. As pre-Cambrian quartzite occurs in Vermont, pebbles of it may occur in the Cambrian.[1]

Dolomite. This rock is found largely in the Starksboro valley and Champlain valley areas. A small, discontinuous band is found in South Starksboro, West Lincoln and Ripton areas, interbedded with the schists and included within the pre-Cambrian area. Much of this is so crystalline as to constitute a marble.

Dolomite, one of the most characteristic rock types of the Green Mountain range, is, when typically exposed, a cream-colored, dense, crystalline rock weathering to a dark brown at the surface. There are, however, many variations from this type in color, composition and texture. Sometimes beds are sandy or cherty, as at Hinesburgh, or are pinkish or grayish in color, as at Monkton. In structure it may be massive, occurring in thick strata as throughout a large part of the area, or it may be schistose, as at Starksboro. Variations in color are found along the west base of Hogback Mountains, pinks and grays and whites being quite common, while in the Starksboro-Hinesburgh area it is largely cream-colored.

The structural relations may be seen by consulting figure 3.

IGNEOUS ROCKS.

Five basaltic intrusive dikes were found, four of which occur in the township of Hinesburgh, and the fifth in the township of Bristol. Plate XII.

Hinesburgh Dikes. One-quarter of a mile SW. of the village of Hinesburgh is a two foot dike of basalt, figure 8, trending for ten feet in an EW. direction and intruding Cambrian dolomite.

This rock, like many others of the same type, weathers to the customary brown color, and more deeply along intersecting joint planes, resulting in sub-spheroidal shapes.

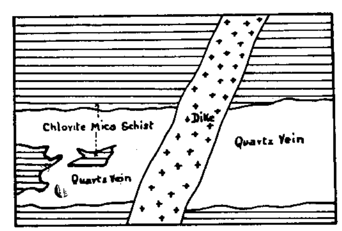


FIGURE 8. Basalt dike cutting quartz vein and chlorite schist with vein holding inclusions of chlorite mica schist. Lincoln Hill, Hinesburgh, Vt.

Under the microscope it presents a massive structure and microophitic texture. Its essential minerals are labradorite, both monoclinic and orthorhombic pyroxenes, and biotite, while the

[1] The Algonkian-Cambrian Boundary East of the Green Mountain Axis in Vermont, by T. N. Dale. Am. Jour. Sci., Vol. XLII, Aug., 1916, p. 123.

accessory minerals are magnetite, limonite, calcite and apatite, with the limonite and calcite as alteration products.

About two and a quarter miles from Hinesburgh is a basaltic dike one foot in width and traceable for 150 feet, which cuts arkosic schists and gneisses with a N. 80° E. trend. A set of rude joints perpendicular to the cooling surface is suggestive of basaltic jointing so well shown in other parts of the world.

In surficial characteristics this dike is not unlike other dikes described in this paper. In descending order of abundance, labradorite and augite make up the essentials, while magnetite, pyrite and calcite complete the accessory minerals. In the cleavage cracks of many of the basal sections of the augite magnetite is found replacing the augite.

About four miles SE. of Hinesburgh on the lower part of the west slope of Lincoln Hill is a small one foot basaltic dike cutting a five foot quartz vein and the chlorite schist series. Figure 8 gives the relations of this dike to the intruded rocks.

In descending order of abundance the essential minerals consist of andesine, labradorite and augite, while the accessories are magnetite and calcite, the latter an alteration product.

Bristol Dike. An accumulation of basalt blocks about three-quarters of a mile NW. of the top of Lincoln Hill indicates a dike near by, in all probability, but no further trace of the outcrop was found.

These dikes, apparently of the same structure, composition and texture, are likewise of approximately the same trend (see figure 3), and the same age, as both the oldest and youngest rocks of the region are alike intruded by them. It is quite possible that they are a part of the great Triassic period of vulcanicity.

METAMORPHISM.

The orogenic movements which brought in the close of the Ordovician and Permian periods in North America, resulting in the development of such mountain ranges as the Taconics and the Green Mountains, likewise transformed most of the sedimentary and igneous rocks into totally different types, the interpretative history of which presents some of our most puzzling questions. Even with the aid of the sciences of chemistry and physics many of the problems of metamorphism have remained unsolved. In the region before us, which is quite a typical one, so far as the western flank of the range is concerned, many problems have presented themselves with no immediate solutions. The pre-Cambrian schists and gneisses have perhaps a greater interest for us than the more massive dolomites and quartzites to the west, because so little is really known about these types in general. For the region as a whole it would have been interesting to have determined whether there has been any progressive

eastward metamorphism. More than the fact that the gneisses and the schists of much of the eastern section are tremendously more metamorphosed than those of the west it is difficult to say, but this much is certain, that had there been greater uniformity and persistency in the formation, this particular region would have presented in all probability just such a phenomenon. The most uniform formations of the region are represented by the quartzites and the dolomites, but it is not quite certain that these show any progressive metamorphism. Of course, there are zones within the quartzites which appear to have undergone a greater degree of compression, resulting in the addition of metamorphic divisional planes. At the contact of the quartzite with the quartzitic schists it would seem more than likely that there should be some evidences of progressive changes, but such critical places were usually concealed, or else there were abrupt changes from the more massive quartzites to the schistose varieties. See figure 6.

Within the arkosic-schist and gneiss area, dynamic metamorphism has brought about many changes, not the least important of which is the development of slip cleavage where the rocks are strongly plicated, or two cleavage planes with different dip, a steeper dip found with the finer grained arkoses than with the coarser grained varieties. In several localities east of Hinesburgh it was possible to differentiate diagrammatically between stratification planes and the metamorphic divisional planes. See figure 5. Some very striking examples of slip cleavage development were also found in the more complexly foliated arkoses, one of which appeared as a vertical set of slip cleavage planes in a twenty foot vertical cliff where the plications were essentially horizontal, with crests an inch apart. The eastern exposures of the arkoses, which are tremendously plicated and contorted, appear to show a decided progressive metamorphism over the western outcrop, which only show feeble foliations, and where the natúral and metamorphic divisional planes can be plainly made out.

It is possible to detect all gradations in the matter of alignment of minerals, from those rocks in which the quartz grains were elliptical, with their longer axes arranged parallel with the schistosity or cleavage, to those devoid of any metamorphic structures. Microscopic study of the massive, feebly foliated and strongly foliated arkosic schists and gneisses revealed this. See page 49.

Origin of the Schists and Gneisses of the pre-Cambrian. For most of the schists and gneisses of this area a sedimentary origin can be assigned for the following reasons, based largely upon field and microscopic evidence: First, conformability of the mica quartz schists and the quartzitic schists with those adjacent metamorphics of known sedimentary origin, such as the Cambrian quartzite and dolomite. Second, the positive sedimentary and stratification characteristics of the arkosic series, as well as their uniformity and persistency for considerable distances along the strike. Third, the alternation of not very unlike beds of the arkose series, as well as that of very unlike beds in the calcareous, chloritic, argillaceous and micaceous quartzose schist series, as found at South Starksboro and West Lincoln. Fourth, the lack of abundant feldspars and the presence of rounded zircons, as found in many of the arkoses, schists and gneisses.

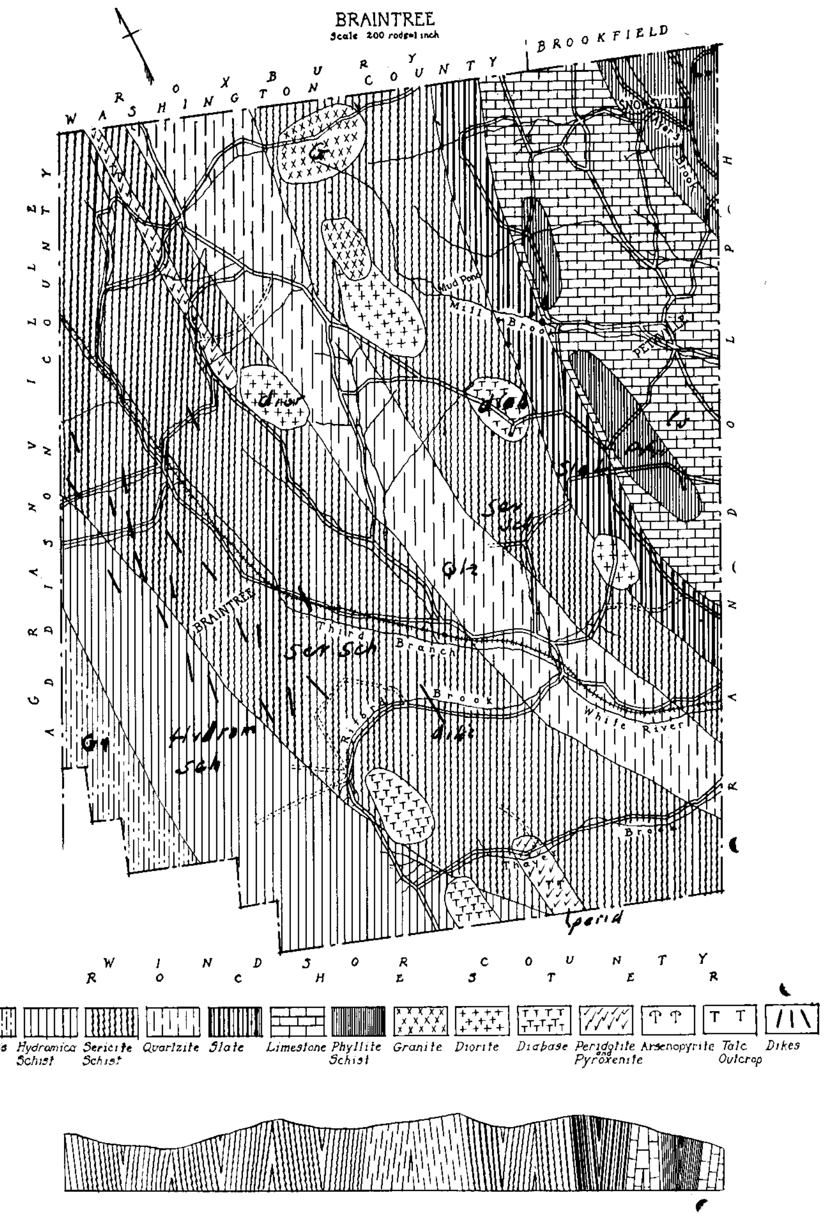
GENERAL CONCLUSIONS.

The rocks of this region, largely of sedimentary origin, now thoroughly metamorphosed, a product of the orogenesis at the close of the Ordovician and Permian periods, belong to the Cambrian and pre-Cambrian periods. The attitude of the dolomite, quartzite, and the conglomeratic-dolomite beds, as seen in figure 6, would lead us to think that inasmuch as the pebbles of quartzite in the conglomeratic dolomite must be derived from older beds, that the pre-Cambrian beds to the east are in their stratigraphic position.

The parallelism of the pre-Cambrian and Cambrian is in all probability to be attributed to the realignment of the pre-Cambrian strike by the Post-Ordovician movement.

The major structures of the region (see figure 3) are folds and faults. Just what the nature of the folding east of Bald Hill is, is difficult at this time to say. It may be anticlinorial or synclinorial, as evidences of both were found. After the region had been elevated and the rocks thoroughly altered, basaltic lavas made their way through a nearly EW. set of fractures. These lavas apparently succeeded other intrusions of siliceous material which carried chlorite and orthoclase feldspar material.

PLATE XV.



Geological Map of Braintree.

THE GEOLOGY AND MINERALOGY OF BRAINTREE, VERMONT.

Charles H. Richardson and Charles K. Cabeen,
Syracuse University.

INTRODUCTION.

The report upon The Geology and Mineralogy of Braintree, Vermont, is of necessity brief. It may best be considered as one of progress in the solution of the intricate geological problems of the eastern half of the State. The first named author traversed this area in reconnaissance work in 1895. Some of the results of this investigation were published under the title, "The Terranes of Orange County, Vermont," in the Biennial Report of the Vermont Geological Survey for 1901-1902. In the summer of 1917 both authors took up a detailed study of the geology and mineralogy of the township. The field relations were found to be intricate and complex. The township is hilly and much of it is densely wooded and difficult to work in an east and west direction across the strike of the different formations. The intrusives were found to be far more abundant than formerly supposed, for this area has always been mapped as purely sedimentary.

The area lies south of the geographic center of the State and about 25 miles southwest of Montpelier. It is further situated in the western part of Orange County.

There were three reasons for the selection of this area. (1) It lies south 40 degrees west from the area covered in "The Terranes of Roxbury, Vermont," which appeared in the Biennial Report of the State Geologist for 1917-1918 and therefore makes the work continuous in a southwesterly direction in the eastern half of the State. (2) It falls in the line of the erosional unconformity between the Upper Cambrian and the Ordovician formations on the eastern side of the Green Mountains. (3) The presence of a large number of basic intrusives which invited a careful petrographic study of both the sedimentary and intrusive rocks.

An areal map showing the geographical distribution of the terranes in Braintree accompanies this report as Plate XV. A cross-section is drawn practically at right angles across the strike of the formations and through the center of the township.

The authors recognize their indebtedness to Prof. Charles R. Schroyer of Syracuse University for his careful and detailed petrographic study of all the microscopic slides prepared in the preparation of this report, to John F. Wright, acting as assistant professor of mineralogy at Syracuse University, for rechecking the work done by Schroyer and the authors, and to W. D. Macumber for his assistance in the field.

DRAINAGE.

The major portion of Braintree is drained by the Third Branch of the White River which flows in a general southeasterly direction into the Connecticut River at White River Junction. Along the Braintree-Granville road the Third Branch of the White River is augmented by three small brooks which flow towards the east. These are Dunham, Jones and Pecor Brooks. Riford Brook also flows in an easterly direction from the Rochester town line and empties into the White River about half a mile below the Braintree town line.

Holman Brook joins the White River from the northeast about one-half mile north of Pecor Brook. Copeland Brook flows in a southerly direction and joins the White River about three miles below Braintree village. A small stream rises between Oak Hill and Nevins Hill in the northern part of the township and flows easterly through Mud Pond and Pethville into Randolph. It is known as Mill Brook. The extreme northeast corner of the township is drained by Ayers Brook which rises in Brookfield, flows into Randolph and empties into the Third Branch of the White River at Randolph village.

The larger streams flow in their old pre-Glacial valleys which are broad and U-shaped. The smaller streams have cut deep V-shaped valleys in the morainal material down to the old, water-worn pre-Glacial beds. In some instances they are out of the old valleys for short distances and falls are the result.

TOPOGRAPHY.

The main valley is the one which the Central Vermont railroad traverses. It is a broad U-shaped, fertile valley extending in a northwesterly and southeasterly direction across the township.

To the west of this valley the elevation rises rapidly in the northern part of the township but more gradually in the southern part until near the western border when the elevation is quite rapid. The western altitude is approximately 2,000 feet above sea-level and nearly 1,000 feet above the village of Braintree. The western part of the township is densely wooded and the higher altitudes were difficult to obtain. The altitude of Braintree village is 777 feet.

To the east of the U-shaped valley there is a steep ridge, the major part of which is also densely wooded. South of the village of Braintree this ridge dies out and a smaller yet broad valley extends northward from the main valley.

The valley of Ayers Brook is pre-Glacial and U-shaped, but most of this valley is in Randolph. The remaining valleys are V-shaped.

GLACIATION.

The township of Braintree is mantled with morainic material to such an extent that the geologist is seriously hampered in the study of the field relations of the different geological formations. The forested area varying from one to five miles in width in the western part of the township, the densely wooded central ridge, and the forested northern portion around Nevins Hill, impede geological progress in the interpretation of true stratigraphic positions of the sedimentaries and the full significance of the numerous dikes.

Evidences of glaciation and the general direction of the ice movement are the striations still remaining on the more resistant rocks of the region. The well-exposed outcrops of nearly pure white, secondary, vein quartz show striations upon their smoothed and polished surfaces. The resistant phyllites, slates, sericite schists and Cambrian quartzites occasionally afford excellent illustrations of glacial grooves.

Three different sets of striations were recorded. These were due south, southeast, and south 60 degrees west. The more westerly trend of the ice is best proven by the striations on the most westerly exposed rocks of the township at the higher altitudes. In the valley of the White River a direction of south 30 degrees west was recorded, and to the south in Randolph a direction of south 25 degrees west was found. The more easterly direction is proven not only by striations on exposed quartz veins but also by the presence of a large boulder resting upon an outcrop of diabase just south of Mud Pond. This boulder is approximately 20 feet in length, 15 feet in breadth and 8 feet in height. It can be easily rocked by hand. The terranes cut by the diabase are Ordovician. The boulder is pre-Ordovician and must have been transported by the ice from the west of the broad Braintree-Roxbury valley. The angularity of the boulder suggests that it has not been transported a very great distance.

The terminal moraine of recession has left boulder trains in its course and often by following in the direction of the boulder train the intrusive rock was discovered which gave rise to these erratics.

The numerous sand and gravel deposits in the valleys represent the outwash of the terminal moraine that traverses Roxbury a few miles north of the Braintree town line. In the village of Snowsville there are a few, though small, kames, eskers, and drumloid hills.

GEOLOGY AND MINERALOGY.

The geology of Braintree is intricate and complex. The terranes consist of a series of highly folded and faulted metamorphic rocks, dipping always at a high angle, and cut by many intrusives mostly of a basic character. The sediments as well as the intrusives differ widely in age, as well as in their mineralogical composition. A careful study of their field relations has been absolutely necessary to avoid the introduction of errors in their interpretation. Forty-two microscopic slides have been prepared for petrographic study from Braintree alone and nearly as many more have been made from samples collected in Randolph. These have all been studied in connection with a similar series of slides made from samples collected from the various townships to the north of Braintree.

In the western part of the township the stratigraphy has been determined largely by apparent field relation and the study of the microscopic slides. In the eastern part of the area covered by this report the stratigraphy has been determined by the discovery of new beds of graptolites in both the slates and the limestones. The graptolites although fairly abundant are not as numerous or as well preserved as they are in the slates of Roxbury and Northfield, and in the limestones of Montpelier.

ALGONKIAN.

If the Algonkian rocks appear in Braintree they are to be found in the extreme southwestern part of the township in an area that is densely wooded and difficult of access. This terrane either belongs to the Algonkian gneiss or else it is a highly feldspathic hydromica schist. If the curve to the eastward in the strike of the Green Mountain gneiss of Northfield corresponds with the curve in the sericite schists it would bring the Algonkian gneiss into the southwestern corner of Braintree.

This terrane consists of a fine to medium grained, silvery white, schistose sedimentary rock. The quartz grains are rounded and granular, and the mica occurs in more or less fibrous masses. Oligoclase appears to be the feldspar present. Magnetite, apatite and biotite are the accessory minerals. Some of the quartz grains are of secondary origin. The chlorite, limonite, and the brown iron stain around some of the quartz grains are all of secondary origin.

The presence of corroded apatite crystals is the strongest proof of the sedimentary origin of this terrane. While quartz is the most abundant constituent there is a considerable amount of sericite drawn out in parallel bands which makes the rock schistose

in texture. The magnetite grains are abundant and shot-like. Garnets are abundant and more or less rounded. If this formation is a duplicate of the feldspathic sericitic quartzite in the central part of Braintree then it has been brought up by a fan fold.

CAMBRIAN.

The term Cambrian as here used signifies a group of highly metamorphosed sedimentary rocks which lie between the eastern foothills of the Green Mountains and the erosional unconformity that separates the pre-Ordovician from the Ordovician formations. These formations consist of hydromica schists, sericite schists, chlorite schists and quartzites. These formations constitute by far the larger part of the terranes of Braintree. The verd antique marble beds, and the talcose schists to the west of the Braintree-Roxbury valley and the talc deposits to the east of the same valley are all within these terranes.

At the close of the Cambrian a crustal movement accompanied by uplift occurred which metamorphosed the sedimentaries derived from the erosion of Algonkian land masses into the various schists and quartzites already mentioned.

HYDROMICA SCHISTS.

The hydromica schists lie on the east side of the Braintree-Granville range of mountains. They are markedly different from the sericite schists that flank them on the east. The hydromica schists are fine grained, greenish, schistose sedimentary rocks which are more or less associated with chlorite. If the original mica of these schists was biotite it has in many instances been largely altered to chlorite.

The essential minerals of this formation are quartz and hydromica. The accessory minerals are magnetite, pyrite, sericite, garnet and apatite. The sericite, chlorite and limonite are of secondary origin. There is an abundance of fine fibrous or scaly mica which has been drawn out into parallel lines. The apatite crystals are well defined. Magnetite is quite abundant and feldspars are entirely absent. The absence of feldspars from the slides of the hydromica schist in the towns to the north of Braintree, even as far north as the Canadian border, and the presence of feldspars in all slides of the sericite schists that flank the hydromica schists on the east lead to the conclusion that they are entirely different terranes. This formation is older than the sericite schists.

first mention

MISSISQUOI GROUP.

SERICITE SCHISTS.

The sericite schists of the Missisquoi group have been continuous from the international boundary on the north southward for approximately 100 miles. Throughout the entire distance they, everywhere, flank the Ordovician terranes on the west and become the easternmost member of the Cambrian group. It is the predominating formation in Braintree as it was in Roxbury. It probably occupies a greater area in Braintree than all other formations combined. It stretches in two separate belts across the entire township. These two belts are separated from each other by a broad belt of quartzite. Perhaps some of the material mapped in as hydromica schist and a part of that mapped as quartzite should in reality have been mapped as sericite.

The sericite schists are fine to medium grained, schistose, sedimentary rocks. They present a light colored appearance upon their weathered surfaces for the essential mineral sericite is silvery white in color. The only essential minerals present are quartz and muscovite (sericite). Magnetite, pyrite, apatite, are accessory. Sericite, albite and limonite are secondary. Albite has been absent from a few slides but is usually present.

Where the sericite predominates the rock is classified as a sericite schist. Where the well rounded quartz grains are in large excess over the mica the rock is classified as a quartzite. In some instances this formation becomes decidedly talcose as in the southwestern part of the township and here the narrow bands are catalogued as a talcose schist.

The great abundance of apatite showing corroded edges is proof of the sedimentary origin of these schists. The parallel banded arrangement of the sericite in scales and needles often presenting a shingle-like appearance is noteworthy.

The general strike of this formation is north 30 degrees east, but there are many variations in the strike. This holds especially true in the neighborhood of Oak Hill where all variations in strike were recorded from north and south to east and west. The intrusives of Oak Hill are in part responsible for these variations. Often the change in direction of strike is very abrupt. Occasional elongated quartz pebbles give evidence of the crushing action of crustal movements.

The dip of the sericite schist is always at a high angle. The formation has been folded into a series of sharp anticlines and synclines with the prevailing dip to the west. These dips are the dips of the cleavage planes and may or may not coincide with the bedding planes.

QUARTZITE.

The Cambrian quartzites have appeared in every township southward from the international boundary through which the erosional unconformity between the Cambrian and Ordovician terranes has been traced. This distance has already exceeded 100 miles. In some instances the outcrops appear fairly uniform in width, while in others the formation is quite lens-shaped. The quartzites are flanked both upon the east and the west by the broad belts of sericite schist.

The main belt of quartzite extends across the entire township in a more or less southerly direction but it curves to the eastward in the more southern part of the township. It is best seen in the northern part of the township a little south of the Roxbury town line and about two miles east of the Braintree-Granville valley.

In texture this quartzite varies from fine to medium grained. Occasionally it is slightly porphyritic. It is a silvery white, schistose, sedimentary rock. The quartz grains are fairly uniform in size but well rounded quartz pebbles of small dimensions were occasionally observed. The essential minerals in this formation are quartz, muscovite (sericite), orthoclase and andesine. The feldspars are minor constituents. The accessory minerals are magnetite, ilmenite, pyrite and biotite. The secondary derivatives are chlorite derived from the alteration of biotite, leucoxene derived from the ilmenite, sericite from muscovite, and limonite from pyrite. The quartz grains have in some instances been secondarily enlarged and in some cases granulated. The presence of andesine indicates that the sediments were derived in part at least from intrusives.

The general strike of the formation is from north 20 degrees east to north 30 degrees east but there are many local variations. The general dip is from 80 to 85 degrees to the west but dips from 80 to 85 degrees east were recorded. It graduates insensibly by the increase of the sericite and the decrease of the quartz grains into the sericite schist and is of the same age. It represents the more arenaceous sediments of the Upper Cambrian.

CHLORITE SCHISTS.

If any of the chlorite schists of Braintree are of sedimentary origin then these schists belong here. If they are igneous in origin as many of them are definitely known to be then their discussion belongs under the caption of intrusives. Under the caption of intrusives, evidence will be presented proving an igneous origin of many of these outcrops.

The chlorite schists occasionally conform in strike and dip with the enclosing sericite schists. In the mapping these narrow chlorite bands are not easily distinguished from the prevailing sericite schists. A ferruginous clay by metamorphism could yield iron-alumina silicates which could be subsequently altered to chlorite. Secondary hornblende has been observed in these Cambrian terranes and hornblende alters to chlorite. Biotite is not uncommon in the more westerly beds of the sericite schists and biotite also alters to chlorite.

In composition the chlorite schists have the mineral chorite or some related mineral of the chlorite group as their determinant constituent. More or less quartz is present. Magnetite is invariably present. Apatite, and a plagioclase feldspar have been observed in some slides.

These rocks are decidedly schistose in texture, fine grained to medium, and in color some shade of green. The intensity of the green color depends largely upon the chlorite content of the rock. In a few samples the quartz content is comparable to the quartz grains in the sericite schists.

ORDOVICIAN.

The term Ordovician as here used embraces a group of metamorphic sediments that lies to the east of the Cambrian terranes already described. These two groups are separated from each other by an erosional unconformity. This erosional unconformity has now been traversed in a northeasterly and southwesterly direction for approximately 150 miles. It is known to extend southward from Braintree through Randolph, Bethel and Barnard.

In general the Ordovician terranes consist of limestones, marbles, calcareous quartzites, phyllite schists and slates.

IRASBURG CONGLOMERATE.

The characteristics of this conglomerate have been given in so many of the earlier reports on the terranes of eastern Vermont that it seems inadvisable to repeat them here. No outcrops were found that presented the striking features of this conglomerate as seen in Irasburg, Albany and Northfield. The area occupied by this conglomerate is densely wooded and deeply buried with glacial débris and consequently the exposures were few. Even where exposures could be found, erosion has not been carried as low in the Ordovician formations in Braintree as it has in the townships to the northward.

WAITS RIVER LIMESTONE.

The Waits River limestone does not occupy an extensive area in Braintree. This formation traverses the northeastern part of the township. It includes a series of limestone, quartzose marbles and calcareous quartzites. No attempt has been made in the mapping to distinguish one phase of these calcareous rocks from another.

In Braintree this formation is usually a fine-grained, dark gray, slightly schistose, sedimentary rock. The calcite is often arranged in parallel bands like the quartz grains. The only essential minerals present are calcite and quartz. The one accessory constituent present in several slides examined is a black to brownish black carbonaceous material which in many instances has been proven to be graphite or uncombined carbon. The outcrops to the northwest of Pethville and to the southwest of Snowsville illustrate well the presence of graphite.

The secondary minerals are muscovite, pyrite and garnet, with limonite derived from the alteration of pyrite. The most striking features are the long, narrow, parallel bands into which the calcite and quartz grains have been drawn, the presence of the uncombined carbon which imparts the dark gray color to the limestone, and the rusty brown color to which the limestone weathers through the oxidation of the pyrite.

This limestone is often shaly and thin bedded and the typical banded Waits River phase is wanting. This latter phase, however, is well pronounced in Randolph a few miles to the east of Braintree. Where the typical calcite cleavage is pronounced, and the crystals are of medium size, and the calcite in excess of the quartz grains the rock is classified as a quartzose marble. Where the well rounded quartz grains predominate the rock is catalogued as a calcareous quartzite. The more highly metamorphosed sections constitute a combined marble and quartzite. In the work now being done upon slides of specimens collected in Randolph this feature is well illustrated.

The strike of these calcareous beds varies from north 20 degrees east to north 30 degrees east. The dip is usually at a high angle to the west but easterly dips were recorded.

MEMPHREMAGOG SLATES.

The Memphremagog slates of Montpelier and Northfield appear also in Braintree. These slates flank the eastern belt of the Cambrian sericite schist upon the east. Furthermore it lies west of the Waits River limestone. Some of the beds of the phyllite schist are slaty and slabs were obtained which had the characteristic ring of slates. It is difficult to separate these narrow beds of slate and phyllite in mapping. Even phyllite schists are present in the beds mapped in as slate.

The cleavage of the slates is not so pronounced as it is in Northfield and the slates can hardly be considered as roofing material. They constitute a series of fine-grained, dark bluish gray to black, schistose, sedimentary rocks. Under the miscroscope they appear scaly and fibrous. The essential constituents are mica, mostly muscovite but with some sericite and quartz. The accessory minerals are magnetite, garnet, graphite and pyrite. An iron stain results from the oxidation of the pyrite and the leaching out of the oxides formed gives rise to small cubical holes in the loose slabs of the slate.

The arrangement of the mica scales and the carbonaceous material in parallel bands is particularly interesting. The presence of a large garnet cutting the flow structure proves it to be of secondary origin. There has been a slight movement of the slate since the garnets were formed. The magnetite instead of being uniformly scattered throughout the slate is drawn out into parallel lines. Several of the microscopic slides examined indicate that much of the material mapped in as slate is a metamorphic rock that falls between a true slate and a phyllite schist.

PHYLLITE SCHIST.

The extreme northeastern corner of Braintree is occupied by a belt of phyllite schist that extends into Brookfield on the north and into Randolph on the east. Several smaller areas of phyllite occur to the west of Snowsville and Pethville and two of these lens shaped areas appear upon the areal map. The phyllite schists are more resistant to erosion than the associated limestones and marbles and therefore they form the more prominent small ridges in this section of the township.

These rocks are fine-grained, bluish gray, schistose, and of sedimentary origin. Their essential minerals are quartz, muscovite, or sericite, and biotite. The accessory minerals are garnet, magnetite, pyrite, graphite and biotite. Biotite is sometimes quite abundant. Sericite, biotite and limonite appear as secondary minerals. The schistosity is well developed. This formation has appeared in every township south of the international boundary for more than 100 miles. Often it forms a broad belt clearly marked off from the enclosing limestones. Sometimes it appears as interrupted non-calcareous lenses within the limestones. It is of the same general age as the Memphremagog slates, Ordovician, and belongs to the Memphremagog group.

ACID INTRUSIVES.

GRANITE.

The largest and the best known granite outcrop in Braintree occurs in the northern part of the township on the farm of Victor I. Spear and on the adjacent farms. It may extend northward into the edge of Roxbury. It occupies a considerable area on the western and southwestern slope of Nevins Hill. This hill is densely wooded and the exact outline of the granite was difficult to ascertain.

This granite could be quarried and used as a constructional and monumental stone. It is best catalogued as a muscovitic biotite granite. In texture it is medium to coarse grained and dense. It is of medium gray color. The essential minerals are

quartz, orthoclase, biotite, with a little muscovite and some oligoclase, microcline and microperthite present. As accessories the granite carries a little magnetite, apatite, zircon, hornblende, pyrite. The secondary limonite stain seen on surface samples is derived from the oxidation of the pyrite. Pyrite grains are most abundant near the contacts and may disappear at reasonable distances from the contact. In the surface samples collected the feldspars are kaolinized, the few scales of muscovite sericitized and the biotite chloritized. Possibly some of the sericite was derived from the alterations of orthoclase.

Several outcrops of igneous rocks that on their exposed surfaces closely resemble a granite and were supposed in the reconnaissance work of 1895 to be granites have now been proven otherwise. They have provided an exceedingly interesting petrographic study. The commercial granites of Braintree are of Devonian age and are contemporaneous with the granites of Barre and Woodbury.

GRANITE GNEISS.

About two miles north of the village of Braintree and about one-half mile east of the Braintree-Granville road there occurs an interesting dike-like outcrop of granite gneiss. The gneissoid structure is quite pronounced both in hand samples and in the outcrop itself. This structure is produced by the parallel orientation of the biotite and muscovite crystals.

The rock varies from fine to medium grain in texture, and in color it is a medium gray. The essential minerals are quartz, orthoclase, albite, biotite and muscovite. The accessory minerals are apatite, zircon, garnet and magnetite. There is present also a little chlorite derived from the alteration of biotite, a little calcite and a faint limonite stain. It is interesting to note the presence of albite in the gneiss and the absence of albite in the granite. Also the presence of Carlsbad twins in the granite and their absence in the gneiss. Whether this gneiss is of the same age as the Devonian granites or not is not known. The gneissoid structure may have been introduced at the close of the Carboniferous times or even later. Gneissoid structure has been observed in the border zone of many small granite outcrops in Vermont.

INTERMEDIATE INTRUSIVES.

NEPHELINE SYENITE.

The nepheline and alkaline syenites, together with some of the lighter colored diorites are among the rocks formerly supposed to be granites. A searching petrographic study of the intrusives of other sections of the State will ultimately lead to a change in the names so far ascribed to many of those intrusives.

A nepheline syenite occurs on the farm of Victor I. Spear in the northern part of Braintree. The rock is fine grained and dense, dark gray and extremely tough. About 50 per cent. of the minerals are light colored and about 50 per cent. are dark colored. The essential minerals are orthoclase, oligoclase, andesine, hornblende, nephelite and arfvedsonite. The accessory minerals are apatite, biotite, magnetite, ilmenite. The apatite occurs in both needles and grains. The secondary minerals are saussurite, calcite, epidote, leucoxene and chlorite. The rock is susceptible of a high polish and would make a beautiful stone for decorative interior work.

ALKALINE SYENITE.

An outcrop of an alkaline syenite was discovered near the Braintree-Randolph town line. The area covered is small. The samples collected were fine grained to moderately porphyritic in texture and of greenish color. The essential minerals are orthoclase, microcline, albite, biotite and hornblende. The accessory minerals are magnetite, ilmenite, apatite, zircon and garnet. The secondary minerals are calcite which may have been derived from the alterations of the ferromagnesian minerals, epidote derived through the changes that have taken place with the feldspars and ferromagnesian minerals, chlorite derived from hornblende, uralite also derived from hornblende, leucoxene derived from ilmenite, kaolinite and sericite derived from orthoclase. There is a large amount of microcline in this alkaline syenite which shows in the phenocrysts the grating structure so characteristic of the mineral. The finding of these syenites on the eastern side of the Green Mountains opens up a new chapter in the petrographic history of Vermont.

BASIC INTRUSIVES.

DIORITES.

The diorites of Braintree are found to the east of the Braintree-Granville valley. They are widely distributed over the northeastern part of the township. Some of them appear as dike-like masses, while others are rounded masses suggestive of stocks.

The diorite of Oak Hill is a fine grained to moderately porphyritic grayish igneous rock. Its essential minerals are oligoclase, andesine, biotite and hornblende. The accessory minerals present are diopside, garnet, magnetite, ilmenite, titanite, apatite and pyrite. Among the secondary minerals present leucoxene was found to be derived from ilmenite, chlorite derived from hornblende, zoisite from feldspars, and a brown iron stain from pyrite. A little free quartz of secondary origin was also observed.

On the hill to the east of the Braintree-Granville road there is a lenticular outcrop of a medium grained schistose diorite. The feldspars of this diorite are largely altered to kaolinite and sericite but not granulated. Secondary calcite is present derived from the alterations of the ferromagnesian minerals, or from the soda-lime feldspars.

A meladiorite occurs on Oak Hill. It is a fine to medium grained dark gray igneous rock. It contains approximately 40 per cent. of andesine, 30 per cent. of hornblende, and 15 per cent. of augite. Ilmenite appears as an accessory mineral even though it makes up about 10 per cent. of the rock. The remaining 5 per cent. is divided among the accessory minerals, apatite, garnet, titanite, magnetite, and the secondary minerals epidote, chlorite, leucoxene.

Diorites are abundant around Quaker Hill. They consist largely of andesine and hornblende. Augite is present in some of them while biotite is present in others. They all carry as accessory minerals apatite, ilmenite and magnetite. Some of them contain titanite and a few diopside. One of them contains a little orthoclase.

Leucoxene is present in all of them and is derived from the ilmenite. Chlorite is present derived from hornblende. Epidote, saussurite, sericite and kaolinite are common secondary derivatives. Zoisite is not infrequent.

DIABASE.

Diabase dikes are extremely abundant in Braintree, especially to the west of the Braintree-Granville road. To be sure that all of these dikes are or were originally diabase would require a large number of microscopic slides for petrographic study. That they are dikes of some basic igneous rock there can be no doubt. They are often very compact, tough, greenish in color, and cross the sedimentaries at many different angles. Sometimes they conform in strike to the strike of the sedimentaries. Some of these dikes are shown upon the areal map. Many may be omitted because of the uncertainty of the outcrop being another distinct dike. It has frequently held true in eastern Vermont that where a dike area was encountered it carried from 50 to 75 dikes within a distance of two miles. These are not to be confused with the basalt dikes that strike east and west across the sedimentaries, always narrow and sometimes more than 50 miles in length.

Another diabase dike area is located both on the east and west side of Oak Hill and to the south of Mud Pond. They are fine-grained, greenish, dense, igneous rocks, sometimes schistose. Essentially they consist of labradorite and augite. A little hornblende may be present. Biotite occurs in the diabase directly south of Mud Pond in the outcrop upon which the rocking stone already mentioned rests. The accessory minerals in all the slides examined from this area are ilmenite, magnetite and apatite. Biotite was present in one slide as a secondary mineral and orthoclase was found in one slide. The secondary minerals usually present are epidote, leucoxene, chlorite, sericite, calcite, kaolinite and limonite. In one slide secondary quartz was observed.

EPIDOTITE.

The introduction of dikes of epidotite into this report will be quite unexpected. This like the alkaline syenites already described suggests the need of much more petrographic study upon many samples of rocks collected in the eastern-half of Vermont from which microscopic slides have not yet been made.

The epidotite dikes are located on the west side of the Braintree-Granville road and in the more southwesterly part of the township. They are fine-grained, dense, pistachio green, non-schistose igneous rocks. Some of them carry more than 60 per cent. of epidote. Chlorite, hornblende, augite and granulated plagioclase are usually present. One slide bears diopside as an essential mineral. Olivine was present in two of the slides, and a few grains of nephelite may be present in one slide examined.

The usual accessory minerals are magnetite, garnet, apatite and pyrite. Ilmenite is not infrequent. The common secondary minerals are leucoxene in all slides where ilmenite is present, chlorite derived from hornblende or biotite, calcite from the alteration of the ferromagnesian minerals. The feldspars are usually undeterminable and often well saussuritized. In some cases the alteration of the feldspars to saussurite is complete.

CHLORITE SCHISTS.

The chlorite schists of Braintree have chlorite as the determinant mineral. They are sometimes fairly schistose in character but often massive and tough. The chlorite occurs in fibrous masses, in needles and green scales. The schist is of bright green color. This true color is sometimes better seen at a little distance from the outcrop than it is in the fresh hand specimen.

The strike of the chlorite schists sometimes conforms with the strike of the enclosing sericite schists but often they cut the schists at high angles. These schists are manifestly alteration products of some basic igneous rock rich in its ferromagnesian minerals. The wide variation in strike from nearly north and south to nearly east and west substantiates this theory. The mineralogical composition also leads to this conclusion.

Chlorite sometimes constitutes approximately 40 per cent. of the rock, epidote 20 per cent., orthoclase 20 per cent., magnetite 10 per cent., hornblende and augite 5 per cent., and sometimes the quartz equals 5 per cent. Diopside, olivine and biotite are sometimes present as essential minerals. Magnetite and pyrite are the prevailing accessory minerals. The epidote, chlorite, calcite, limonite and quartz are all secondary in origin. Two characteristic features are the absence of ilmenite which has been so pronounced in the diorites and diabases and the great abundance of calcite which in some slides appears in bunches. The quartz is smoky.

EPIDOTIC ACMITE SCHIST.

An unexpected epidotic acmite schist occurs near the west town line of Braintree. It is a fine-grained, greenish, dense, schistose, igneous rock. Its essential minerals are acmite, epidote, hornblende and andesine. Its accessory minerals are magnetite, garnet, ilmenite, biotite. The secondary minerals are leucoxene, epidote, uralite, calcite and quartz. The acmite is deep green and fibrous. The uralite is fibrous and with frayed ends. Calcite is fairly abundant and olivine is present.

SAUSSURITE SCHIST.

In a railroad cut south of the village of Braintree there occurs an exceedingly interesting saussurite schist. This schist is from medium to dark green in color, fine-grained in texture, slightly schistose and of igneous origin. Its essential minerals are saussurite, albite, hornblende and quartz. The accessory minerals are magnetite, biotite and rutile. The secondary minerals are saussurite, chlorite, epidote, calcite and a little quartz. The saussurite has been derived from the alteration of feldspars. The needles of rutile occur in the quartz grains. The chlorite occurs in long fibrous forms. Ilmenite which has been so common in the intrusives of Braintree is entirely absent.

AGE OF BASIC DIKES.

The age of these basic dikes is not definitely known. Whether they were all introduced at the same time or not may be a matter of conjecture. They may have been introduced at the close of the Cambrian but it is not certain that all of them if any of them were introduced at that time. The more highly altered and the more schistose dikes probably were introduced at the close of the Cambrian. A proof of this age may be found in the basic boulders that have from time to time been found in the Irasburg conglomerate. Unquestionably there was an introduction of basic intrusives into the Cambrian sediments at the close of the Cambrian.

There is an argument in favor of the dikes that carry ilmenite and its alteration product leucoxene being introduced at the same time. They may represent the arms or off-shoots of a vast body of igneous rocks that have not yet been reached by erosion. The great variety of these dikes may be due to the differentiation products formed in the cooling of the magma. As the fresher dikes are approaching so close to the Ordovician terranes in the eastern part of Braintree they might have been carried even into the Ordovician terranes in Randolph. If they are found cutting these terranes in Randolph then they can not be pre-Ordovician and most likely have come in at the close of the Devonian. Further field study is necessary in Randolph to prove this point. Further study of the microscopic slides made from samples already collected in Randolph may help settle the question of age.

PERIDOTITE AND PYROXENITE.

There are two belts of peridotite and pyroxenite in Braintree. One of these constitutes a narrow belt of about two and one-half miles in length, situated in the northwestern part of Braintree about one mile east of the Braintree-Granville road. Its strike is nearly due north and south. It extends northward into Roxbury. In the more northern portion the strike of the vein is north 20 degrees east. This belt carries two distinct talc veins. The easternmost vein outcrops on the farm of E. S. Abbott for nearly one-half mile. These outcrops are practically continuous. This vein is from 40 to 50 feet in width. The pulverized product of the best samples is pure white and gritless. On the farm of George Jerd the talc outcrop is continuous for about 75 rods. Many isolated outcrops of talc appear in the southern extension of this peridotite and pyroxenite belt in Braintree. The western wall of these veins consists of chlorite.

The western talc vein enters Braintree about one mile south of the Roxbury town line. This is the vein that the Eastern Talc Company of Granville is now operating. Their plant is capable of producing 100 tons of talc per day.

The altitude of the spruce ridge on the Abbott farm is 1,450. The altitude of Webbs Mills on the Central Vermont Railroad is approximately 850 feet. The talc could easily be conveyed from the mine to the railroad by a bucket tramway.

A microscopic slide from the talc deposit on the farm of E. S. Abbott showed talc as the only essential mineral. Its texture was scaly and fibrous. Quartz, calcite, dolomite and magnetite, which are characteristic of so many talc deposits were all absent save a few microscopic grains of dust that may be magnetite. A few scales of phlogopite were observed. The abundance and purity of this talc suggest that the mine should be opened up and systematically worked.

A fine sample of peridotite consisting essentially of olivine with a very little plagioclase was obtained on the farm of George Farrington. The one accessory mineral present was magnetite. The secondary minerals present are serpentine (antigorite), saussurite, chlorite, epidote, quartz and limonite. The presence of olivine abundantly disseminated through the rock in grains and large rounded crystals is noteworthy.

A second belt of peridotite and pyroxenite appears in the southern part of Braintree and extends southward into Rochester. The peridotite has been metamorphosed into a verd antique marble and the pyroxenite into talc.

The verd antique marble is a fine-grained, grayish green, massive, metamorphic rock which is susceptible of a fine polish. Its essential minerals are serpentine (antigorite) and talc. The accessory minerals are magnetite, dolomite and breunnerite. Secondary talc, calcite, dolomite, and either a little muscovite or phlogopite are present. Free quartz is entirely absent in the slides examined.

The pyroxenite phase of this intrusive has given rise to some lenses of talc but more often to a talcose schist. This rock is fine-grained, greenish, foliated and schistose. Its essential minerals are talc and quartz. The scales and plates of talc arranged in parallel planes produce schistosity. The accessory minerals present are magnetite and pyrite. The secondary minerals are talc, quartz, chlorite, ankerite, hematite and limonite.

METALLICS.

ARSENOPYRITE.

The only metallic mineral of commercial importance known to occur in Braintree is arsenopyrite, a sulpharsenide of iron, FeAsS. This mineral occurs in a well defined vein on the farm of Knowlton Howard of East Braintree. The vein is located about one-half mile east of Snowsville and about 100 rods west of the Randolph town line. It is therefore in the extreme north-east corner of Braintree. It occurs in a thickly wooded section only a few rods from the highway at an altitude of approximately 920 feet. It is further situated about 5 miles from Randolph.

The strike of this vein varies from north and south to north 10 degrees east. Outcrops were found proving the vein at least one-fourth mile in length. Where a little trenching had been executed several years ago the vein appeared to be more than 20 feet in width. The gangue mineral is quartz and the origin of the arsenopyrite is hydrothermal.

Four different samples have been analyzed for their content of metallic or elemental arsenic with the following results:—Percentage of arsenic, 43.58, 43.03, 43.24, 43.72. It has also been assayed for silver and found to carry from one to two ounces of silver per ton. The silver is present in too small a quantity for profitable extraction.

PALEONTOLOGY.

In Vermont no fossils have as yet been found in the hydro-mica schists, sericite schists, and non-calcareous quartzites on the eastern side of the Green Mountains. Their relative age has been determined by continuity, lithological characteristics and stratigraphical position. They are unquestionably pre-Ordovician for they furnish the pebbles in the Irasburg conglomerate in Irasburg, Albany and Northfield, which lies at the base of the Ordovician series in eastern Vermont.

The frequent occurrence of a conglomerate in the Cambrian terranes would imply that the hydromica schist was Lower Cambrian and that the sericite schist with its associated quartzite was Upper Cambrian. The hydromica schist has received but little attention for it generally occurs in a densely wooded area and at the higher altitudes along the crest of the lower mountain ridges. When systematic cross-sections can be run westward to the Green Mountain axis the stratigraphic position of the hydromica schist can be determined. If it should prove Upper Cambrian then the Cambrian conglomerate is interformational. The sericite schist and the quartz-sericite schists are known as the Missisquoi schists. They have been continuous from the Missisquoi valley where they are very abundant southward for more than 100 miles. They have retained their northern characteristics the entire distance. It might be added that the Cambrian quartzite is only a sericite schist in which there is a preponderance of quartz over the fine scaly or fibrous muscovite (sericite).

The discovery of new beds of graptolites in Braintree and Randolph is significant. Graptolites were very abundant in the slates on the east side of Cram Hill in Roxbury and this slate with its graptolite content extends southward into Braintree. This proves the southern extension of the Memphremagog slates into Braintree and Randolph as early Ordovician. Graptolites were also found in the interstratified phyllite schist but much distorted. Well preserved graptolites were found in Braintree in the shaly limestone beds to the west of Snowsville and Pethville, thereby proving the age of limestones in Braintree and Randolph as Ordovician.

ECONOMICS.

The Missisquoi schists in Braintree are of little commercial value. Slabs of these schists have been used for culverts, bridge guards, underpinning and foundation work. It is also used somewhat in road construction. In some localities the schist appears suitable for flagging purposes.

The more quartzitic phase styled the Cambrian quartzite has a fine grit, does not gum and could easily be manufactured into whetstones of a good grade. These would have to be selected from the beds that are the richest in quartz and the poorest in iron.

It is doubtful if any of the slate in Braintree is sufficiently fissile for roofing purposes. Thin beds were found in the northern and eastern part of the township that were fairly fissile. It did not appear that any of them possessing this characteristic were of sufficient dimension for a good slate quarry.

The limestones and quartzose marble in the northeastern part of the township may have a local use in the construction of culverts, bridges, foundation work and permanent roads. The typical rusty brown color on many exposed surfaces proves them too rich in iron content for monumental work. They do, however, work easily into good rectangular blocks. The purest of them are susceptible of a good polish.

The verd antique marble of the southern part of the township is in places susceptible of a good polish and well suited for decorative interior work. The belts, however, appear to be narrow and not comparable in size to the well known marble deposits of Roxbury.

The talc deposits on the E. S. Abbott farm as well as that on the George Jerd farm in the northern part of Braintree should find a ready and waiting market. The deposits are of sufficient purity and of adequate tonnage to meet the requirements of a good mill that might best be located at Webbs Mills. The talc should be carried from the mine to the mill by an aerial tramway.

The arsenopyrite vein in the extreme northeast corner of Braintree has never been opened up save to secure some very fine specimens. A little trenching has been done to determine the width of the vein. This trench is now nearly filled with débris. The vein should be opened up systematically by sinking a shaft in the ore body and by cross cutting to determine the width of the vein. This ore body must be catalogued as an arsenic reserve.

SUMMARY.

The areal map is designed to show roughly the general distribution of the different terranes in Braintree. Without topographic maps in a country as rugged, broken and densely wooded as Braintree accurate mapping would be extremely difficult. The map must be regarded as an approximation. It will be a pleasure, however, to map in these terranes and to locate accurately the numerous dikes of Braintree whenever topographic maps may make their appearance.

The protracted section which accompanies the areal map shows the dip of the cleavage planes and does not always coincide with the bedding planes. In fact a wide difference can be seen in these planes in many localities. The nearest approach to these planes coinciding with each other is to be found in the thin bedded and shaly limestones of the northeastern part of Braintree.

The erosional unconformity which was so pronounced in Irasburg, Albany and Northfield has been proven to extend southward through Braintree, Randolph and into Bethel. The definition of the different sedimentaries has been effected by the petrographic study of a large number of microscopic slides. The discovery of a large number of apparently lamprophyric dikes is intensely interesting. It may reasonably be assumed that beneath these dikes there is a large batholith of granitic rocks. The absence of the customary aplite dikes may be explained by the fact that these basic rocks are more easily fused than the acidic ones and that erosion has not been carried low enough to bring the aplites into view.

The discovery of unquestioned olivine in many slides, both in grains and in well defined crystals with rounded edges throws additional light upon the problem of the origin of the verd antique marble of eastern Vermont. Some of the chlorite schists and all of the chloritic dikes have been definitely proven to be of igneous origin. Their definition has been determined by the careful petrographic study of a large number of slides. The definition also of the lamprophyric dikes has been determined by their mineralogical composition. This long continued petrographic work has revealed the presence of igneous rocks in eastern Vermont that hitherto were not known to exist in Vermont. This work has also led to the discovery of several minerals hitherto unmentioned in the mineralogic literature of Vermont. A detailed petrographic study will be conducted during the next two years on material collected in Randolph in the hope of throwing some light upon the age of the dikes and the discovery of some new rock masses that do not fall within the definition given to any igneous rocks hitherto described either in Vermont or elsewhere.

The discovery of several new beds of graptolites in the slates and shaly limestones of Braintree and Randolph has proven the stratigraphic relations of these terranes. Just how far to the southward these diagnostic features can be secured is somewhat a matter of conjecture. It is believed, however, that they will be found in each township as far south as Barnard.

77-89

A DETAILED STUDY OF THE TRENTON BEDS OF GRAND ISLE.

George H. Perkins.

INTRODUCTION.

During the summers of 1901 and 1902 the writer spent several weeks in a general investigation of the different rock formations of Grand Isle County. Some of the results of this study were published in the Third[1] and Fourth[2] Reports of the Vermont State Geologist and geological maps of the county were also published. Necessarily, this investigation was not as detailed as it might have been had there been longer time which could have been given to the work and it was the intention of the Geologist to make a detailed study of the different formations of the region as soon as possible. This intention had not been carried out until the summer of 1919 and the present summer, 1920, when the Trenton beds of Grand Isle were carefully examined and collections of the fossils made. These fossils have been studied by Dr. Rudolph Ruedeman of the New York Geological Survey and the writer feels sure that they could not have been committed to better authority. Dr. Ruedeman's report on these fossils will be found on following pages.

PREVIOUS GEOLOGICAL WORK.

A thorough study of the formations of Grand Isle as a whole has yet to be made. Seely and Brainerd[3] made a most excellent report on the Chazy of the southern part of the island and allusions to the geology of the island are found in the *Second Report* of C. B. Adams made in 1846, in the *Appendix* to Thompson's *Vermont,* 1853, pp. 40-44, and in *Geology of Vermont,* Hitchcock, 1861, pp. 281-301, but these last are little more than allusions so far as the region here considered is concerned. In 1898 Dr. T. G. White published in *Bulletin of the Geological Society of America* a paper entitled *"Upper Ordovician Faunas in Lake Champlain Valley,"* in which, page 458, he speaks of "23 feet of lower Trenton beds" at the southern end of the island. Doctor White writes only very briefly of these rocks, but mentions his

[1] Pages 102-173, plates XXI-LIII.
[2] Pages 103-143, plates XXXVII-LXIX.
[3] *Bulletin Am. Museum Natural History,* vol. III, pp. 1-27.

vol.?

collecting a large lot of fossils which were placed in the Geological Museum of Columbia University, where he evidently intended to work them up. The death of Doctor White before he had done any of this work prevented the undertaking.

An examination of these specimens, which are still in the Columbia Museum, proved quite unsatisfactory because all were labelled in such a manner that only the one who collected them could determine the locality from which any given fossil was taken, also many are very imperfect. Had Doctor White lived to give the results of his work on Grand Isle more fully and been able to supply lists of the fossils he found, his work would have been very helpful to those who might follow him.

So far as the writer has been able to ascertain, no other work than that mentioned has been done on the Trenton beds of the island.

FORMATIONS OF GRAND ISLE COUNTY.

The general topography and distribution of the various formations of South Hero and Grand Isle County have been given in the Third and Fourth Reports of this Survey as has been already noticed, but for the sake of completeness a brief résumé may be included in this article. All the rocks, except those which must be referred to the *Pleistocene,* the covering of clays, sands and gravel, which occur in this region are Ordovician and to a greater or lesser extent all the main subdivisions of this age are exposed on Grand Isle and Isle La Motte, while North Hero and Alburg show only a black shale which in this article is placed at the top of the Trenton.

On Grand Isle the Beekmantown and Chazy are well exposed, but only in very limited areas, especially the former. The Black River outcrops in several places both on the lake shore and inland, but by far the greater part of this island is covered by Trenton.

On Isle La Motte there is a very little Upper Trenton shale and in the northern part a small area of Lower and Middle Trenton. The southern half of Isle La Motte is wholly Chazy except just along the lake at "The Head" where there is a bold exposure of Beekmantown.

In this paper only the Trenton of Grand Isle will be considered as there has not been sufficient time for any further study of this group, but it is intended to report later on the Trenton of Isle La Motte and other Vermont localities.

DISTRIBUTION OF THE TRENTON IN VERMONT.

Until within a few years no Trenton has been recognized in Vermont only in the western part along Lake Champlain, but during field work east of the Green Mountains, Dr. C. H. Richardson has found in a very dark, silicious limestone which he has called the Waits River Limestone, in many localities from near the Canada line to below the middle of the State numerous graptolites, which though for the most part badly crushed have been recognized by Dr. Ruedeman as Lower Trenton species.[1]

From this it is probable that at one time Ordovician beds were common all over eastern Vermont, but have since been so changed and in many cases entirely metamorphosed that they were not recognized. It appears to be most probable that these Ordovician beds extend much further south than is thus far known, as the southern part of the State has not yet been explored for them. However this may prove to be, it is at present in the immediate vicinity of Lake Champlain that one must look for typical Trenton rocks. Here they are found in greater or lesser areas, from near the north line at Highgate to Benson, not continuously, but frequently. This is a distance of eighty miles.

The unchanged beds extend east from the lake shore only a few miles until the limestones, shale, etc., are metamorphosed into the schists and gneisses of the Green Mountains and these form the major part of the mountains.

Aside from the distribution of the Ordovician bed mentioned above and regarding only the distinctly Trenton limestones, one finds them at McNeil Point and Cedar Beach in Charlotte, in Ferrisburg, Panton, Chimney Point, Larrabee Point in Shoreham and some few other localities. Most of these areas are small, but the limestone is well filled with fossils and good opportunity is readily found for studying these typical Trenton beds. Doctor White examined most of the above named beds in his study of *"The Upper Ordovician Faunas in Lake Champlain Valley,"* referred to on a former page.

THE TRENTON ON GRAND ISLE.

As already stated, the following pages will refer alone to the well defined Trenton beds of the largest of the islands of Lake Champlain, Grand Isle. Here the rocks which may be called typical Trenton, with a slight exception, form a continuous area which extends from McBride Bay, about a mile north of the extreme south end of the island, north for six miles in a ridge, which is a conspicuous topographic feature of the island as it forms much of the highest land visible.

Although, with one or two exceptions, there are no higher elevations on the island than those made by the Trenton uplift, yet they are not high, for none are above a hundred and forty feet above the lake, which is reckoned on the topographic maps as a hundred feet above sea-level (this for convenience of reckoning as it is not that within three or four feet, even at highest

[1] Eighth Report Vermont Geologist, p. 181.

water in the spring). Only a few of the highest points in this ridge are over a hundred feet above the lake and most of the elevation is less.

While as a whole this ridge of Lower and Middle Trenton is higher than the rest of the area of the island, there is a knoll or hillock of what has heretofore been called Utica Shale, but which is regarded in this article as Upper Trenton, which is the highest point on the island. This shale elevation is about a mile north of Robinson Point in the northeastern part of its area. There is also a small knoll of Chazy rock a half mile north of Phelps Point. The former of these elevations is two hundred and eighty feet above sea-level, the latter two hundred and sixty feet.

The Lower and Middle Trenton are exposed on the lake shore at several points. At the south, Trenton rock first appears at McBride Bay on the west shore (the Upper Trenton alone is seen on the eastern shore); indeed, of the more than forty miles of shore line, only five miles are cliffs of any other age than this. As has been noticed elsewhere, beginning at Phelps Point and ending at Wilcox Cove on the north we have various outcrops of Chazy, Black River and Trenton (Lower and Middle) but nowhere else on the island.

For a half mile from McBride Bay to the middle of Barnes Bay the shore is Trenton, then for about three-quarters of a mile to Table Bay only Black River appears, then for a mile to Rockwell Bay, Chazy, and north from Rockwell Bay to the north side of Wilcox Cove, Trenton, probably mostly Middle, and all the shore for many miles north from Wilcox Cove, around the north end of the island, south along the east shore and along the south end for more than half its breadth, all is Upper Trenton shale. This shale will be discussed later.

Between Rockwell Bay and Wilcox Point, just at and a little south of Gordon Landing is a small exposure of Upper Trenton which breaks the continuity of the lower beds for rather more than half a mile.

All the above mentioned outcrops of the Lower and Middle Trenton, which are seen on the shore of the lake, four in number, are continuous with the larger area inland as they are extensions westward. There is besides a very small knoll of the same rock just south of the road which runs from South Hero Station to McBride Bay on the road running south from this to Phelps Point. This is a curious little elevation made up of a series of outcrops rising in the midst of Chazy beds. This mass of Trenton is only about three hundred feet long, fifty to a hundred feet wide and thirty feet high. Apparently this is a Trenton remnant once a part of the larger area. It affords several species of Lower Trenton fossils.

The main mass which forms the ridge through the island is a somewhat irregular anticline with faults and more or less disturbance in many places, though, as will be seen, in some parts, especially along the shore of Lake Champlain, the beds are very regularly horizontal.

Professor C. E. Gordon who went over a considerable part of these rocks with the writer, called attention to what he regarded as shearing and a few overthrusts in the southern part of the Trenton uplift, that is east of Sawyer Bay. All this shows that in connection with the uprising of the Trenton beds there was considerable disturbance, though, as will be noticed later, by no means so great or extensive as occurred after the deposition of the Upper Trenton. This is the distribution of the Trenton as we now find it in the region we are discussing. Some error may easily arise because the surface of the island is extensively covered by the clays deposited in the Champlain Period so that it is not now possible to investigate fully some large areas. Still, as in many places the surface soil is thin and has been washed off so that the underlying rock can be seen and examined, the distribution given is not far from correct. Where the limestone has been little disturbed, it does not show itself in the broad level fields of the island until one comes very near, so that as one looks over such a field from the outside there seems to be no rock visible, but when careful examination of the whole surface often shows bare spots hidden in the grass from which knowledge of the underlying rock may be had. All the formations now seen on the island have been more or less eroded and therefore covered far greater area than is now exposed or seen. That is, the Beekmantown, Chazy, and Black River may each have covered a considerable part of the island, but now are in part concealed by later deposits and in part have disappeared through erosion. It is more probable that the three divisions of the Trenton were all more extensive and that at one time the island was all Lower Trenton, then Middle Trenton and finally Upper Trenton, all this supposing rise and sinking of the area and also modification of the form of the shore.

The Grand Isle of Beekmantown time may well have been less than half as large as now, but after the Chazy seas had finished their contribution to the limestone beds and these beds had risen above the water, the then island was undoubtedly much larger than it had been, perhaps than it is now. Then the land was again submerged and the peculiar beds now called Black River were deposited and these covered the whole island, and so on through Lower, Middle and Upper Trenton time.

The character of the rocks shows more or less plainly the character of the sea and the sea bottom during these different periods and more interesting still is the story of the life of each period as shown by its fossils. Geologists do not need to be told that both rocks and life of each of the periods named are different in each case and fully characteristic of each.

The Beekmantown and Black River do not abound in fossils, at least not in the localities on the island, but the Chazy and Trenton may be very satisfactorily studied.

The Upper Trenton, too, is quite barren of fossils, large masses affording none and generally there are few.

At this time the seas became very muddy and shale largely replaced the limestone of former times. This formation long known as the Utica Shale and so called in previous Reports of this Survey was more widely extended than any of those that preceded it as has already been shown.

CHARACTER OF THE TRENTON BEDS ON GRAND ISLE.

As everywhere, the Trenton beds on this island are limestone and shale, with very rarely a slight mixture of sand, but there is nothing that can be called sandstone. Much of the material of the lower beds is clear, hard, compact limestone which in the middle beds is often in regular layers intercalated with thinner layers of soft, friable shale. In cliffs such as that shown in Plate XVIII, the regular arrangement of hard, limestone layers, from three to twelve inches thick alternating with the shale layers from a fraction of an inch to several inches in thickness, but in the typical rock never nearly equalling the limestone, is very interesting and in most cliffs there is no variation in this arrangement, every limestone layer being without exception separated from the next by the layer of shale. I was not able to find fossils in those shale layers that I examined, but of course if there are any they must be the ordinary Trenton species.

In the lowest beds of the Trenton there is little shale and therefore the alternation does not occur. In passing from the middle to the uppermost beds there is a noticeable increase in the proportion of shale which is very evident in certain localities, as in the cliffs south of Gordon Landing and south of Wilcox Cove, though elsewhere the same transition from beds largely limestone to those largely shale is found. In some places the cliffs of the Upper Trenton are almost wholly composed of shale, but usually there are beds, perhaps only a few inches thick, which are solid and compact. Thus it is seen that, while there are distinct contacts between the Chazy and Black River and the Chazy and Trenton, no such distinction can be found between what has been called Trenton and that called Utica Shale.

THICKNESS OF THE TRENTON.

It is not possible to make out with certainty the exact thickness of the whole Trenton on the island for reasons which may readily be inferred from what has been said. Because of faults in some places and disturbance in others and the concealing of the rock elsewhere by the glacial clays many difficulties arise to prevent sure measurement. As quoted, Doctor White gives the thickness at the south end of the island as twenty-three feet, but this is far from correct. While the writer does not wish to make positive statement he is ready to express his belief that the beds aggregate far more than this. I have measured what I could and estimated other beds and it seems to me that not less than two hundred and fifty feet of the Lower and Middle and not less than as much more of the Upper Trenton are to be made out in the various outcrops on the island and I should be willing to increase rather than decrease the above figures, which is to say that in all not less than five hundred feet of Trenton, and probably more, may be found on Grand Isle. None of the Trenton beds are as thick as the heaviest Chazy or even Black River nor are there any beds made up of great numbers of brachiopods like *Rhynchonella* beds of the Chazy. Layers only a few inches thick are the rule and beds more than a foot thick are uncommon, except in the upper strata.

DISTRIBUTION OF THE FOSSILS.

In none of the layers was I able to find such abundance of species as may often be seen in some of the New York Trenton, nor is the number of species contained in these beds very large. In the lower and middle beds some species are found throughout, though in more or less varying numbers. For example, *Isotelus* and *Calymene* are to be obtained from the lowest to the upper middle layers and, though rarely, in the shales of the upper. *Calymene* has not been found as extensively distributed, but its range is nearly as great as is that of *Isotelus*. So *Prasopora* is found in many of the layers, but is much more common in the lower than above these. *Hebertella* is also distributed in much the same manner as is *Rafenesquina*. Some layers of the Middle Trenton, as those north of Rockwell Bay, are full of fragments of *Isotelus,* but even pygidia are not usually common and glabellæ still more rare, though a few entire specimens of good size, and still fewer large specimens, have been found. *Stictopora* is abundant on the surface of some layers of the top of the middle strata, but in the lower they are not common, though found, and none appear to be in the upper shale.

Sinuites is abundant and well preserved in the lowest layers, but is not common elsewhere. *Cryptolithus* is not found in the lowest layers, but soon becomes abundant through a few feet of what appear to be the middle and upper part of the Lower Trenton. Above the lower beds this trilobite is nowhere abundant in these rocks. *Rhynchotrema* is found commonly in the lower strata as is *Platystrophia*. The latter is always very small, as if the conditions were not favorable to its growth. The smaller species of *orthocerata* are found, but not abundantly, from the lowest to the highest layers. The great *Endoceras proteiforme* begins to appear in the middle beds and is found sparingly up to the shales formerly assigned to the Utica. Of the coiled *Cephalopods* few have been found here, the *Trocholites* and still more rarely, *Cyrtolites* do now and then occur. Pelecypods are always uncommon, but *Ambonychia, Edmondia* and *Modiolopsis* are to be had by searching. *Gastropods* are conspicuous by their absence though, as the list given shows, a few have been found. *Algæ* are wholly absent from most of the beds, so far as ascertained, but in a few places they are very sparingly found. In the beds of the Upper Trenton only a very few species have thus far been found, but it should be noticed that there are extensive areas of these beds on the north end of Grand Isle and also North Hero and Alburg that have not been thoroughly explored. *Triarthrus becki, "Orthoceras coralliferum," Glossgraptus quadrimucronatus* and a few other species occur. (See Ruedemann's Report following.)

It may be that the above notes on the fauna of the Grand Isle beds will not be found very valuable and at any rate the writer wishes it to be remembered that they give a summary of one or two seasons' work over a very limited area such as this has been shown to be. For whatever they may be worth they are given. Further research, as is often true, may cause many changes in these statements. It is to be remembered that only the Trenton of one not very large island, an area of about six miles long and of very variable breadth, from one to three miles, has been carefully studied, the Upper Trenton not being included in this. In most cases only generic names have been given here because the full specific name is given in the list of fossils following. It may be said that the common Trenton species are intended when only the generic name is given.

As will be seen by following pages, examples of the fossils collected in these beds have been studied by Dr. Rudolph Ruedemann of the New York Geological Survey and his report upon them is given herewith.

DETAILED ACCOUNT OF THE PRINCIPAL SECTIONS OF THE AREA.

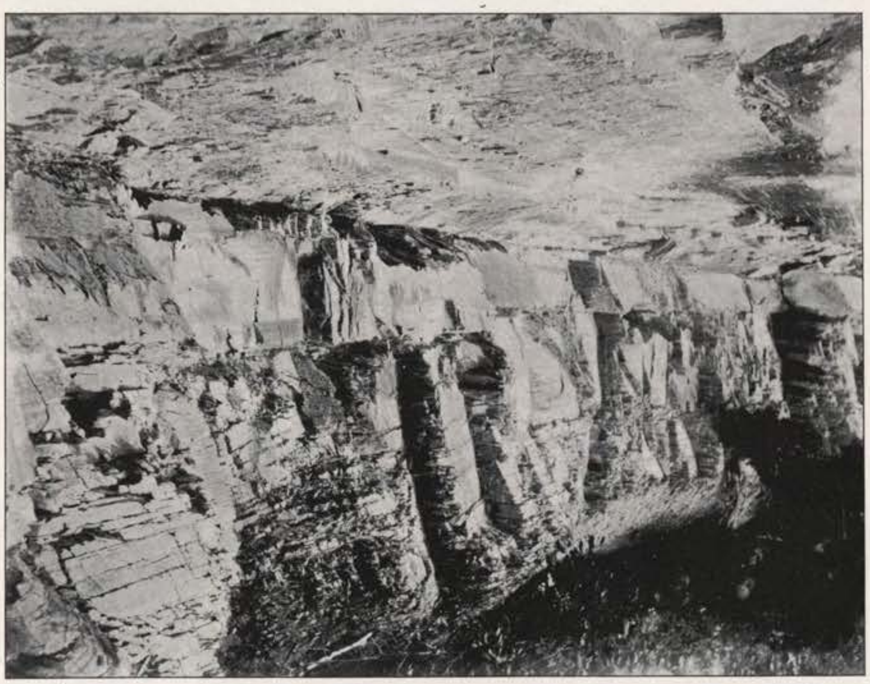
To those who wish to study this area further a more detailed account of its main portions may be helpful. It is proposed therefore to take up each of the most important localities in the area in some detail.

Beginning at the south end of the island, the Trenton is first found on the shore of Lake Champlain at the north shore of McBride Bay, Plate XVI. There is a point which extends from the main body of the limestone out into the lake. On the south of this is McBride Bay and on the north is Barnes Bay. From Barnes Bay for two miles no Trenton comes to the shore, but at

PLATE XVI.

Trenton cliffs north of McBride Bay.

PLATE XVII.



Contact of Trenton and Black River beds at McBride Bay.

the north shore of Rockwell Bay it again appears and from this point it continues without interruption, if the upper beds are included, to a short distance north of Wilcox Cove and as has been shown, the rest of the shore around the entire island is Upper Trenton Shale.

At the middle of McBride Bay the rock is characteristic Black River, but as one goes north the Lower Trenton appears in a cliff about four feet high made up of layers varying from 3 inches to 8 inches thick, each layer separated, as has been noticed in other cases, by a much thinner layer of shale.

A very interesting contact between the Black River and the Trenton is well shown at McBride Bay, Plate XVII. This is one of the very few places where there is a suggestion of sand mixed with the limestone and it is not very pronounced here, but is evident. Apparently, these beds were formed in shallower water than most of those seen. For perhaps a third of a mile these beds continue north along the shore when, as has been mentioned, an outcrop of Black River limestone crowds the Trenton back as it comes between it and the shore. These beds grow thicker from the water to the top and are also heavier toward the north. The stone is very dark gray, but the different layers do not present as uniform an appearance on the weathered surfaces as in the main mass since some are very little changed by weathering, while others are much lighter and browner on the surface, presumably because of the greater amount of iron oxidized. Plate XVII shows the general structure of these beds. The fossils of these layers are not abundant except on the surface of some on which there are numerous sections of crinoids and a few brachiopods.

At Rockwell Bay is the next shore exposure of the typical Trenton, and here the beds are almost entirely undisturbed for a considerable distance. Plate XVIII is a good illustration of these and shows the regularity and the alternation of thin shale layers which has been previously mentioned. As shown, the beds are nowhere thick, but there are many of them, in some places more than fifty. A few of the layers are lighter gray than most and resemble those of the Chazy in that they are full of small, broken fossils. All these beds are barren in fossils, except on the surface where some of them are covered with small crinoids, bryozoa, and small brachiopods. In the main mass of the rock, which is usually black or at least nearly so, there are many fragments of *Isotelus, Endoceras* and, less commonly, *Calymene*. In many layers these few species seem to be about all there are. *Cryptolithus* does not appear to have lived in these waters, though common elsewhere. Until within a few years very interesting specimens of *Endoceras* could be picked up near the shore of the lake, these having been split out of the rock by frost action and after the high water of spring had subsided they were left exposed along the beach. Now, however, too many passersby have picked up all that can be found and it is only an occasional specimen that can be found. Here the *Isotelus* were all large and, judging from the abundance of fragments, must have been abundant in the waters in which some layers were deposited. As everywhere, entire specimens are the rare prizes of the fortunate collector.

There are several places along the shore where the very gradual change from typical Trenton limestone to typical Utica shale is plainly seen. One of the best of these is just south of Gordon Landing. As one proceeds north from Rockwell Bay towards Gordons for more than a mile, he finds only the usual limestone with the fossils that have been mentioned above, and always with the intercalated thin beds of soft shale, but here, as in all these transition localities, the shale gradually grows more abundant, finally equalling the limestone and then exceeding it until after a few rods, it may be, there is much shale and little or no limestone.

On page 167 of the Third Report, 1902, I noticed the occurrence of *Isotelus gigas* and *Glossograptus quadrimucronatus* on the same small bit of stone, which is here, limestone rather than shale. This was found at Wilcox Cove rather more than a mile north Gordon Landing. A short distance north from Wilcox Cove the beds become very typical Utica and in these I have been able to find very few fossils of any sort, though in places *Glossograptus, Triarthrus* and other formerly considered characteristic Utica species are found.

The transition beds are more disturbed than most of the more regular ones, at least this is true of the limestone, and for several rods south of Wilcox Cove there is much disturbance in evidence. The rock has been tilted, crushed, etc. and is filled with white calcite veins. Similar disturbance of the strata is found on the north side of Wilcox Cove and it is evident that there has been faulting and some upheaval at this point. Indeed I suppose that all the numerous bays which add greatly to the beauty of the island scenery, are due to faulting and carrying out of rock. This is not always evident, but often is.

The limestone north of Wilcox Cove is the last that is not mixed with shale, that one finds along shore. From this point north to the end of Grand Isle, around the extreme north end at Ladd Point and on from there along the whole east shore south to Allen Point and thence north to the outcrop of Chazy limestone there is shale. On the northwest of Allen Point nothing is found on the shore except what has been called Utica Shale. In many places there are strata of compact black limestone in the midst of the shale, but by far the larger part of these rocks is regular shale. In the bays where rock has gone out the shore is sandy for a short distance, but this is a minor exception. The

PLATE XVIII.

Trenton beds north of Rockwell Bay. Nearly horizontal.

distance thus indicated must be, following the irregularities of the shore, between thirty and forty miles.

Inland from the lake the shales extend so that they cover a large part of the surface of the island, I should judge, at least two-thirds.

A few words should be added concerning the Lower and Middle Trenton as they appear away from the shore. It should not be supposed that the shore cliffs are distinct from masses inland, for, as has been noticed, the Trenton is in a single area and therefore the cliffs which are so well seen on the shore are only projections of the main mass. As has been shown, there is a broad ridge which extends from east of McBride Bay north for five or six miles which is Trenton. In some places, as at Sawyer Bay, this comes near the shore, that is it is only a few rods from the shore, from which the Trenton is separated by outcrops of Black River and Chazy. The road from Sawyer Bay to the east side of the island, where it joins the main north and south road near the Iodine Spring House, shows a very good series of outcrops.

Starting on the west shore at the lake where the Black River has been carried out we soon come to the lowest outcrop of Trenton and as the hill over which the road runs is ascended, outcrop after outcrop is found. The Trenton uplift is crossed by this road at nearly its highest point for here it is two hundred feet above sea-level or one hundred above the lake.

In the lower beds the limestone is a tough, dark gray, compact stone, not very full of fossils. Here each outcrop is small, as much of the area is covered by drift, but it appears in more than a dozen places in and beside the road. Much better collecting, however, can be found in the pastures on each side of the road.

In the field south, *Calymene* is more common than elsewhere, as well as other species of the lower beds. South of the road mentioned the Trenton is seen forming the ridge for about a mile and a quarter when it disappears and is followed by the Chazy. North it can be followed through the fields nearly to the cross-road from Pearl Bay west, that is nearly to Grand Isle Village.

As one goes from any outcrop to that above, the character changes somewhat and some of the layers are more or less shaly. Nowhere are the beds very thick, mostly only a few inches, but sometimes two to three feet.

At the railroad station the rock is all shale, but the limestone ridge is not far west and, as one drives north, it is conspicuous for miles on the west, coming almost, or sometimes quite, to the road but this is always on the shale. Much of the Trenton, Lower and Middle, away from the lake is more or less heavily covered by glacial clays and over wide areas cannot be seen, but level outcrops are not infrequent and from these a probably correct idea of the whole can be obtained. As a rule the rocks of the northern portion are much less fossiliferous than those south.

In the report which has been furnished by Dr. Ruedemann will be found mention of the fossils which have been found in the Trenton as described above and a full list of the species found is given.

THE UPPER TRENTON.

In addition to what has already been said concerning the Upper Trenton, Utica Shale of former writers, it may be well to give a more detailed account of some portions of the island.

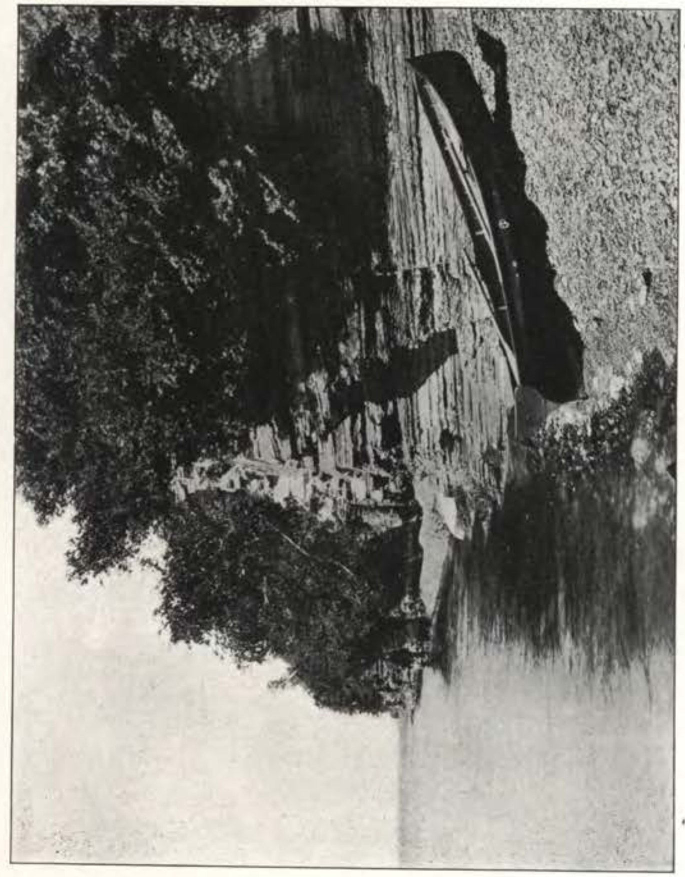
As has been repeatedly noticed, two-thirds of the area is covered by the shales of this age. But this is by no means the full extent of the formerly called Utica Shale in this region, for not only does it now cover the larger part of Grand Isle, but the whole of North Hero, Alburg Peninsula, narrow strips along western Vermont adjacent to the lake and two small bits on the eastern shore of Isle La Motte. It is plain that the shales of each side of the Alburg Passage and La Motte Passage as well as other parts of the lake are continuous under the lake, so that at the close of this period there was a body of land where now the islands named are seen, connected with the mainland of the Vermont side. That is, Vermont extended some miles farther west than now and this body of land was approximately thirty-five miles long and not less than ten miles from east to west. The then lake must of course have been considerably narrower than at present.

CHARACTER OF THE ROCK.

While everywhere the rock of the Upper Trenton is a black, or at least very dark stone, its character is quite variable as to hardness and texture. In large part it is a rather soft, friable, thin splitting shale, but many layers are compact, hard and several inches thick.

At Kibbe Point and in a few other localities there are bands of hard, rust colored stone, rust colored on the weathered surface and therefore conspicuous against the black rock surrounding. These bands at a distance have precisely the appearance of dikes, but apparently they differ from the rest of the rock only in being harder and containing more iron. In other layers, nodules of pyrite are abundant and probably all the rock contains a noticeable percentage of iron. Very little is as soft as is the material in the thin layers mentioned as usually found between those of the Lower Trenton beds. Some of it contains little lime carbonate and only slightly effervesces with acid, other samples effervesce freely.

PLATE XIX.



Upper Trenton at Corbin Beach.

DISTURBANCE OF THE UPPER TRENTON.

As Plate XIX shows, the Upper Trenton is in places little disturbed, but very much of it is tilted, crushed and faulted sometimes to a very great degree. It is also often much jointed in many places and often more or less so.

There is a large shale cliff a few rods south of Sandbar Bridge back of Mr. Phelps' house which is one of the finest examples of tremendous disturbance that can be found anywhere. This cliff has been well figured in previous Reports, especially the Third, Plates, LI, LII, LIII, and the Eighth, Plate XXIII. Here the strata of shale are seen in utter confusion and dipping in every conceivable direction. Plate XX in this Report shows the excessive jointing not seldom seen, but this plate does not show the lines of stratification, which dip northerly or, as the plate is made, from the upper right of the figure down to the lower left.

Slickensides are not uncommon and in many places are innumerable veins of white calcite which are from a mere hair line to several feet in width. Usually these veins are a fraction of an inch wide, but their abundance and contrast with the black shale make them a very conspicuous feature of many cliffs and of the shale pebbles on the shore. There are also some dikes cutting the shale, though these are not as numerous as in the Chazy limestone.

FOSSILS OF THE UPPER TRENTON.

Already mention has been made of the barrenness of the shale in all its outcrops. For a list of the species found the reader is referred to Dr. Ruedemann's report following.

For the most part diligent search is not rewarded by a single specimen, but in rare localities the rock is more satisfactory to the collector and *Graptolites, Obollela* and *Triarthrus* are fairly abundant, but nowhere are there many specimens of any other species.

The thickness of the Upper Trenton is probably much more than at first appears. Some of its highest portions are a few feet above the Trenton ridge which has been shown as conspicuous in the middle of the island. The highest knoll on the island is of this shale, east of Ladd Point in the northeast part, where it is one hundred and eighty feet above sea-level. As indicated previously, I do not think that there is less than five hundred feet of Upper Trenton and most probably more.

90

REPORT ON FOSSILS FROM THE SO-CALLED TRENTON AND UTICA BEDS OF GRAND ISLE, VT.

RUDOLF RUEDEMANN.

Professor G. H. Perkins, State Geologist of Vermont, has taken great pains to obtain a representative collection of fossils from the Trenton limestone and overlying black shale (so-called Utica shale) of the town of South Hero on Grand Isle in Lake Champlain, and has sent these fossils with a few from other parts of the island to the writer for determination. Having carried on an investigation for several years as occasion offered, of these limestones and shales on both the New York and Vermont sides of the lake, the writer is especially gratified at having through the liberality of Professor Perkins, been given access to this collection.

The limestone which is bluish-black in color, compact, partly shaly in texture, contains:

Algae.
Buthotrephis cf. succulens Hall.

Echinodermata.
Crinoid columnals (Schizocrinus nodosus Hall?).
Cheirocrinus cf. logani Billings (plates).

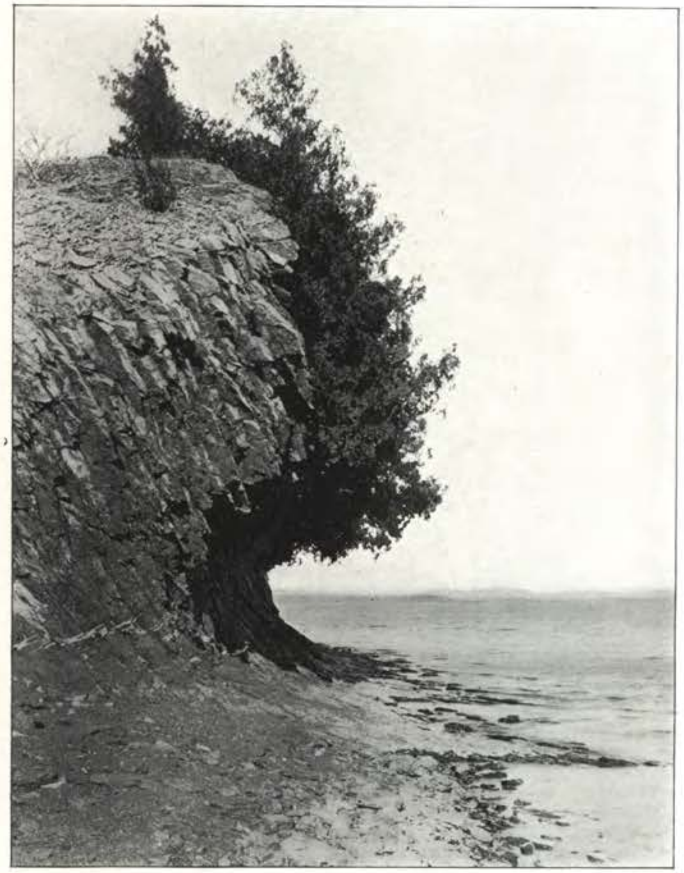
Bryozoa.
Escharopora sp.
Eridotrypa aedilis minor Ulrich.
Pachydictya acuta (Hall).

Brachiopoda.
Trematis terminalis Emmons.
Lingula obtusa Hall.
Dalmanella rogata (Sardeson).
Plectambonites sericeus (Sowerby).
Rafinesquina alternata (Emmons).
Protozyga exigua (Hall).

Mollusca.

PELECYPODA.
Ambonychia orbicularis (Emmons).
Modiolopsis sp. nov.
Orthodesma sp. nov. cf. nasutum (Hall).
Clidophorus foerstei Ruedemann.
Ctenodonta levata (Hall).

PLATE XX.



Upper Trenton at Allen Point. Tilted and jointed.

GASTROPODA.

Sinuites cancellatus (Hall).
Holopea sp. (small section).
Hormotoma gracilis (Hall).
Lophospira cf. bicincta (Hall).

CEPHALOPODA.

Orthoceras (Geisonoceras) tenuitextum (Hall).
Endoceras proteiforme (Hall).
Trocholites ammonius Hall.

PTEROPODA?

Conularia trentonensis Hall.

Crustacea.

TRILOBITA.

Cryptolithus tesselatus Green.
Isotelus gigas DeKay.
Illaenus cf. americanus Billings.
Calymene senaria Conrad.
Ceraurus pleurexanthemus Green.

OSTRACODA.

Bythocypris cylindrica (Hall).
Tetradella subquadrans radiomarginata Ruedemann.

CIRRIPEDIA.

Lepidocoleus jamesi (Hall and Whitfield).

The gray, crystalline limestone contains:

Bryozoa.

Hallopora sp.

Brachiopoda.

Lingula cf. trentonensis Conrad.
Trematis terminalis Emmons.
Dalmanella rogata Sardeson.
Dinorthis pectinella (Emmons).
Rafinesquina alternata (Emmons).
Protozyga exigua Hall.
Parastrophia hemiplicata Hall.

Mollusca.

GASTROPODA.

Bucania cf. punctifrons Hall.

CEPHALOPODA.

Spyroceras bilineatum (Hall).

Crustacea.

TRILOBITA.

Cryptolithus tesselatus Green.
Isotelus gigas DeKay.
Calymene senaria Conrad.
Pterygometopus eboraceus Clarke.

OSTRACODA.

Bythocpyris cylindrica (Hall).

The black, so-called Utica shale, contains:

Diplograptus amplexicaulis Hall.
Climacograptus typicalis Hall mut.

Trematis terminalis Emmons.
Schizocrania filosa Hall.
Serpulites sp.
Triarthrus becki Green.
Calymene senaria Conrad.

The fauna of the limestone is that of the lowest portion of the Trenton group and especially that of the Glens Falls limestone, which underlies the Trenton as exposed at the type section at Trenton Falls and is the basal division of the Trenton group. This Glens Falls limestone is characterized by the abundance of *Parastrophia hemiplicata* and *Cryptolithus tesselatus* which mark its two successive divisions or faunal zones as distinguished by Raymond.

It will be noted that the fauna of the gray limestone contains *Parastrophia hemiplicata* as a common fossil, while that species is absent in the bluish-black limestone. The latter, on the other hand, is characterized by the abundance of *Cryptolithus tesselatus*. It is thus evident that the gray limestone represents the Parastrophia beds of the Glens Falls limestone, and the bluish-black limestone the Cryptolithus-horizon. The rest of the fauna fully agree with these index fossils in denoting earliest Trenton age for these limestones.

The presence of the true Trenton in South Hero is indicated by slabs of dark gray limestone containing abundant specimens of *Prasopora simulatrix orientalis* Ulrich and *Trematis terminalis* Hall, besides the ubiquitous *Plectambonites sericeus* and *Dalmanella rogata*. The presence of this horizon in the northern part of the Champlain valley was noted by Raymond who states that it is exposed on Crab Island near Plattsburg.

The fauna of the black shale is that of the Trenton shales of the Hudson valley. Its Trenton age is determined by the presence of *Triarthrus becki* Green, as distinguished from the Utica form *Triarthrus eatoni* Hall; *Trematis terminalis* and *Diplograptus amplexicaulis*. Also the longer ranging *Climacograptus typicalis* is represented by an early mutation that approaches the Snake hill form *Climacograptus spiniferus* Ruedemann.

These black shales of Grand Isle form a part of the continuous belt of black Ordovician shales that extends from the upper Hudson River region through the Champlain valley, mostly on the Vermont side. They form there the top of the Ordovician series and are considered to this day as Utica shale for the apparently good reasons, that they are black shales of the appearance of the Utica shale, rest upon Trenton limestone and while very barren, still contain in *"Triarthrus becki"* and *"Diplograptus pristis," "Climacograptus bicornis, Schizocrania filosa," "Orthoceras coraliferum"* (see Perkins, 1904, p. 106) species that would appear as fair evidence of Utica age.

The existence of a fine transitional series from the Trenton limestone to the "Utica" shale on the shore of Lake Champlain in the town of Panton, Vt., was pointed out to the writer by the late Dr. Theodore G. White of Columbia University, and the locality visited in 1899. From the fossils then obtained, especially the presence of a *Corynoides,* the writer later (see Ruedemann, 1908, p. 37) inferred that the black shales intercalated in the top of the Trenton limestone series, represented early Utica and were of about the same age as the shale at the Rural Cemetery at Albany, then also considered as early Utica. When this shale later (Ruedemann, 1912) was recognized to be of early Trenton age and placed with the Canajoharie shale, and it became further obvious that no Utica shale was developed as such in the Hudson valley, and Utica beds there probably absent altogether, the question of the age of the so-called Utica shale of the Champlain region came up at once; and it has since been the conviction of Dr. Ulrich and the writer that there is no Utica shale in that region, but that the black shales, attaining such a great thickness in western Vermont are older than Utica age.

The writer had in 1899, collected only from the transitional beds, but Rev. E. W. Gould of Bristol, Vt., an enthusiastic student of geology, undertook in 1918, upon my suggestion, to collect from the entire shale section. He found two exposures of shale, one extending from Arnold Bay northward (and southward) until rather abruptly replaced by heavy Trenton limestone, apparently by a fault. This limestone farther north changes gradually through about 50 to 100 feet of transition beds (limestone beds, about 2 feet thick with soft black shale between) into the black shale.

Rev. Mr. Gould and the writer visited the section in 1919, collecting from the top of the Trenton limestone, the transition beds and all parts of the overlying black shale; the latter taking the covered intervals at the north end in account, reaches 400 feet or more in thickness.

The top of the Trenton limestone, just below the transition beds consists of gray crystalline limestone and contains:

Mesotrypa quebecensis (Ami).
Rafinesquina sp.
Plectambonites sericeus (Sowerby).
Dalmanella rogata (Sardeson).
Parastrophia hemiplicata (Hall).
Protozyga exigua (Hall).
Calymene senaria Conrad.
Isotelus sp. (fragments).
Ceraurus pleurexanthemus Green.
Aparchites minutissimus (Hall).
Leperditia sp.

On top of the limestone cliff, the writer had before collected:

Streptelasma corniculum (Hall).
Dalmanella cf. rogata (Sardeson).
Liospira americana (Billings).
Spyroceras bilineatum (Hall).
Bythocypris cylindrica (Hall).
Primitia sp.

The limestone at the beginning of the transitional series has afforded:

Mesotrypa quebecensis (Ami).
Dinorthis meedsi W. & S. (Large form) c.

The intercalated shale contains near the base:

Climacograptus strictus Ruedemann (putillus auct.).
Climacograptus spiniferus Ruedemann r. (bicornis auct.).
Mesotrypa quebecensis (Ami).
Dalmanella rogata Sardeson c.
Rafinesquina sp.
Leptobolus insignis Hall r.
Rhynchotrema increbescens (Hall).
Ctenodonta levata (Hall) r.
Primitiella unicornis Ulrich cc.
Ulrichia bivertex Ulrich) c.
Cryptolithus tesselatus Green.
Bathyurus cf. spiniger (Hall) (glabella, free cheek, pygidium) r.

In the higher transitional beds $\left\{\frac{1}{A\ 10} - \frac{1}{A\ 13}\right\}$:

Corynoides calicularis Nicholson c.
Climacograptus strictus Ruedemann cc.
Climacograptus spiniferus Ruedemann r.
Climacograptus typicalis Hall rr. (one specimen).
Diplograptus amplexicaulis Hall r.
Lasiograptus eucharis (Hall) r.
Mesograptus mohawkensis Ruedemann c.
Leptobolus insignis Hall c.
Schizambon canadensis (Ami) rr.
Lingula curta Hall c.
Dalmanella rogata Sardeson c.
Ulrichia bivertex (Ulrich) c.
Lepidocoleus jamesi (Hall and Whitfield) rr.

This fauna of the transitional zone is unmistakably that of the Canajoharie shale and corresponds to the lower division of the Canajoharie.

The black shale in the northern exposure, following the transitional beds has afforded to Rev. Gould:

Corynoides calicularis Nicholson c.
Climacograptus strictus Ruedemann c.
Mesograptus mohawkensis Ruedemann c.
Glossograptus quadrimucronatus cornutus Ruedemann c.
Lingula sp.
Schizambon canadensis (Ami) rr.
Dalmanella rogata Sardeson c.
Cryptolithus tesselatus Green cc.
Calymene senaria Conrad.
Ceraurus sp.
Geisonoseras sp.

This upper shale mass is likewise undoubtedly of Canajoharie age and corresponds to the upper division as exposed in the Rural Cemetery, Albany, N. Y.

Isolated outcrops of black calcareous shale along the east shore of Button Bay, representing still higher beds of the shale formation contain:

Corynoides calicularis Nicholson cc.
Climacograptus strictus Ruedemann c.
Glossograptus quadrimucronatus (Hall).
Leptobolus insignis Hall.
Worms (new species), like those at Rural Cemetery.

Finally, the 500 feet of black shale exposed from Arnold Bay to the Trenton limestone contains:

Mastigograptus sp. (fragment) rr.
Corynoides calicularis Nicholson r.
Diplograptus (Mesograptus) mohawkensis Ruedemann cc.
Diplograptus (Amplexograptus) macer Ruedemann r.
Diplograptus amplexicaulis Hall r.
Diplograptus vespertinus Ruedemann c.
Lasiograptus eucharis (Hall) c.
Trematis terminalis Emmons rr.
Leptobolus insignis Hall r.
Orthoceras sp. rr.

This shale is also of Canajoharie age and appears to represent a still higher horizon than the north end of the northern shale exposures. *Corynoides calicularis* and *Mesograptus mohawkensis* are by far the most common fossils and were collected throughout the section, at over 20 stations.

Diplograptus (*Amplexograptus*) *macer* occurs in the upper beds.

It thus appears that the entire mass of black calcareous shale at Panton, representing three different horizons and altogether comprising probably as much as 1,000 feet of rock, or a thickness corresponding to the maximal thickness recorded for the Vermont "Utica" belongs to the Canajoharie and not the Utica shale, and is thus of Trenton age.

On the New York side a few feet of black calcareous shale are exposed on the road from the village of *Ticonderoga* to Addison Junction (now R. R. station Fort Ticonderoga). This shale contains:

Corynoides sp. cf. calicularis Nicholson.
Climacograptus strictus Ruedemann.
Glossograptus quadrimucronatus (Hall).
Lasiograptus eucharis (Hall).
Glossina trentonensis Hall c.
Lingula sp. nov. cf. obtusa Hall.
Ctenodonta sp. cf. levata (Hall).
Aparchites minutissimus (Hall) cc.

This faunule indicates that also the black shale at the south end of Lake Champlain, near Ticonderoga, is referable to the Canajoharie shale.

A long exposure of black shale is found at the north end of *Willsboro Point,* about two-thirds down the lake, and half way between the Panton outcrops and the large outcrops of black shale on Grand Isle, Vermont. The contact or transition with the Trenton limestone was not observed. Unfortunately a strongly developed cleavage cuts this shale perpendicular to the bedding places and this makes collecting extremely difficult. There were found however:

Mesograptus mohawkensis Ruedemann.
Leptobolus insignis Hall.
Dalmanella rogata Sardeson.
Liopsira sp.
Triarthrus becki Green.
Primitiella unicornis (Ulrich) cc.
Aparchites minutissimus (Hall) cc.

This faunule indicates the uppermost division of the Canajoharie shale and demonstrates that the latter extends northward beyond the middle of the Champlain basin.

There is but one outcrop of shale on the New York side of the lake between Willsboro Point and the Canadian boundary line, that at *Stony Point,* 1½ miles south of *Rouses Point,* and thus close to the International boundary. Here were found in hard, splintery, dark bluish-gray calcareous shale:

Climacograptus spiniferus Ruedemann c.
Glossograptus quadrimucronatus Hall c.
Lasiograptus eucharis (Hall) r.
Leptobolus insignis Hall r.
Triarthrus becki Green cc.

This faunule is characterized by the combination of *Glossograptus quadrimucronatus* and *Climacograptus spiniferus,* with *Lasiograptus eucharis and Triarthrus becki.*

Climacograptus spiniferus and *Triarthrus becki* point unmistakably to the eastern shale belt and a northern continuation of the Martinsburg, Snake Hill and Canajoharie shales of Pennsylvania and New York into this northern Champlain region. As to the age of the rock we infer from these two fossils that it is still older than Utica and probably homotaxial to late Trenton, a conclusion that is not contradicted by the other graptolites because they also occur in the Snake Hill and Canajoharie shales, though ranging considerably higher up.

We observed a continuation of this shale on the other, Vermont, side of the lake at *Windmill Point* in the town of Alburg, where in like hard, black, calcareous shale the following species were obtained:

Glossograptus quadrimucronatus (Hall).
Lasiograptus eucharis (Hall).
Leptobolus insignis Hall.

How far south this horizon extends in the black shale belt of Vermont we do not know, but suspect from some observations of ours that it reaches the southern extremity of Grand Isle.

One and one-half miles east of the outcrop at Windmill Point, along the lake shore at Alburg, Vermont, there were found in alternating black calcareous shale and black to dark gray impure limestone, mapped with the Utica shale by the Vermont Survey, the following forms:

Lingula (Palæoglossa) trentonensis (Conrad).
Lingula cf. curta Conrad r.
Dalmanella rogata Sardeson r.
Protozyga exigua (Hall) r.
Calymene senaria Conrad r.
Odontopleura trentonensis (Hall) r.
Primitiella unicornis Ulrich c.
Primitia sp.
Ulrichia bivertex (Ulrich) r.
Tetradella subquadrans radiomarginata[1] Ruedemann cc.
Lepidocoleus cf. jamesi (H. & W.)

The most common and characteristic fossils of this faunule are *Protozyga exigua, Primitiella unicornis* and *Tetradella subquadrans radiomarginata.* These, in association with *Lingula trentonensis, Odontopleura trentonensis* and *Ulrichia bivertex* leave no doubt of the Trenton age of this dark, calcareous shale,

[1] This variety has all the characters of the Trenton species Tetradella subquadrans Ulrich, with the exception of the frill which bears distinct radiating lines, instead of being smooth, and is sharply bent up instead of being concave. Two specimens measured 2.2 mm. x 1.1 mm. and 2.1 mm. x 1.1 mm., the variety thus having the exact dimensions of the typical form.

which on lithologic grounds is considered as Utica shale. (Perkins, 1904, p. 117; 1916, p. 214.)[1]

The Alburg shale contains an interesting combination of two of the characteristic ostracods of the Canajoharie shale in the Mohawk valley, *viz.*, *Primitiella unicornis* and *Ulrichia bivertex,* with Trenton fossils not observed in the Canajoharie shale. The most common of these is *Protozyga exigua,* a Middle Trenton species so far known only from the Watertown-Lowville region of New York. Also *Lingula trentonensis* is a Middle Trenton species, and *Odontopleura trentonensis* is an element hitherto only known from the Trenton of the Bay of Quinte in Ontario. It is thus seen that the shale at Alburg forms a connecting link between the Canajoharie shale and the northern Trenton.

The shales at *Cumberland Head* near Plattsburgh, were first noted by White (1900, p. 460) who considers them as either "very high Trenton or Utica" and cites a fauna, that is said to establish a connection between those of New York and Canada. This fauna is prevailingly Trenton. White points out that similar rocks occur on Grand Isle, directly opposite Cumberland Head and Cushing thinks that these are the transition beds mentioned from there by Perkins (1902, p. 114). Cushing (1905, pl. 13) has mapped these beds which he is inclined to consider as passage beds from the Trenton to the Utica as "Cumberland Head shale" and described them (*ibid,* p. 375) as consisting of the blue-black slaty limestones and calcareous shales, with some firmer limestone bands. Ulrich, in the Revision, has correlated the Cumberland Head shale with the Lower and Middle Trenton, or in a general way, with the Canajoharie shale.

The writer had the pleasure of spending, in 1919, a day at Cumberland Head under the competent guidance of Professor G. H. Hudson of Plattsburgh, N. Y. It was seen that the Cumberland Head shales are lithologically very different from the Canajoharie shale of the Panton shore and the southern Champlain basin in general, for the prevailing element is slaty limestone and graptolite shale was not observed at all. The beds, as far as seen, are strangely barren in fossils. The following forms were collected:

Stromatocerium sp.
Lasiograptus eucharis (Hall).
Arthrostylus cf. obliquus Ulrich (fide Ulrich).
Leptobolus insignis Hall.
Schizocrania filosa Hall.

[1] Professor Perkins is, however, aware of the fact that not all black shale in Vermont is of Utica age, for he states (*ibid,* p. 208):
"In Vermont, as in Canada, New York and elsewhere, there is in many of the exposures no separation between the Trenton and the Utica, for while the latter is almost wholly shale and the former limestone, yet in places there is compact limestone bearing Utica fossils and shale with Trenton fossils.
"Moreover in some localities the Trenton passes into the Utica so far as the contained fossils indicate."

Dalmanella rogata Sardeson.
Conularia trentonensis Hall.
Isotelus cf. latus Raymond (pygidium and pleuræ).

This faunule, small as it is, suggests a Lower and Middle Trenton age of the beds as before inferred by Ulrich. It is then probable that these slaty limestones are in part at least equivalent to the Canajoharie shale. They represent, however, lithologically and faunistically a different facies, and were clearly deposited under different conditions, if not in a separate basin, and should for that reason be distinguished by a name of their own.

The "Utica" shale forms a broad belt in Vermont from the Canadian boundary line southward over the islands of the lake, especially North Hero and Grand Isle (*see* Perkins, 1904, p. 103) and attains there a considerable thickness. This shale is described by the Vermont geologists as being remarkably barren of fossils, *Triarthrus becki* and *"Diplograptus"* being the only fossils mentioned as common in places. This combination of *Triarthrus becki* and *Glossograptus quadrimucronatus* (the *"Diplograptus pristis"* of the earlier authors), as well as *Climacograptus typicalis* which the writer has collected on Grand Isle, indicate that the Stony Point shale reaches, on the Vermont side, in pretty strong development to the middle of the Champlain basin.

There is, however, little doubt that the Canajoharie shale which reaches such great thickness along the Panton shore, only 30 miles south of South Hero, is also still represented in the lower part of the black shale mass of the island and its fauna is still recognizable in the shaly limestone at Alburg, close to the Canadian boundary. The U. S. National Museum contains specimens (No. 15244) of *Lingula* (*Palæoglossa*) *trentonensis* (Conrad) (*fide* Schuchert) from the "Utica" of Grand Isle, and the faunule collected by Professor Perkins indicates a horizon of the Upper Canajoharie or of the Snake Hill division of the Trenton shales.

The black Ordovician, so-called "Utica" shales of the Champlain basin consist then in the south entirely of Canajoharie shale; in the north prevailingly of the Stony Point shale. In the middle they may meet, the Stony Point shale resting upon the Canajoharie shales on Grand Isle and in the Vermont portion of the northern part of the basin; while on the New York side the Canajoharie shale is replaced by the peculiar facies of the Cumberland Head shale, the latter placing itself between the lower division of the true Trenton limestone and the black Stony shale. It seems that the zone of the Cumberland Head shales extends northwards over Point de Roche and merges into the dark, impure limestone of the Alburg "Utica" belt described above.

From the evidence here presented, it can be stated as a general conclusion that the *Ordovician series ends in Vermont with beds probably no younger than the Trenton group;* this group

no Utica

being represented there by limestones and overlying shales. The limestones correspond mainly to the Glens Falls or basal division of the Trenton group; the black shales to the Canajoharie shale of New York, and in part, probably also to the Snake Hill division, or the Schenectady beds, according to their deposition in the more easterly or westerly of the two troughs in which the Trenton shales of the shale belt came to be deposited.

BIBLIOGRAPHIC NOTE.

Nearly all the fossils here listed have been elaborately described and figured either by *James Hall* in *Paleontology of New York,* vol. 1, 1847, or by *E. O. Ulrich, Charles Schuchert* and others in the *Paleontology of Minnesota* (vol. III, pt. 1, 1895; pt. 2, 1897). Full bibliographic references are found in *Bassler's* invaluable *Bibliographic Index of Ordovician and Silurian Fossils.* (U. S. National Museum bulletin No. 92, 1915.)

The subdivisions of the Glens Falls limestone here cited are described by *P. E. Raymond* in *Summary Report of the Geological Survey, Department of Mines of Canada, for 1912* (1914), p. 342 and in *Bulletin of the Museum of Comparative Zoology at Harvard College,* Vol. 56, No. 3, 1916, p. 252. The Canajoharie and Snake Hill shales here cited, have been described by *R. Ruedemann* in *N. Y. State Museum bulletin 162* (1912).

PROGRESS IN TALC PRODUCTION.[1]

ELBRIDGE C. JACOBS,
UNIVERSITY OF VERMONT.

Vermont talc producers are still enjoying a period of great prosperity. Several report that they are many car loads behind in their orders and are installing additional mining and milling facilities.

The increasing demand is attributable to several causes, among which may be mentioned the substitution of talc for English china clay as a filler for paper and other goods, and the many new uses which have been found for talc. Then, too, domestic talc has been found of sufficiently high grade to take the place of that previously imported for talcum powders, gas tips, etc. There is ample business for all producers and the price-cutting practices so much in vogue a few years ago seem entirely to have disappeared. The small producers are obtaining as good prices for their products as the large ones. At the same time, price increases have not been excessive, average prices for the first half of 1920 being only about fourteen per cent. over those for 1918.

There has also been some revival in the soapstone industry, which has long been dormant in this State. This will be referred to in its proper place. Vermont still maintains her place as the greatest producer of talc in the Union and, taken all together, the situation is roseate. It is not to be expected that this prosperity will always continue for production is bound eventually to catch up with consumption. But the constantly increasing uses that are being found for talc will, it is hoped, make the chase a "stern chase" and therefore a long one.

The United States Bureau of Mines is giving much attention to all phases of talc production and its bulletins should be, as they doubtless are, in the hands of all our producers. Mr. Raymond B. Ladoo of this Bureau, has compiled and published in a bulletin a very full list of the uses of talc and soapstone. With this acknowledgment, the list is here reproduced, as it is deemed of much importance in acquainting the people of the State with the subject.

[1] The geology of the Vermont talc deposits has been considered by the writer in articles in the Ninth and Tenth Reports of the Vermont State Geologist.

REPORTS OF INVESTIGATIONS, BUREAU OF MINES, MAY, 1920, DEPARTMENT OF INTERIOR.

I. Uses of Powdered Talc and Soapstone.

1. *Paper Manufacture.*
   a. Filling or loading of all grades of paper.
   b. Ingredient of coating mixture on glazed or finished papers.
   c. In tissue paper manufacture from sulphite stock.
   d. In the manufacture of blotting and absorbing papers.
   e. For the bleaching of cellulose.
   f. For removal of resin from cellulose.

Quality: 200 mesh or finer.
Colloidal property demanded.
Presence of lime sometimes objectionable.
Color: Colorless; free from ferric salts, for white paper.
Color not important for wrapping paper, etc.

2. *Roofing Paper Manufacture.*
   a. Filling or loading.
   b. Coating (to prevent sticking together).
   c. Surfacing.

Quality: For filling and coating, 200 mesh.
For surfacing, 40 to 80 mesh.
Color: Negligible.

3. *Textile Manufacture.*
   a. Dressing cloth.
   b. Coating—sizing and bleaching cotton cloth.
   c. Dyeing.
   d. Dry polishing or sizing of pile fabrics.

Quality: 200 mesh.
Color: Dependent upon use.

4. *Rubber Manufacture.*
   a. Filling.
   b. Dusting.
   c. Packing material for rubber.
   d. Protective coating for crude rubber.

Quality: 200 mesh.
Color: Negligible.

5. *Paint Manufacture.*
   a. Pigments. Absorption of complex coloring matters.
   b. Filler or extender, particularly in mixed paints.
   c. Cold water paints.
   d. Enamel paints.
   e. Waterproof paints for metal, stone and wood protection.
   f. Flexible roofing paints and cements.
   g. Fire-proof or fire-resistant paints.

Quality: 200 mesh or finer. Colloidal property demanded in most paints.
Color: Dependent upon use.

6. *Soap Manufacture.*
   a. Filler.
   b. Constituent of soap compound.

Quality: 200 mesh only, colloidal property demanded in (b).
Color: Dependent upon use.

7. *Foundry Facing Manufacture.*
   a. Replacing graphite.
   b. Mixed with graphite.

Quality: 200 mesh.
Color: Dependent upon use.

8. *Toilet Preparations.*
   a. Face powders.
   b. Toilet powders.
   c. Foot powders.
   d. Creams, pastes and lotions.

Quality: 200 mesh or finer, freedom from grit, iron and lime, good slip. Colloidal property advantageous when used with liquids.
Color: White or flesh.

9. *Wire Insulating Compounds.*

Quality: 200 mesh.
Color: Dependent on use.

10. *Lubricants—Liquid or Grease.*
    a. Talc alone.
    b. Incorporated with heavy oils, 40-60% talc.
    c. With water—talc in colloidal state.

Quality: 200 mesh.
Color: Negligible.

11. *Linoleum and Oil Cloth Manufacture.*
    a. Filling.
    b. Dusting.

Quality: 200 mesh.
Color: Dependent on use.

12. *Pipe Covering Compounds.*
13. *Pottery and Porcelain.*
    a. Body material for china, porcelain and porcelain crucibles.
    b. Glaze.
14. *Electrical Insulation.*
    a. Artificial or synthetic lava—talc with binder.
    b. Substitute for electrical porcelain—talc with clay, with or without liquid binder.

Quality: 200 mesh.
Color: Dependent upon use.

15. *Rope and Twine Manufacture.*
  a. Filling.
  b. Finishing.
Quality: 200 mesh.
Color: Dependent upon use.

16. *Leather Manufacture.*
  a. Dressing skins and leathers.
  b. Drying oily leathers.
  c. Substitute for wheat flour in making glace kid.

17. *Cork Manufacture.*
  a. Dusting molds.
Quality: 200 mesh.
Color: Negligible.

18. *Oil Manufacture.*
  a. Filtering medium.
Quality: 200 mesh.
Color: Negligible.

19. *Glass Industry.*
  a. Polishing powder for glass, especially plate glass.
  b. For dimming and clouding glass.
  c. Dusting glass, bottle molds.
Quality: 200 mesh.
Color: Negligible.

20. *Portland Cement and Concrete.*
  a. Ingredient of special cements.
  b. As part of concrete aggregate.
  c. As surfacing material.

21. *Wall Plaster.*
  a. As ingredient.
  b. Finishing.

22. *Asbestos Industry.*
  a. Ingredient of asbestos shingles, blocks and slabs.

23. *Manufacture of Crayons, Placques and Blocks.*

24. *Preservative Coating on Stonework.*

25. *Cleaning and Polishing Rice, Peas, Coffee, Beans, Maize, Barley, Peanuts and Other Similar Food Stuffs.*
Quality: 200 mesh.
Color: Negligible—colored talcs used for colored products.

26. *Bleaching Barley Grain of Inferior Color. Used with Sulphur Dioxide Gas.*
Quality: 200 mesh.
Color: Negligible.

27. *Rubber Stamp Manufacture.*
  a. Dusting.
Quality: 200 mesh.
Color: Negligible.

28. *Composition Floor Manufacture.*

29. *Insulating Material for Switch Boards, Floors of Generating Stations, etc.*

30. *Imitation Stone.*
  a. Marble and jointless flooring.
  b. Sanitary Appliances.

31. *Boot and Shoe Powder.*
Quality: 200 mesh.

32. *Glove Powder.*
Quality: 200 mesh.
Color: White.

33. *Dermatology.*
  a. Absorbing colors, colloidal solutions, fats and oils.
  b. Absorbing odors.

34. *Absorbing Colors of Animal, Plant and Artificial Origin.*

35. *Veterinary Surgery.*
Used for dusting wounds and sores and in treating skin diseases of cattle and other animals.

36. *Purification of Waste Waters.*
  a. Purifying, decolorizing and degreasing.
Quality: 200 mesh, colloidal properties demanded.
Color: Negligible.

37. *Manufacture of Water Filters Similar to Berkafeld.*

38. *Conserving Fruits, Vegetables and Eggs.*

39. *Sugar Refining.*

40. *Contact Material for Catalytic Reactions.*

41. *Absorbent for Nitroglycerine.*

42. *Packing Material for Metallic Sodium and Potassium.*
Used wetted with oil.

43. *Fireproofing Wood.*
Used with sodium silicate (water glass).

44. *Acid Proof and Fireproof Packing and Cement.*
For pipe, etc.

45. *Automobile Polish.*

46. *Fertilizer Manufacture.*
  a. As filler.

47. *Agriculture.*
  a. As filler or extender for insecticides.
  b. As ingredient of remedies for plant diseases, *e. g.*, "Foshit" or mixture of copper sulphate with ground talc or soapstone.

48. *Shoe Polish and Cleaner.*
 a. As cleaner for white canvas and buckskin shoes.
 b. As ingredient of polish for leather shoes.
49. *Yarn and Thread Manufacture.*
 a. As dressing.
 b. As polish.
50. *Chemical—Pharmaceutical Industry.*
 a. As powder.
 b. As tablets.
51. *Colored Crayons.*
 a. Crayons of chrome colors, pastel colors, etc.
52. *Stove Polishes.*
53. *Imitation Amber.*
 Used for clouding effects.
54. *Cleaning and Glossing of Hair and Bristles.*
55. *Floor Wax.*
56. *Terrazzo or Mosaic Flooring.*
 Used in place of oil in laying terrazzo.
57. *Candy Manufacture.*
 Used with starch, etc., as dusting agent to prevent sticking in molds, on molding boards, etc.

II. Uses of Massive Talc and Soapstone.

1. *Lava Blanks for Electrical Insulation, Gas Burner Tips, etc.*
 Quality: Massive, fine grained talc, free from iron and grit, no cracks of clearage planes. Must be soft and easily machineable but compact and strong. Must be tested under heat.
 Color: Negligible in raw state, but white color preferred when burned.
2. *Crayons and Pencils.*
 Quality: Compact, massive talc, medium hard, strong when sawed into thin, narrow strips.
 Color: Negligible.
3. *Tailors' Chalk or French Chalk.*
 Quality: Compact and strong, fine grained, but medium soft.
 Color: White or light.
4. *Glass Making.*
 a. Molds for bottles, watch glasses, etc.
5. *Metallurgical Industries.*
 a. Molds for casting of iron, brass, copper, etc.
6. *Refractories.*
 a. Fire brick and blocks.

7. *Polishing Agent.*
 a. Wooden handles, etc. Small blocks of talc tumbled in cylinder with wooden handles to fill grain of wood and give rough polish.
 b. Polishing and lubricating wire nails used in automatic box-nailing machines. Blocks of talc tumbled with nails.
8. *Carvings.*
 Chinese and other oriental carvings.
9. *Cooking Utensils.*
 Used by uncivilized natives in various parts of the world.
10. *Soapstone Slabs.*
 a. Electrical switch boards and base plates.
 b. Acid-proof laboratory tables, sinks, hoods, tanks, etc.
 c. Laundry tubs and sinks.
 d. Fireless cooker stoves.
 e. Foot warmers.
 f. Griddles.

Factors Upon Which Uses Depend.

In the investigation of present and possible future uses of talc it must be remembered that talcs in common with the other non-metallic minerals, do not have definite and constant physical and chemical properties and that results obtained in the study of one talc will not necessarily hold true for all talcs. Just as each clay used in pottery must be tested for its own peculiar properties, so must talcs be tested, for some uses. Clays differ in color, grain, size, plasticity, bonding strength, melting point, vitrification range, etc. Talcs probably do not vary as widely as clays, but nevertheless, a variety of talcs should be studied for each use. Thus, in testing talc for use in porcelain bodies, one ceramist might find the fusion point of talc low and the range of vitrification very short; another might find a high fusion point, with a long vitrification range and a slow uniform fusing. Both might be right, for the particular material used; but neither result could be said to be true for all talcs. Furthermore, some materials sold and used as talcs are not talcs at all, strictly speaking, but pyrophyllite, or hydrous aluminum silicate instead of a hydrous magnesium silicate. It is thus very important that representative samples of a wide variety of talcs be tested uniformly in all research work.

Some of the properties of ground talc which should be determined are:

(1) *Physical Properties.* Grain size, shape of grains, color, impurities, melting point, vitrification range, absorption, bonding strength, "slip," colloidal properties;

(2) *Chemical Properties.* Presence of lime, iron and other impurities, amount of uncombined water.

THE WORLD'S PRODUCTION OF TALC, 1914 TO 1918, IS GIVEN BELOW[1]:

[In metric tons of 2,204.6 pounds.]

Country	1914	1915	1916	1917	1918	Percentage in 1918
United States	137,066	150,898	175,368	180,180	173,706	59
France[1]	(1)	(1)	(1)	(1)	57,588	19
Italy[2]	22,477	23,931	27,483	21,863	[2] 23,951	8
Canada[3]	9,804	10,782	11,888	14,336	16,502	6
Austria[4]	[4] 15,000	[4] 12,000	[4] 12,000	[4] 12,000	[4] 12,000	4
Norway[5]	2,100	2,990	5,500	......	3,023	1
Spain[6]	4,612	963	3,556	3,450	3,328	1
Germany[7]	......	......	......	......	3,000	1
India[8]	1,015	1,094	1,233	7,954	[8] 2,772	1
British South Africa[9]	......	......	120	712	608	..
					296,478	100

[1] Statistique de l'industrie minérale en France pour l'année 1913, p. 61. (Statistics from 1914 to 1917 not available. Average production for 1912 and 1913 given under 1918.)

[2] Rivista del Servizio minerario, 1917, p. 63. Not available for 1918, but the average crude for 1913-1917 is 23,951 tons.

[3] Canada Dept. Mines, Mines Branch, Ann. Repts., 1913-1918.

[4] Statistics for Austria not available for years mentioned in table. Department of Commerce reports talc exported from Austria-Hungary in 1913 as 80,828 metric quintals, or 8,083 metric tons. Much talc is used in Austria, especially for paper. If we assume that somewhat less than half of the total output is used in Austria, the total production in 1913 was about 16,000 tons. As talc is rather a peace mineral and war delayed production, the output in 1915-1918, inclusive, would probably average less than 12,000 metric tons annually, although the capacity of the mines apparently is greater.

[5] Norges Officielle Statistik—Norges Bergverkskrift.

[6] Estadistica minera de Espana, 1913-1918.

[7] Mineral Industry, 1918.

[8] India Geol. Survey Rec., vols. 46-49. Statistics not available for 1918. Average for 1913-1917 is 2,772 metric tons.

[9] Ann. Repts. Government Mining Engineer, Union of South Africa, Dept. Mines, 1917.

TALC IMPORTATIONS AND DOMESTIC PRODUCTION IMPORTATIONS.

General imports of talc, ground or manufactured, into the United States, 1917 and 1918.[2]

Country	1917 Quantity (short tons)	1917 Value	1918 Quantity (short tons)	1918 Value	1918 Average price per ton
Canada	10,287	$145,404	12,185	$214,036	$17.57
England	55	869	.....	....	.....
France	1,512	11,024	22	491	22.32
French Africa	33	678	.....	....	.....
Italy	4,167	98,064	490	36,575	74.64
Jamaica	66	1,220	.....	....	.....
Japan	10	184	.....	....	.....
Spain	1	11	.....	....	.....
	16,131	$257,454	12,697	$251,102	$19.78

[1] Statistics compiled from records of the Bureau of Foreign and Domestic Commerce, Department of Commerce.

[2] Mineral Resources of the United States, 1919, p. 115.

These figures may be compared with the total imports of former years.

	Short tons	Average price
1908	7,429	$13.07
1909	4,417	12.74
1910	8,378	12.71
1911	7,113	12.38
1912	10,989	11.19
1913	13,744	10.04
1914	15,644	11.29
1915	15,945	11.70
1916	16,683	13.08

The decrease in imports in 1918 is noteworthy and it is seen that this is due to the practical ceasing of French shipments and the greatly reduced tonnage of the Italian product. Canada, which has steadily forged ahead as an exporter of talc to this country, now furnishes ninety-five per cent. of our imports.

In spite of this decreasing importation, the domestic producers evidently fear the effects of foreign competition, for a committee of the newly formed Talc and Soapstone Producers' Association, of which Mr. Freeland Jewett, of the Eastern Talc Company, is president, has drawn up a new tariff schedule, which is embodied in House Bill No. 9063. This bill provides for a tariff of one-half cent a pound on crude talc or soapstone; two cents a pound on cut or sawed pencils, blanks, or cubes; and fifty per cent. *ad valorem* on manufactured talc if not decorated, or sixty per cent. if decorated. This bill failed to pass the last session of Congress.

DOMESTIC PRODUCTION.

The following figures, taken from the Mineral Resources of the United States, show the domestic production of talc for 1917 and 1918.

State	1917 Quantity (short tons)	1917 Average price per ton	1918 Quantity (short tons)	1918 Average price per ton
Vermont	93,960	$ 6.65	90,537	$ 8.56
New York	74,671	11.80	71,167	12.68
California	4,152	17.82	10,364	16.48
Virginia	6,432	13.35	3,265	7.57
North Carolina	2,175	19.20	1,661	43.56
Georgia, Maryland, Massachusetts, New Jersey, Pennsylvania	13,404	6.50	145,002	10.01
Totals	198,613	$ 9.51	191,477	$10.91

It is to be noted that Vermont maintains her lead as the largest producer, although the grade of her product is obviously low. California has made noteworthy progress in talc production, as a comparison of the figures for 1916 (630 short tons produced) with those of 1918 will show. The quality of the California talc is evidently high.

TALC PRODUCTION IN VERMONT.

The active talc companies in the State are the American Mineral Company, at Johnson; the American Soapstone Finish Company, at Chester Depot; the Eastern Talc Company at Rochester and East Granville; the Magnesia Talc Company, at Moretown; and the Vermont Talc Company, at Chester Depot. The Vermont Talc Products Company, which started to reopen the mines at Fayston, Warren and Waitsfield, has suspended operations.

These are the only companies producing talc in the State. From returns made to the writer the following figures have been tabulated:

	Short tons	Average price
1918, total production	92,290	$7.84
1919, total production	76,258	8.24
First half 1920, total production	47,779	9.07

It will be seen that, if production for the second half of the year keeps pace with that for the first half, 1920 will surpass all previous records. The average prices shown give too poor an idea of the quality of most of the talc, since the averages are lowered by a relatively small amount of very low grade material. The lowest average price of any one company was $7.00; the maximum, $10.42.

THE COMPANIES.

The American Mineral Company, Johnson, Vt.—President, F. S. Rix; vice-president, J. R. Gordon; treasurer, J. S. Moore; general manager, H. A. Macbeth; superintendent of mine and mill, W. R. Reilly. Main office, Johnson, Vt.

The company is actively mining talc from its great deposits in East Johnson. The new shaft, sunk in the middle of the deposit, has reached 120 feet in depth and from this shaft the mine is opened up by four levels and numerous cross-cuts to the borders of the talc lens. The lens has been opened up for a distance of 1,200 to 2,400 feet, while its breadth has been shown to be 200 to 300 feet. The company is thus seen to have an enormous supply of talc in sight, which will last for many years to come.

To accommodate its increasing business, the company is now having built a new mill, near the site of the old structure, and it is hoped to have grinding operations begin early in 1921. The mill is being built by the Guaranty Construction Company, of New York, and is designed for an output of 125 tons per day. It will be equipped with jaw and gyratory crushers, Raymond Roller Mills and Neweygo screens. The crushed product will be stored in six silos, a novelty in Vermont mill equipment. The company's product finds extensive use in paper and rubber filling, cloth finishing, talcum powder, roofing paper, etc.

The Magnesia Talc Company, Waterbury, Vt.—President, Elias Lyman; vice-president, J. T. Smith; secretary and treasurer, J. S. Patrick; sales manager, J. H. Burleigh; mining engineer and superintendent, E. W. Magnus; assistant superintendent, H. L. Bingham. Main office, Waterbury, Vt.

The company is still finding ample stoping ground in its mine at Moretown. The mining is done through an adit and this adit has now been driven over 2,500 feet along the strike of the lens, with no indication that the end is at hand. Stoping is still being carried upwards towards the higher adit and an excellent quality of talc, containing but little grit, is being encountered. The increased length of the adit has made expedient the installation of electric haulage for the mine cars and, accordingly, an electric mine locomotive, actuated by Edison storage cells has been purchased and is giving excellent satisfaction. Besides the mine at Moretown, the Magnesia Company has in reserve a large deposit of talc in the neighboring town of Stowe, so that reserves of mineral are assured for many years to come.

In the mill, four Raymond cage mills have been added to the existing equipment of Raymond Roller Mills and buhrstones, increasing the capacity to 150 tons per day. Besides its ground talc the company also manufactures crayons for metal work and has a capacity of 150 gross per day. The ground product is carried to the railroad station by motor trucks. With its aggressive management the Magnesia Company has become in a few years the second largest producer of talc in the State and it is still growing.

The Eastern Talc Company, Boston, Rochester, East Granville.—President, Freeland Jewett; vice-president, T. Ledyard Smith; general superintendent, C. B. Hollis; mine captain, Joseph Winot; engineers, B. F. Jacobs, E. G. Brooks. Boston office, International Trust Co. Building; Vermont headquarters, Rochester.

This is the largest talc mining and milling company in the world. Besides its large Vermont business the company is interested in some of the high grade California talc deposits, which produce an article selling from $40 to $60 per ton. The company, furthermore, is doing exploratory drilling on some Canadian properties.

At East Granville, the company is still at work on the chain of talc lenses which has occupied it for many years. A lower adit is being driven to tap the lenses at a lower level and it is estimated that a very large tonnage of talc still remains to be mined.

At Rochester, the old Williams mine, which has been worked more or less continuously since 1861, has been abandoned—not that the talc was exhausted but because the workings had become so deep that the mineral could not be economically mined. The wisdom of the company in using the diamond drill for prospecting purposes has been shown by the number of lenses of talc located near the old mine—in fact the hill seems to be studded with talc deposits. The most important of these, the so-called Number 8 Mine, which has been in course of development for several years, is the only mine now being worked in this vicinity. This mine is opened on a great lens, striking as usual north and south and situated about 2,000 feet north of the old Williams mine. The lens is at least 200 feet between walls and has been opened up by an inclined shaft to a depth of 300 feet. Two levels have been driven, one at 190 feet and the other at the bottom of the shaft. The mine is served by the company's narrow-gauge railroad, which conveys the mineral to the mill at South Rochester (Talcville). Both mine and mill are now actuated by electricity, power being supplied by the Hortonia System, from its Gaysville plant. Much more good talc ground has been proved to the north of Number 8 Mine, so that the company has reserves for many years.

The No. 3 Mill, built in 1913, has already been described in previous issues of the Report. The company has been a pioneer in the State in the matter of employing trained engineers and scientific methods in its business and its success has abundantly justified this policy.

The Vermont Talc Company, Chester Depot.—President, N. P. Avery; treasurer, J. N. Hubbard; secretary, Giles Blague; assistant treasurer and general manager, J. B. Aikman; mill superintendent, J. B. Monier. Main office, Holyoke, Mass.; Vermont office, Chester Depot.

The management of the company has been placed in the hands of Mr. John B. Aikman, who has had a long experience in the paper trade. Mr. Aikman has given a new impetus to the business and there is no reason why his efforts should not meet with success. The company has ample reserves of excellent talc and has a large clientele in the paper and rubber trade. The mine, which is in Windham, some ten miles from Chester Depot, has reached a depth of about 200 feet. Motor trucks deliver the mined mineral to the mill, which is located beside the railroad

tracks at Chester Depot and is equipped with Raymond crushing machinery, etc.

In spite of the general car shortage, Vermont talc companies report no difficulty in moving their products.

The American Soapstone Finish Company, Chester Depot.—C. P. Dodge, sole owner; E. E. Holt, superintendent.

This company mines a low grade talc from the Carleton Quarry, in Chester, and makes it into a variety of substances: plaster board, soapstone finish, dusting powder for tires, etc. It also sells its product to the roofing and paper trade.

SOAPSTONE.

As already stated, the soapstone industry in Vermont has been at a standstill for several years, although this substance is by no means exhausted.

Recently the Steatite Electric Products Corporation, of Yorktown Heights, N. Y., has been formed for the manufacture of a new electric flatiron, the core of which will be made of soapstone. It is understood that this corporation has leased the old Union Soapstone Company's properties and will supply itself with soapstone from them.

REPORT

OF THE

STATE GEOLOGIST

ON THE

MINERAL INDUSTRIES AND GEOLOGY

OF

VERMONT

1919-1920

TWELFTH OF THIS SERIES

GEORGE H. PERKINS

State Geologist and Professor of Geology
University of Vermont

BURLINGTON, VT.:
FREE PRESS PRINTING CO.
1921.

STAFF OF THE VERMONT GEOLOGICAL SURVEY, 1919-1920.

GEORGE H. PERKINS, *State Geologist, Director.*
Professor of Geology, University of Vermont.
ELBRIDGE C. JACOBS, *Assistant.*
Professor of Mineralogy, University of Vermont.
CHARLES H. RICHARDSON, *Assistant.*
Professor of Mineralogy, Syracuse University.
CLARENCE E. GORDON, *Assistant.*
Professor of Geology, Massachusetts Agricultural College.
NELSON C. DALE, *Assistant.*
Professor of Geology, Hamilton College.
J. W. MERRITT, *Assistant*, 1920.
Sapulpa Refining Company, Oklahoma.
ROLF A. SCHROEDER, *Assistant*, 1920.
U. S. Engineers Office, Chattanooga, Tenn.
D. B. GRIFFIN, *Field Assistant.*

CONTENTS.

STUDIES IN THE GEOLOGY OF WESTERN VERMONT.

CLARENCE E. GORDON,
MASSACHUSETTS AGRICULTURAL COLLEGE.

TABLE OF CONTENTS.

INTRODUCTION.

General. The writer's studies among the rocks of the Taconic region were begun in the summer of 1906 in Dutchess County, N. Y.[1] and were continued intermittently for several seasons, first in the Hudson valley around Poughkeepsie and later eastward into the Dover-Pawling valley and the hills that bound it east and west. The area at the east proved so complex that it appeared advisable to examine other portions of the Taconic belt before suggesting any interpretations of the geological structure.

In the summer of 1912 an examination was begun of the southwestern portion of the State of Vermont, in Bennington County. Although only about three weeks were spent in this region a number of interesting observations were made, and because it did not appear practicable to continue the work with the idea of mapping a quadrangle, the results obtained were published in the Report of the Vermont State Geologist in the form of notes on the geology in the vicinity of Bennington.[2] The work around Bennington, although hardly more than started, opened up many problems and served as a stimulus to further studies in western Vermont which it is the object of this paper to describe. These later studies were undertaken with the kind consent of the State Geologist.

The field studies on which this paper is based were made in part in the summer of 1918 during a three weeks' trip on foot through the Vermont valley and portions of the Champlain lowland, from Bennington at the south as far north as Vergennes, with occasional trips into the mountains which hem in the valley on each side and bound the Champlain lowland on the east. Very brief examination was also made during the same season of the formations around Burlington and along the lake shore at Malletts and St. Albans bays. This trip was cut short by an attack of influenza. During parts of the next two summers more detailed studies were made in the towns of Pittsford, Chittenden, Brandon, Leicester, Whiting, Shoreham, Sudbury, Orwell, Benson and Hubbardton. In addition the writer was able in the season of 1920 to inspect with care portions of the formations on Grand Isle, both alone and in company with the State Geologist, and to review some of the relations in the vicinity of Bennington. In the season of 1918 it was hoped to make a more thorough study of the rocks within the slate belt and also in the Green Mountain plateau than circumstances permitted.

In all the work it was the practice to inspect as many outcrops as possible, but especially in connection with the studies in Brandon, Sudbury and Orwell, which was a region selected in

[1] Geology of the Poughkeepsie Quadrangle, N. Y. State Mus. Bull. 148, 1911.
[2] Ninth Report of the State Geologist, pp. 337-370.

which to make a wide surface section from the Green Mountains to Lake Champlain. The real purpose in mind of getting a first-hand knowledge of some of the important field relations shown by certain formations and their members under various aspects of deformation and erosion at widely separated places made it advisable to give a discursive but critical examination to a rather extensive region.

Brief historical statement. To most people the rocks of Vermont are known because of the great quarries of marble and slate which have been opened in them and from the excellent descriptions which have been given of these valuable assets of the State. To geological students the part played by Vermont rocks in the annals of American geology has become known and appreciated through the work of many geologists, among whom may especially be named that keen, patient and tireless investigator, Rev. Augustus Wing. Vermont rocks also played a part in the controversy which grew out of the diverse interpretations made by different students in efforts to unravel the difficult stratigraphy and structure of the Taconic region. The great controversy has passed into history and most of the reverberations of its acrimony have died away; but many differences of opinion have persisted and probably always will. These and the controversy itself have served useful ends in directing attention to a region of much interest and importance in the geology of eastern North America.

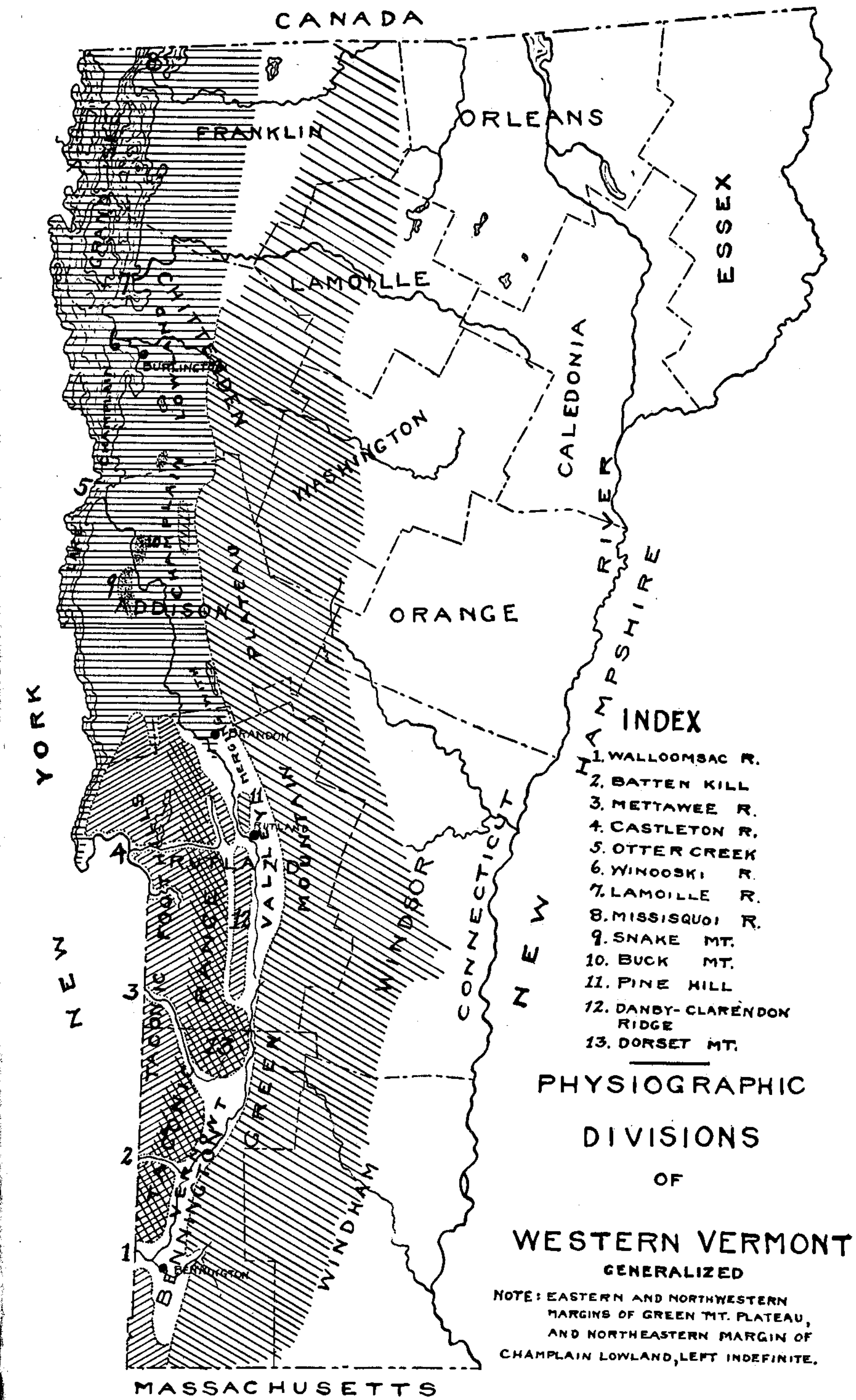
In the end probably all will have to subscribe to what Elkanah Billings wrote as long ago as 1872, that, on account of the extremely complicated structure of the rocks, no man living (and one might add, or those who are to come) would ever see a perfect map of the Taconic region. Nevertheless, towards that end the workers of future generations will continue to go forward.

General plan of the paper. The paper is divided into two somewhat distinct and yet closely correlated parts:

1. (a) The description of the principal physiographic divisions of western Vermont;
   (b) An account, accompanied by brief descriptions, of the characters, distribution and other features of the various formations with which the paper deals.
2. (a) The description and discussion of a number of observations made by the writer in various parts of western Vermont, particularly with reference to the secondary deformations of the different rocks;
   (b) Conclusions reached or interpretations suggested by the writer.

A part of the program is avowedly an ambitious one. It should be stated that any interpretations which are offered are advanced with a full appreciation of the difficult geology involved and of the achievements and contributions of others who have labored to solve the problems of the region.

PLATE XXI.



PHYSIOGRAPHY.

General. Mention has been made of certain physiographic features of Vermont which for the general reader require a somewhat further brief description. The natural relief features and to some extent the political boundaries of a region are landmarks which form the framework on which one hangs, in the form of maps and otherwise, the description and account of the geological features. A map is therefore offered to show the principal physiographic divisions of western Vermont. This map may be useful in conveying some idea of the present lay of the land. It has, however, many limitations in following any but the most recent geological processes. If the present land forms and surface conditions are too narrowly followed they may become a source of embarrassment in interpreting the true geological history.

For the purposes of the paper four physiographic divisions are recognized. The discussion of the geology is inevitably developed about these divisions. As explained above, personal observations have not been made with equal thoroughness over all four divisions.

1. The Green Mountain Plateau and Its Ranges.
2. The Vermont Valley.
3. The Taconic Range and Its Foothills.
4. The Champlain Lowland.

GREEN MOUNTAIN PLATEAU AND ITS RANGES.

This prominent physiographic division from which Vermont has derived its name, is a broad upland which extends as a wide region lengthwise across the State from north to south. It crosses Massachusetts and its counterpart forms the highlands of western Connecticut, southeastern New York and New Jersey and may be traced to Pennsylvania and beyond. Northward it passes into the Province of Quebec. The western portion of this division which extends from New Jersey northward into Canada was designated by Dana[1] as the "protaxis" of the Appalachian chain, which extends from Alabama to Canada.

In their present development the Green Mountains form an elevated plateau throughout their extent. In Vermont the plateau is already deeply trenched by some rivers, particularly in its northern part, and more or less incised by tributary and other streams. On the whole its rugged outlines give it a youthful aspect, which may be attributed in part to the resistant character of its rocks.

Generally speaking, the surface is broadly undulating and averages roughly about 2,000 feet above sea-level. There are numerous rather broad areas about 500 feet higher, and numerous peaks and ridges rising to and above 3,000 feet. Mt. Mansfield, the highest elevation, is 4,406 feet high. The sharper elevations

[1] Manual, Fourth Edition, p. 24.

which may be thought of as the more distinctly ridge-like elements of the plateau, in the northern part of the State form two rather distinct ranges which merge into one in the southern half.

The highest peaks of the State are all only a few miles distant from the western edge and succeed one another along a line that suggests a prominent general structural axis which rather closely parallels the western margin of the plateau. This margin is marked for long reaches by a prominent scarp or by a series of cliffs. It begins in Pownal in Bennington County and follows a north-northeast direction to the northeastern part of Manchester township and thence has a general northerly direction to about the latitude of Pittsford. Then it bends slightly to west of north and is sharply distinct as far north as Monkton. North of Monkton it appears more broken in character, but a general return to a north by east course can be discerned. The margin as thus described has embayments at places from Pownal northward. The structural and physiographic axes often have suggestive coincidence, although there are variations whose import is not clear.

While generally well settled and intersected by roads, some of which cross the plateau into the valley at the west, there is a wide strip along the western portion, from the Massachusetts boundary northward two-thirds the way across the State, which has only a few roads and is still mostly a wilderness.

THE VERMONT VALLEY.

Directly west of the Green Mountain plateau, and extending from Pownal to Brandon, lies the "Valley of Vermont." The topographic break between the two divisions is generally abrupt. The western margin of the plateau upland is usually bold, often precipitous. The streams which come down from it to the valley have not strongly impressed their drainage upon the plateau.

In its present topographic stage of development this division is only a relative lowland between the Green Mountains on the east and the rugged Taconic range on the west. In its southern part the lowest contours are 540 feet along the Walloomsac River near Bennington, and 620 feet along the Batten Kill at Arlington. Along the course of Otter Creek from Danby northward the contours descend from 660 feet to 340 feet near Brandon, where the Vermont valley merges with the Champlain lowland.

The floor of the valley is in fact almost throughout a moderate upland which is obscured by the higher lands which hem it in. It is mostly uneven and studded with hills. The average relief is probably above 800 feet. The valley form is not, as one unacquainted with it might infer, such as would have been produced by a single master river running through it.

North and south of Bennington, around the head streams of the Walloomsac River, this division is about six miles wide. To the west along the river it passes by a broad gap into the Hudson valley lowland. At Bennington the Vermont valley is offset two miles to the east and in Pownal is completely intercepted by the Mount Anthony-Mason Hill ridge. Towards the north in Sunderland it narrows to a width of two miles. It widens again near Manchester around the head streams of the Batten Kill and the Mettawee. North of Manchester it is interrupted by Dorset Mountain and here is about one-fourth of a mile wide. North of Dorset Mountain the major valley is broken into minor ones by prominent intermediate ridges. Otter Creek occupies the eastern minor valley, which from Wallingford to Rutland is over three miles wide. As the topographic map shows the creek changes direction at Rutland from north to west, crossing the structural axes of the rock formations; but at Center Rutland the stream regains a general northerly direction and flows through a narrow valley to Proctor. Thence it passes into the open valley of Pittsford which leads into Brandon. In Brandon the major valley has a more uniform surface and widens out northward to form the Champlain lowland.

The Vermont valley has its physiographic, and to a considerable extent also its geological, counterpart in the Berkshire valley of western Massachusetts along the upper reaches of the Hoosic and Housatonic rivers. There is a recognizable apparent similarity in general configuration between the two, and in the modifications occasioned by hills, ridges and outlying masses of the other physiographic divisions.

The Berkshire valley continues into Connecticut, but at Canaan the Housatonic leaves a wide valley for a narrow one across the upland, which in Connecticut, however, has a lower average elevation than in Massachusetts and Vermont. In northwestern Connecticut and southeastern New York irregularities appear consequent upon the geological structure and relations there present.

THE TACONIC RANGE AND ITS FOOTHILLS.

The Taconic range bounds the Vermont valley on the west throughout its length, except for erosion gaps, the widest of which is west of Bennington. In Vermont this division is the continuation of a similar range that lies along the border between Massachusetts and New York. It extends in Vermont from Shaftsbury in the southwestern part of the State to Orwell and Sudbury. North of Pownal practically all the range is in Vermont and all the higher summits are in this State. Viewed as a broad unit the range overlaps the New York-Vermont boundary in its southern half. North of Rupert the western margin hugs

the State line as far as Poultney, whence it passes due north to Orwell and Sudbury.

In its course across Vermont the relation of the range to the Vermont valley is marked by at least two prominent structural irregularities. Southwest of Bennington, in correspondence with offset in the Vermont valley already mentioned, Mt. Anthony lies farther east than does West Mountain in Shaftsbury, and in the town of Dorset the mass of Dorset Mountain rises abruptly in the valley midway in its course from Bennington to Brandon.

The higher elevations of this division range from about 2,500 feet to about 3,500 feet above sea-level. Equinox Mountain reaches 3,816 feet and Dorset Peak is 3,804 feet high. Most of the higher summits lie along the eastern border of the range. West and north the surface falls off in elevation into the foothill region; but many scarps and precipices marking probable fault lines greatly disturb the surface regularity and contribute notably to the present topographic outlines. Although symmetry of contours is therefore lacking in the present stages of topographic development if one were to generalize very broadly the northern and western slopes of the division, the erosion features of the elevation would fall off gradually westward and northward by slopes of similar gradient to the relative lowlands of the Hudson and Champlain valleys.

This division is cut across and otherwise by streams whose branches heading rather deeply into it have dissected it into a series of peaks and ridges. In its outlines the division offers some contrasts with western edge of the Green Mountain plateau; but stream incision has not been pronounced in either wall of the valley and the topographic outlines of its two slopes wear much the same expression for long distances.

The valleys which cut through the range mark the extension of the lower Hudson valley levels into the intermediate upland of the Vermont valley. There are certain notable differences among these valleys which may be mentioned here. The valley of the Walloomsac River is wide and is really a broad extension of the Vermont valley westward. That of the Batten Kill is narrower and hemmed in by steeper slopes. The valley formed by the Mettawee and the West Branch of the Batten Kill is fairly wide and the bottom lands are well developed. The valley of Castleton River is rather narrow and its northern are steeper than its southern slopes, as nearly all its branches within the range come in from the south.

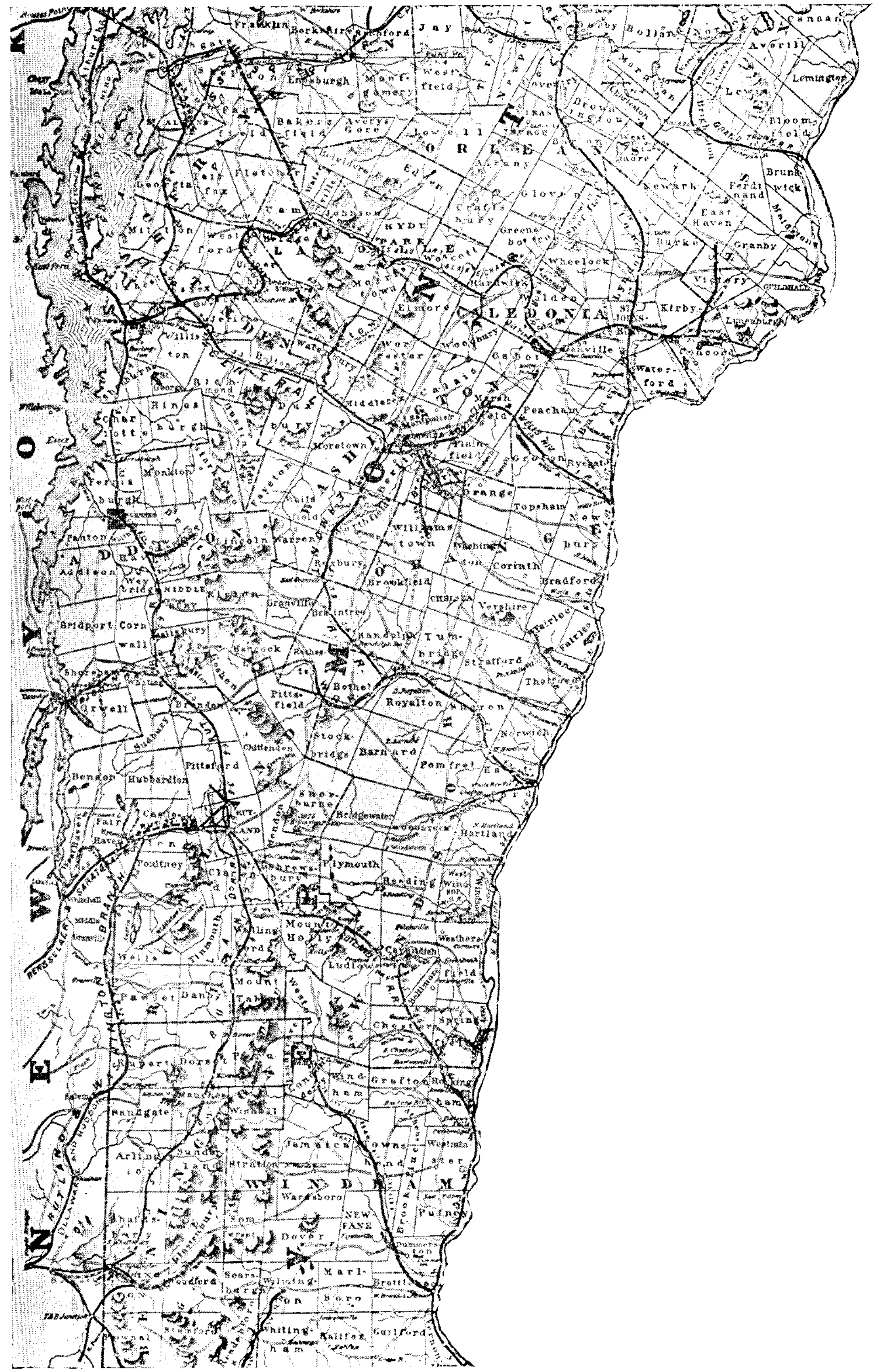
THE CHAMPLAIN LOWLAND.

The distinctness of this physiographic division as a whole is sharper when viewed from a distance in broad sweeps rather than from a close examination of the topography of its surface, which, like that of the Vermont valley is studded, in some places more than in others, with hills. It may first be described in its larger outlines.

Lake Champlain lies along its western border, and rising from the western side of the lake, with their bases dipping into it at places or separated from the lake shore by a narrow strip of hilly land, stand the rugged Adirondacks. In its southwestern portion it is bounded by the northwestern foothills of the Taconic range. The boundary at the southwest swings eastward around the Orwell hills and then encloses a narrow embayment extending up the valley of the Lemon Fair River between the Orwell and Sudbury hills. It then passes around the northern end of the Sudbury hills to Brandon and thence northerly along the western base of the Green Mountain plateau, with the topographic break sharply outlined between the lowland and the plateau as far north as Monkton. North of Monkton the Green Mountain plateau surface is more broken along the edge; but the higher average relief is well enough preserved to give an outline to the Champlain valley in its extension northeastward to the Canada line. At the north the Champlain lowland merges with the St. Lawrence valley. At the south along the narrow region of the lake it joins with the Hudson valley.

The lowest surface in this division is that of Lake Champlain, which for high and low water conditions averages about 100 feet above sea-level. But the lake occupies a depression, the actual depth of whose rock bottom will probably never be known, as it could hardly have escaped being modified by glacial deposits. Soundings have shown that the waters now fill a basin of varying depth and bring out in the channel-like character of its western portion the indication of former stream erosion. The maximum depth reached is about 400 feet near Essex, N. Y., but the present bottom ranges from that depth to comparatively shallow water. The bottom of the lake in many places thus stands in marked contrast with even the lowest portion of the present exposed surface of this lowland. The lake has many low islands of varying dimensions throughout its extent.

Between Lake Champlain on the west and the Green Mountains on the east for a distance of about 40 miles from the northern end of the Taconic range to Burlington, converging somewhat towards Burlington, and again north of Georgia through St. Albans and Highgate to the Canada line, a large portion of the surface ranges from about 100 feet at the lake to 350 feet inland, with the rest of it from 350 to over 400 feet. Along parts of the Otter Creek valley and along the lake for a width of about six miles, in the areas just described, the contours are relatively



Township Map of Vermont.

widely spaced and run long distances without closing. There is distinguishable a low range of hills extending north from Orwell, which is so reduced over most of its surface as hardly to deserve the name, but which is noticeable by reason of the lower land along the lake and from the excavation of Otter Creek on the east. This range reaches its greatest altitude in Snake Mountain (1,271 feet) and terminates in Buck Mountain (927 feet) south of Vergennes. Mt. Philo in Charlotte is 968 feet high. In Bristol and Monkton there are prominent hills including Hogback (1,220 feet), and several conspicuous hills occur west and north of Lake Dunmore. St. Albans Hill (910 feet) and Aldis Hill (840 feet) are the conspicuous elevations north of Georgia. The Orwell-Buck Mountain ridge at the south merges topographically with the western foothills of the Taconic range.

In late Pleistocene time much of the Champlain lowland was covered probably by the waters of the sea which probably extended into the Vermont valley as far south as Rutland. The present surface, both on the islands of the lake and on the mainland, gives clear evidence of the former submergence of a wide portion of this lowland by an inland water body.

North of the Winooski River to the latitude of Georgia the surface has a more uniform and a uniformly higher elevation, ranging from 300 to 350 feet. The contours are more narrowly spaced and close within short distances, giving a more cut-up topography.

Four streams, Otter Creek, and the Winooski, Lamoille and Missisquoi rivers, cross the lowland to enter Lake Champlain.

REVIEW OF THE GEOLOGICAL TERRANES AND FORMATIONS OF WESTERN VERMONT AND THEIR DISTRIBUTION.

General remarks. A short acquaintance with the rocks of western Vermont in their field relations will soon convince one that they have had a long and varied history, that their present geography is very different from that which existed at various times in the past, and that many of them are now remote from the positions which they once occupied.

The general geology of areas contiguous to Vermont and extending for some distance north and south of the State shows that while the Vermont rocks have had in some ways an independent history they are in a broad way genetically related in age and perhaps quite as much so in certain general structural characters to rock formations over an extensive region.

It is more or less widely recognized that many similarities in the age and structural relations of the rocks over this wide region permit a certain amount of generalization with regard to broad crustal movements concerned in their deposition. Account has been taken of great tectonic displacements which are known to have occured, in explaining the absence of certain strata, or better perhaps certain faunas, over the entire region and the apparent limitations of others; but these phenomena have also been explained, at least in part, on the basis of minor crustal movements which have operated to cut off faunal provinces from each other and to restrict the areas of continental seas.

As investigations have extended our information concerning details of stratigraphy we have had positive confirmation of the wide extension of certain ancient seas within the region. On the other hand extensive study has failed to reveal any conclusive evidence of the former presence of certain seas, which are generally assumed to have been wholly absent, or the wider extension of others, whose faunas are present in places, and whose ancient boundaries are set on the basis of known outcrops.

From the nature of the complex geological relations now present the explanations of these absent intervals cannot be based upon positively identified depositional unconformities between younger and older rocks than those which are absent. It is, of course, necessary to recognize the possible existence of erosion intervals of varying degrees of duration among sedimentary formations, due to periods of restlessness of the internal forces which disturb the crust, but one must also consider the evidence that the crust may apparently remain relatively quiet for immense intervals of time, and particularly, for the region of western Vermont and related areas, it is necessary to take account of the evidence of profound crustal displacements and metamorphism, and of erosion at various periods of the region's history.

It has not been clear just how far it would be well to go for the profit of the general reader as well as for the more precise information of the geological student in reviewing the characters, variations and distribution of the different terranes and formations of the region under discussion. It is clear that some idea of these different rocks and the confusion that prevails among them in the field should be given as an aid to the discussion that will follow.

A categorical statement of such matters is likely to leave an impression of simplicity; but care will be taken in the sequel to point out the many difficulties that lie in the way of positive determinations of field relations and that conclusions are based on what seems most probable, with the evidence at hand, among several possibilities that are presented.

The following descriptions are purposely given with considerable fullness, but structural considerations are largely postponed for later treatment.

PRE-CAMBRIAN.

According to many observers the pre-Cambrian basement, or old sea floor, on which the Lower Cambrian rocks of this general region were deposited, is decisively exposed at various places in the Green Mountain plateau. The rocks which have been described as pre-Cambrian consist of gneisses, which are notably chiefly of probably igneous origin, and other rocks such as schists, quartzites, graywackes and crystalline limestones.

The discrimination of the pre-Cambrian is most satisfactory in those places at which a heavy basal quartzite, or a conglomerate, appears to rest unconformably upon, or to be separated by a thin, schistose layer from a rock whose structural features are in pronounced discordance with those of the younger rock, and are apparently of much more ancient date. In Massachusetts and New York similar relations have been described and seem to leave no doubt of the exposure at the present surface of a pre-Cambrian core in the Green Mountains. That certain old gneisses antedated the Cambrian and formed its floor of deposition is substantially borne out by numerous localities where the advancing Cambrian sea caught and preserved portions of the regolith of the land which it was overlapping. The more or less decayed material seems to have been only partially sorted at times and seems to have taken on in greater or less degree the bedded structure of the Cambrian while grading at depth into less altered rock which retained more or less of the structure of the parent gneiss. Such relations seem especially significant with respect to the question of depositional unconformity in a region that gives evidence of more than one orogenic movement and of profound overthrusting; for it is conceivable that contacts of pure quartzite, or even conglomerate, could in such a region be the results of other processes than marine overlap. It will be noted later also that there are numerous places in western Vermont where Ordovician limestones apparently rest by unconformity on rock that appears to be Cambrian without any traces of a basal transgressive sand or other rock intervening.

The separation of the Vermont pre-Cambrian into systems such as have been recognized elsewhere is a task which has yet to be worked out for the Green Mountain plateau generally. In various parts of the plateau Whittle, Keith and others have described as probably pre-Cambrian various metamorphic rocks such as quartzite, schists and crystalline limestones which have been called Algonkian, Huronian and so forth. Similar rocks have been described for Massachusetts, New York and Quebec. The discrimination of older rocks from altered Paleozoic has not always been made with a sharpness that is conclusive.

While there is, generally speaking, an abrupt passage from the less metamorphosed rocks of western Vermont to those of the plateau this fact by itself is discounted somewhat by the undoubted upthrust or overthrust relation of the plateau to the rocks at the west of it. It is somewhat significant, although exhaustive search has yet to be made, that in northwestern Vermont no pre-

Cambrian basement contacts have yet been discovered to the Paleozoic rocks.

In spite of metamorphism and apparent absence of fossils, investigations have already extended the range of Paleozoic seas over this region, although it remains to show that in some cases these were the same seas that laid down the rocks of what is now western Vermont.

In western Massachusetts Professor Emerson early suggested a separation of the pre-Cambrian, and in early descriptions of certain rocks he used the term Algonkian. Coming in later years apparently to a more conservative view he called the pre-Cambrian rocks of western Massachusetts, Archaean, and the Green Mountain plateau a "broad Archaean-Silurian upland."

The basal Cambrian quartzite has been found some distance eastward from the western outcrops of the gneisses in Vermont, Massachusetts and elsewhere where it has been preserved by down-folding or down-faulting as erosion outliers. The quartzite or its probable equivalent extends for miles as a fringe along the western margin of the plateau. Throughout the ages-long history of these rocks we may believe it has in some way been protected from erosion. It is plausible that conditions were not favorable for the preservation of vast areas of Cambrian beds, and possibly also later ones, elsewhere in what is now the plateau.

West of the Green Mountains presumably the pre-Cambrian extends at unknown depth beneath the rocks now present at the surface.

CAMBRIAN.

Lower Cambrian.

The Lower Cambrian has been described as represented in Vermont by the following-named formations:

1. "Vermont Formation."
2. Dolomite and a quartzite-dolomite interbedded series.
3. "Red Sandrock."
4. "Georgia Slates" ("Georgia Group").
5. "Roofing Slates" (with associated rocks).

Parts of all these formations were presumably contemporaneous and lithological differences were presumably due to different conditions of deposition. Certain members of the Vermont Formation can be reasonably shown to be basal and conformable to the dolomite. The interbedded series in some places lies on the dolomite and this seems to be the normal succession. There has been so much disturbance of the region that the present relations are sometimes obscure. In some places the interbedded series apparently lies on quartzite of the Vermont Formation. The Red Sandrock has been described as conformably subjacent to the Georgia Slates in northwestern Vermont. As indicated above the base of the Vermont Formation and its pre-Cambrian contact has been fairly conclusively demonstrated; but the depositional bases of the Red Sandrock and the Roofing Slates are unknown.

Each formation presents horizontal differences which are better shown in some than in others. In all cases the intrarelationships and the relations of the formations to each other and to associated rocks are much confused and disguised by deformations which the rocks have suffered.

The Vermont Formation. The Vermont Formation has the following-named members at various places throughout its extent at the present surface:

a. Various basal gneisses or schists, probably altered derivatives in most cases of pre-Cambrian gneisses and other rocks, sometimes rather sharply delaminated from the parent rock, but often imperfectly transitional between gneiss and quartzite, conglomerate, or arkose.

b. Arkoses.

c. Conglomerate.

d. Granular quartz rock.

e. Massive brownish quartzites.

f. Schistose quartzites and schists.

The first-named have been described by different observers. Conglomerate is not uncommon, sometimes arkosic. White, granular quartzites are very common and pass into massive, brownish rocks, which in turn grade into schistose quartzites. The massive quartzites with conspicuous, white, granular members are of great apparent thickness and prominence in scarps along the western front of the Green Mountain plateau and by faulting are also widely distributed along the Vermont valley.

By thrusting, members of this formation may have been carried westward into the Taconic division, but this question will be discussed beyond.

Fossils in the quartzite (and the limestones) together with the field relations fix the age of these various rocks certainly in some cases and probably in the others, as Lower Cambrian.

Dolomite and the interbedded series. This formation contains:

a. At some places at least, at the base, a limestone of moderate thickness; at other places at the base a dolomitic limestone of uncertain thickness.

b. Above (a) a succession of dolomitic limestones interbedded with calcareous quartzites, rather pure, massive quartzites and schistose quartzites.

In the interbedded series the quartzitic members seem to be more abundant near the base. The more purely siliceous members range in thickness from about 2 inches to one bed at least 10 feet thick, possibly 20 feet, unless folded. The dolomitic members range from a few inches to about 3 feet in thickness.

The interbedded series is extensively developed along the Vermont valley from Bennington northward and was traced by the writer as far north as East Middlebury. It is best shown among the hills along the eastern portion of the valley and forms the visible part of most of the camel-hump arches that make up the valley floor. The outcrops of the members of this series are conspicuous features and the quartzites have undoubtedly been important factors in preservation from erosion. The series is often clearly present beneath the surface in places intermediate between the hills just mentioned. The westward extension of these rocks and their relations to other terranes will be discussed at other places.

The intimate association of this series with quartzite of the Vermont Formation is clear at many places along the Vermont valley. At Bennington the succession from quartzite of the Vermont Formation through dolomitic limestone to interbedded limestones and quartzites is particularly clear (see fig. 21). The two formations have plainly been deformed together in a large way, although the interbedded rocks appear to have suffered some independent deformation both with regard to folding and faulting.

The present distribution of the series tells nothing about its original horizontal extent.

Red Sandrock. This name has been and is now applied to a formation that shows much variation in composition and in color, and which in some localities is chiefly dolomite. The formation is practically restricted in its outcrops to the west central and northwestern parts of the State. It is prominent at the present surface around Monkton, at Snake Mountain in Weybridge and Addison, at Buck Mountain in Waltham, and thence northward through Charlotte, Shelburne, Burlington and beyond. At the south in Addison County, and also along the shore of Lake Champlain in Shelburne and Burlington, much of this rock is a quartzite and often has a dark, brick-red color. In Chittenden and Franklin counties it is described as prevailingly dolomitic. In Georgia, as early described by Walcott, it consists of a series of bluish gray, steel gray, gray massive, and reddish pink dolomitic limestones and gray, massive, arenaceous limestone, variously banded, colored, or mottled, and passes upward into the Georgia Slates.

At the Canadian line, according to Logan, it consists of white and red dolomites and sandy layers, with some strata mottled red and white and a few brick-red. Some beds were said to be very siliceous. All weather yellowish or reddish brown. The Red Sandrock series extends across the Canada line for about five miles.

The quartzitic members are all more or less calcareous and the dolomitic beds are all somewhat siliceous.

The base of this formation is not known. The formation has been described by some observers as merging with the quartzite of the Vermont Formation near Monkton.

Lower Cambrian fossils have been found at various places and within different phases of this formation.

Along the lake shore at and near Burlington, members of this formation can be seen to rest by thrust on younger (Ordovician) rocks.

Except for certain marked features of color the Red Sandrock series bears much resemblance in general sequence to the quartzite and its overlying dolomite and interbedded series that have been described.

Georgia Slates ("Georgia Group," "Georgia Slate Group"). The members of this group were first described from the town of Georgia by C. D. Walcott and were represented as conformably succeeding the Red Sandrock series. The group is typically developed in the towns of Georgia, St. Albans, Swanton and Highgate in Franklin County.

Walcott distinguished a series somewhat as follows, beginning at the base:

a. Argillacio-micaceous and arenaceous shales, with many Lower Cambrian fossils ("Georgia Shales"), 200 feet.

b. Argillaceous shales with occasional layers of hard gray limestone, ½ inch to 2 inches thick, 3,500 feet.

c. Light gray quartzite, 50 feet.

d. Gray limestone in massive layers, with intercalated bands of argillaceous shale, 1,700 feet.

e. Argillaceous shales similar to (a) conformable at base with (d) and cut off at the top by a fault, 3,500-4,500 feet.

The total thus gave the extraordinary maximum thickness of 9,950 feet. The correlation was mostly with Lower Cambrian. In 1891 Walcott described (d) of the above as appearing to be a great lenticle of limestone and the fossils as approaching the Upper Cambrian (in the absence of Olenellus).

Ulrich has "hazarded" the opinion that the upper 3,500 feet of the shale of the section described by Walcott may be of "Canadian" age (basal Ordovician). He also questions the age, in the stratum of limestone and shale to which Walcott assigned a thickness of 1,700 feet, of a limestone which gives fossils that may be of Middle Cambrian age.

The thickness assigned the series and other features may have to be revised by future study of the deformations of the region.

Roofing Slates (and associated rocks). From the northern end of the Taconic region southward along its western slopes, forming in Vermont a strip 8 to 11 miles wide north of Fairhaven and a strip from 2 to 3 miles wide south of Fairhaven to West Rupert, and extending from the north and east into eastern New

York to form a broad band in that State, is a belt of rocks known over much of its length of 70 miles or more as the "roofing slate belt." Over a distance of 40 to 50 miles the rock of this belt is extensively quarried for roofing slate.

At the northern end of the Taconic range in Sudbury, arenaceous slates and phyllites which have been described as Cambrian occur in close association with masses of heavy quartzite and again in proximity to other phyllitic rocks which have been described as of probably Ordovician age. South of Hubbardton near the western boundary of the State and across the line in New York have been described large areas of slate of probably Lower Cambrian age, as determined by fossils in associated limestones, interspersed in no regular way with slates and other rocks which have been described as of Ordovician age on the basis of graptolites found in the slates, and apparently sometimes from associated limestones and other field relations. Lower Cambrian fossils are reported widely distributed among the rocks of the slate belt and numerous localities yielding graptolites have been found.

The structural relations of the rock masses yielding these different fossils are still mooted problems.

In 1888 Walcott published a preliminary map of this region. In 1891 he correlated the Cambrian slates of this belt with those of Georgia, Vt. In 1899 T. N. Dale published a revision of Walcott's map and added many additional fossil localities to those which had been reported by Walcott.

As described by Dale the members of the slate belt are as follows:

CAMBRIAN.

a. Olive grit (a graywacke), more or less massive, sometimes with small quartzite beds. Has associated with it, in places, a bed of quartzite 12 to 55 feet thick.

b. Roofing slates, grayish green, purple, or mixed green and purple, alternating with beds of calcareous quartzite (5 feet) and limestone breccia up to 40 feet thick.

c. Dark gray grit, or sandstone, with shaly patches.

d. Black shales or slates with thin beds of limestone breccia.

e. Quartzite usually with spots of limonite, with some variations and sometimes associated with a quartz conglomerate.

ORDOVICIAN.

a. Gray or black shales and thin-bedded limestones; possibly intermittent ("Calciferous").

b. Black or gray shales and slates, sometimes banded from bedding ("Hudson Shales").

c. Greenish or black, more or less quartzose, shales and slates, weathering white or whitish ("Hudson White Beds").

d. Gray grit (graywacke) interbedded with black shales or slates ("Hudson Grits").

e. Green or dull reddish or purplish phyllite with very thin beds of quartzite, more frequent towards the east ("Hudson Thin Quartzite").

f. Red and green roofing slate or shale ("Hudson Red and Green Slate").

Limestone is also described as occurring mostly west of the slate belt. It is called "Trenton," and is thought of as perhaps representing Trenton, Chazy and Calciferous (Beekmantown). "Berkshire Schist" (sericite, chlorite and quartz schists), containing beds of greenish quartzite up to 10 feet and over in thickness, is further described as occurring east of the slate belt, and is regarded as probably representing all the above-named terrigenous rocks called Ordovician, and as including Lorraine and Utica horizons.

Middle Cambrian.

Over most of western Vermont, so far as records obtained from present outcrops go, there is above the Lower Cambrian a great absent interval. That later Cambrian, and particularly Middle Cambrian, may have once been more fully represented is indicated by the discovery of a Middle Cambrian fauna within a rock which was designated as an "intraformational conglomerate."

This so-called intraformational conglomerate was described by G. E. Edson as formed of dark-colored, fine-grained limestone; bluish or dove-colored limestone; arenaceous shale, in which in some instances are found nodules of pure limestone and enclosed water-worn pieces of bluish-colored slate; sandstone resembling quartzite; arenaceous limestone in which the enclosed grains of sand are dark thus giving the rock a mottled appearance; and a light-colored limestone. The rocks (fragments) forming this conglomerate vary in size from small pieces to bowlders weighing many tons.

According to Edson this formation first appears at the present surface near the north line of Georgia. Here its "brecciated" condition does not appear at its best and the rock has the appearance of a massive, dark-colored, arenaceous limestone. The outcrop is described as continuing without a break to the north line of Georgia, but there disappears. It reappears northward in St. Albans. At this place the "brecciated" condition is usually well shown and the rock is in places associated with a shale. It appears intermittently northward to the St. Albans line and passes into the town of Swanton, in which town it is represented by the shale with which it is associated farther south. Northward the conglomerate appears again and passes into Highgate, to the bank of the Missisquoi River.

The State Geologist submitted specimens of the fossils found in this conglomerate to Dr. Walcott, who had in his possession some which he had collected from the same region. From a preliminary examination Walcott thought the fossils Middle Cambrian. They showed a considerable range, but *Paradoxides* was described as occurring in the matrix which would make this rock actual Middle Cambrian and an "interformational conglomerate."

As further described by Edson a *L. acuminata* was found in a shale lying close to the conglomerate. In Swanton shale is found on both sides of the conglomerate and also "interstratified" with it. On the western side shale passes under the conglomerate and dips to the east. The same fossils are described as found in the various limestones and sandstones as are found in the shale and the matrix of the conglomerate. From the descriptions it appears that the structural relations to other formations are problematical. One may hazard the opinion that the structural relations of the rocks to each other are also complicated and possibly abnormal in some cases. The possibility of the so-called conglomerate being an autoclastic needs to be considered.

Upper Cambrian.

On the New York side of Lake Champlain an Upper Cambrian sandstone is widely present and has been described as resting by depositional unconformity on pre-Cambrian rocks. Exposures occur around Port Henry, Essex, Port Kent, and Keeseville. This sandstone forms a wide fringe along the northern side of the Adirondack mass of ancient pre-Cambrian rocks. Professor Kemp has described small outliers back from the lake, west of Port Henry. On the west side of the lake faulting is common in this sandstone and in some places erosion has been heavy. This rock has long been known as the Potsdam from its type locality at Potsdam, St. Lawrence County, N. Y.

In his descriptions of the exposures around Port Henry, Ruedemann has indicated that what is regarded as the base of this formation in this region shows anomalous features in comparison with localities in Clinton County, N. Y., and on the northern side of the Adirondacks, especially in the slight development of a conglomerate and in the absence of red, hematitic arkoses, and reaches the conclusion that near Port Henry the Potsdam formation does not attain the great thickness which it has farther north and that the lower Potsdam, and perhaps the upper, were not as fully developed as in Clinton County.

East of Lake Champlain the outcrops of known Cambrian that have certainly and definitely been determined by fossils, except the "intraformational conglomerate" described above and occasional small exposures to be mentioned beyond, belong to the lower part of this system, including the rocks along the lake shore which as has already been mentioned, can be seen to rest by overthrust on greatly disturbed younger (Ordovician) rocks.

In his early studies in the town of Highgate, Walcott described a limestone conglomerate in the shale (apparently representing the rock discussed above under Middle Cambrian and later described by Edson) containing fragments of limestone varying in size from pebbles to masses 6 feet in diameter. At that time Dr. Walcott thought the fossils to have an Upper Cambrian aspect. In his later examination of specimens submitted to him by the State Geologist and in a re-examination of his own material he gave the forms a wide range, although inclined to concede a Middle Cambrian age for the matrix of the conglomerate, if *Paradoxides* occurred in it (see above, page 129).

A somewhat siliceous and magnesian limestone, associated with a thick-bedded, barren, dolomitic series that stratigraphically lies above it, is known in southeastern New York State, and in its exposures near Poughkeepsie in Dutchess County, in the Wappinger (Barnegat) limestone, was first described by W. B. Dwight and later further discussed and described by the writer. Fossils were found by both observers, consisting of brachiopods, (*Lingulepsis pinnaformis,* and others according to Dwight) and of trilobites, (*Ptychoparia,* of species found by Walcott at Saratoga). These fossils were considered to mark the rock as of "Potsdam" age. The region was mapped by the writer and the fossiliferous rock just described was found to pitch southward, in what was called the western strip of the Wappinger belt, beneath the thick-bedded, barren dolomite which was regarded as perhaps forming in part the upper portion of the Cambrian of the region and as older than other strata of "Calciferous" (Beekmantown) age lying above the Potsdam along the so-called "central strip" of the Wappinger belt as shown near Rochdale, a hamlet just northeast of Poughkeepsie.

The fossiliferous limestone in Dutchess County, assigned to the "Potsdam" by Dwight and Gordon, Walcott correlated with a rock, carrying similar fossils, which he had described as occurring at Saratoga. He has called the horizon the "Potsdam-Hoyt Limestone," and is inclined to place it in the Upper Cambrian. There is some resemblance lithologically between the rocks of the two localities thus correlated, particularly between certain gray, arenaceous beds carrying blackish streaks and patches.

Messrs. Brainerd and Seely in a paper entitled "The Calciferous Formation in the Champlain Valley," wrote with much positiveness of an Upper Cambrian (Potsdam) horizon, represented by a sandstone and a magnesian limestone directly beneath other beds which they called Beekmantown. The line between the "Potsdam" and the Beekmantown was drawn just above certain strata in which brachiopods related to *Lingula* were found.

In the writer's studies in Vermont, in the towns of Shoreham, Orwell and Benson, following in some places in the steps of Brainerd and Seely, these so-called "Potsdam" rocks were examined and their lithological similarities in some places with the Dutchess County strata, familiar to the writer, were noted. But what was more striking was the aspect of similar deformation in both cases. The characters of the Vermont rocks just mentioned will be further discussed beyond.

Mr. Wing argued for the presence of the Potsdam beneath the Calciferous in Addison County, in his descriptions of the sections near Shoreham, and gave practically the same account of the rocks as that furnished later by Brainerd and Seely. Mr. Wing also apparently, like a great many other observers of his time, regarded certain rocks that are now more generally looked upon as Lower Cambrian as belonging to the Potsdam.

In December, 1889, Walcott announced the discovery during the preceding summer of a small outcrop of Potsdam sandstone at Phillipsburg, Canada, on the east side of Lake Champlain, along the shore of Missisquoi Bay, and just north of the Vermont border. It was described as carrying characteristic fossils and as lying subjacent to limestone of the Beekmantown terrane. At the same time he mentioned the discovery during the same season in the lighter-colored members of limestone at Point Levis, Quebec, of numerous fossils of Upper Cambrian or "Potsdam" age.

In 1889 Ells described among several distinct zones of conglomerate present in the vicinity of Quebec, one at Point Levis interstratified in the fossiliferous shales of the Levis Formation and which contained a mixed fauna. Some of the pebbles held an abundance of "Potsdam" forms, while the paste of the conglomerate contained fossils characteristic of the Beekmantown formation. He further described a series consisting of red and green shales, green and gray sandstones, and beds of limestone which represents what was formerly called the "Sillery and Lauzon" of the "Quebec Group" of Logan. He considered the series to be of Upper Cambrian age.

On the Montreal Sheet, Eastern Townships map, Province of Quebec, to accompany Part J, Vol. VII, new series, Geol. Sur. of Canada, a large area, beginning about 15 miles north of the Vermont boundary and extending from Brigham Junction north-northeast to the boundary of the map, is shown as probable Upper Cambrian. The rocks are red and green shales with sandstones and grits, and belong to the upper part of the Sillery of the Quebec Group.

In western Quebec and eastern Ontario the Potsdam sandstone appears to pass without a break into the overlying Beekmantown. The lithological dissimilarity between the Potsdam of western Quebec and the supposed Upper Cambrian of the eastern townships is very striking and is supposed to have been due to different conditions of deposition. The lower part of the Sillery is said to be undoubtedly Cambrian and to carry characteristic fossils (*Agnostus,* etc.).

Some of the rocks bordering the Sutton Mountain anticline in Quebec have also been thought to be Upper Cambrian; but the basal portion of these rocks was thought to be the equivalent of the Georgia series of Vermont and thought to lie on "Huronian."

It is now known that the conglomerate beds in the Levis Formation carry in their pebbles Lower Cambrian, Upper Cambrian (or Lower Ordovician) and Beekmantown fossils.

Ulrich has created and defined a new period and system under the name "Ozarkian," based on sections in Missouri, Arkansas and the southern Appalachians, which is made to intervene between the true "Upper Cambrian" and the basal Ordovician (Canadian). In this system he places the New York formations known as the Hoyt Limestone, the Potsdam Sandstone, the Little Falls Dolomite, and certain "passage beds" first described by Cushing from Jefferson County, N. Y., and called the "Theresa Formation."

Schuchert adopted the term Ozarkian (1909), but used it in a different sense from that of Ulrich and made it synonymous with Upper Cambrian, or "Cambric" in a restricted sense.

Schuchert has referred certain conglomerates of the "Quebec Series," whose fossils have been described by Walcott, to the "Ozarkian," as he employed the term. The formation from which the conglomerate pebbles came is not known in the St. Lawrence valley.

Schuchert would also put Brainerd and Seely's divisions A and B of their so-called Beekmantown, and apparently their so-called Potsdam also, as described for Shoreham, in the "Ozarkian," as Ulrich would also, but with a different general signification for the term.

It is not fully settled whether any true Potsdam, and how much that may properly be called Upper Cambrian, can be distinguished with certainty in western Vermont.

ORDOVICIAN.

Beekmantown (Calciferous).

The Vermont report shows this formation, as traced on a lithological basis, as rather limited exposures in the western parts of Addison County and in the northwestern part of Rutland County. The thickness is described as about 300 feet. The large areas of limestone lying to the east in Addison County and northern Rutland County were called by the special name of the "Eolian Limestone."

Mr. Wing first described Calciferous fossils from this "Eolian Limestone" and is reported to have found them in the Otter Creek

Valley at New Haven, Middlebury, Salisbury, Leicester and Brandon, on the east side of the stream, and in Weybridge, western Cornwall and Shoreham, on the west side of the creek. Mr. Wing also thought the Calciferous to occur half way between Rutland and West Rutland, and also farther south.

Brainerd and Seely studied this formation particularly in the Champlain valley and with great industry examined "every important exposure on the Vermont side of Lake Champlain from Phillipsburg, Canada, to Benson, Vermont, and most of those on the New York side." From the sequence exhibited at Shoreham they estimated the entire thickness as about 1,800 feet. The formation was described as showing a variety of rock and in some beds an abundant fauna. Partly on the basis of lithology and partly by fossils the Beekmantown was separated into divisions known as A, B, C. D, and E, and described somewhat as follows (descriptions abbreviated):

1. Dark, iron-gray, magnesian limestone, more or less siliceous, often almost a sandstone, in beds usually 1 to 2 feet thick. Div. A, 310 feet.

2. Dove-colored limestone, intermingled with light gray dolomite, in massive beds. Div. B, 295 feet.

3. Gray, thin-bedded, fine-grained, calciferous sandstone; followed by thick beds of magnesian limestone; then sandstone, sometimes pure, but usually calciferous or dolomitic; magnesian limestone containing masses of chert. Div. C, total 350 feet.

4. Blue limestone in beds 1 to 2 feet thick; drab and brown magnesian limestone; sandy limestone in thin beds; blue limestone in thin beds separated from each other by thin, tough, slaty layers, often with conglomeratic appearance in the presence of small, angular pebbles. Div. D, total 375 feet.

5. Fine-grained, magnesian limestone in beds 1 to 2 feet thick, weathering drab, yellowish or brown. Div. E, 470 feet.

From Phillipsburg, Quebec, a series extends into Vermont for four or five miles in which Brainerd and Seely found beds lithologically similar to all the above-described divisions, although division E seemed "poorly represented" at the north. The Phillipsburg series was classed by Logan in his "Quebec Group," under his divisions A and B.

Beekmantown strata are described for many somewhat scattered localities along the lake shore and among the islands. The series as a whole, and the different divisions, are variously represented at the present surface in the different exposures of this formation. At Shoreham the apparent thickness is great and the formation is well represented in Orwell township and in adjacent portions of New York State.

An assemblage of remarkable fossils was early discovered at Fort Cassin. The collections which were made here by Professors H. M. Seely and George H. Perkins were described

chiefly by Whitfield and became known as the "Fort Cassin Fauna." Through the stratigraphic work of Brainerd at Ball's Bay, according to Seely, this fauna was finally assigned to the upper part of division D. Representatives of the fauna were also found at a few other places, as at Stave and Providence islands (near Grand Isle), at Valcour Island (Van Ingen and Ruedemann), and at Phillipsburg (Billings); but nowhere in the abundance and fine condition of preservation as at Fort Cassin.

The Beekmantown shows a small exposure on Grand Isle and is present at the southern end of Isle La Motte and in both places has been mapped by Professor Perkins. Brainerd and Seely, and later Cushing and Ruedemann, identified the several divisions described for Shoreham on the west side of the lake by means of similar lithologic characters.

The Vermont report shows a wide band of calciferous rock (called "Eolian") extending from Milton southward through Charlotte and Hinesburgh into Monkton. The rock is predominantly calcareous, but usually somewhat siliceous. Its precise age has proved difficult to assign. Professor Perkins classifies it tentatively with the Beekmantown, although suggesting that part of it may be Cambrian. In Colchester, Mr. Dan B. Griffin, assistant to the Survey, has found fossils (*"Pleurotomaria"* and *"Cryptozoon"*) and the State Geologist is inclined to think that this band is largely if not wholly Beekmantown.

The localities in Salisbury, Leicester and Brandon at which Wing reported Beekmantown (Calciferous) fossils were described by him as occurring west of the marble belt, and as belonging to the upper part of the Beekmantown terrane (*"Ophileta* beds"). Following the stratigraphy of that time, the quartzite lying along the eastern border of the valley being regarded as Potsdam, the limestone which lies directly west of it, "half way from Rutland to the West Rutland valley," was supposed to be Upper Calciferous (*"Ophileta* beds"), but no fossils were found.

The extent of the Beekmantown formation, in Addison County, and along both sides of the lake, its northern extension into western Quebec, its representation southward in eastern New York State, and even farther south, so impressed Seely that he wrote: "and when all the geological facts are in, will it not be found that the valley quarries of limestone and masses of marble, those early known as Stockbridge and later as Rutland, are largely comprehended in the Beekmantown?"

The calciferous rock lying to the east of the marble belt in Salisbury, Leicester and Brandon, and southward through the Vermont valley, and which borders the Lower Cambrian quartzite of the plateau on the west and is associated with the quartzite of the valley, has been described as a part of the Lower Cambrian series. See above. On the map to accompany his paper on

"The Commercial Marbles of Vermont," Dale calls this somewhat regular belt of dolomitic rocks "Cambrian Dolomite." He draws a distinction only between this formation and the marble, although he includes some dolomite with the latter. In the legend he calls the whole limestone formation of the valley "Cambro-Ordovician." In the text he writes: "The marble has been shown by Wing and others to include beds of Chazy age and probably some of Trenton age above them and possibly some Beekmantown below them. There is, however, a question whether any or how much of the dolomite is of Beekmantown age. As this formation along Lake Champlain is largely dolomitic it would naturally be sought among the dolomite beds of the Vermont valley."

In the present state of knowledge the assignment of any portions of the limestone of the Vermont valley to the Beekmantown is conjectural and provisional.

Dale has described a number of localities in the slate belt which exhibit certain dark-gray, calcareous or very quartzose, finely-bedded shales or black shales with thin limestone beds. These rocks are described as inconspicuous and easily overlooked. They are of inconsiderable thickness, and are further characterized by extremely fine bedding and a graptolite fauna. These features serve to distinguish them from adjacent rocks. While some of the fossils have a range outside the Calciferous (Beekmantown), several of them are regarded as probably of Calciferous age. It is uncertain whether the horizon is everywhere present or only intermittent.

In eastern Quebec is so-called Calciferous (Levis Formation) which is very different lithologically from the Beekmantown described from western Quebec, Ontario, Vermont, and eastern New York. It consists of black, gray and green shales, and beds of dolomites, sandstones and conglomerates, the latter carrying Cambrian fossils (Walcott). As explained on the map to accompany Part J, Vol. VII, new series, Montreal Sheet, Eastern Townships, the Levis is supposed to be the age equivalent of the western Quebec Beekmantown and the differences in lithology as due to different conditions of deposition. The Levis shales carry a very different fauna from the western Beekmantown. The fossils are graptolites which were correlated by Lapworth with Arenig (basal Ordovician) of England. This correlation is said to ally the Levis fauna with a different faunal realm from that of the Beekmantown of the lake region, the latter being the eastern extension of a "Pacific realm" fauna which was prevented from intermingling with the eastern European fauna represented by the Levis by a land barrier which separated the "Levis trough" on the east from a more western "Chazy trough" on the other side of the Green Mountain axis.

As explained in the discussion of the Upper Cambrian, Schuchert, and Ulrich by implication, place the lower portion of

Brainerd and Seely's Beekmantown in the "Ozarkian," which Schuchert makes Upper Cambrian and which Ulrich regards as a separate system, belonging to the basal Ordovician.

It has been suggested that the upper part of Brainerd and Seely's Beekmantown is probably more closely allied with the Chazy.

Chazy.

In the Vermont report the Chazy was grouped with Birdseye (Lowville) and Black River, which together were shown forming a strip about five miles wide narrowing north and south, along the shore of Lake Champlain in Addison County. Other strips were shown on Grand Isle and Isle La Motte.

First Wing and later Brainerd and Seely extended our knowledge of the occurrence and distribution of the Chazy rocks.

Wing found the Chazy well represented by fossils at West Rutland in the "Eolian Limestone," and reported other fossils from Leicester, East Cornwall and Middlebury.

On a map to accompany a paper entitled "Preliminary Report of the Geology of Addison County," Seely later showed no Chazy in Addison County east of the eastern boundaries of the towns of Addison, Bridport and Shoreham. On page 308 of the paper he wrote: "The deposits at the lime quarries near Leicester Junction have been regarded as massive Chazy and yet the structure approaches the Beekmantown. As Beekmantown it may remain until new light is thrown upon the obscure problem."

Wing described a "striped stratum" which was regarded as a marked feature of the Chazy, "by which the rock may be recognized without its fossils." This was found in Middlebury, in northern Salisbury, in the western part of Brandon, and in western Pittsford. This stratum "doubtless reaches the marble quarries of West Rutland and continues southward through Tinmouth and the whole State."

Chazy fossils were also reported by Wing from West Cornwall, North Cornwall, Orwell, Weybridge Upper Falls and near Bristol village.

In 1891 Brainerd described sections at Valcour Island, Crown Point and Chazy, N. Y. and also at Isle La Motte, Cornwall, Orwell and Highgate, Vt., and at St. Armand, Quebec. At Valcour Island 890 feet of Chazy were measured and separated into divisions designated as A, B and C, corresponding to Lower, Middle and Upper Chazy.

The distinction among the different divisions of the Chazy was made on the basis of fossils and lithology. The lower and upper boundaries of the formation were ultimately established and when all the lower members are present it has now for its recognized base a ferruginous sandstone which is prominently developed at Isle La Motte and is known as the "Isle La Motte sandstone." It carries *Lingula limitaris,* Seely, as a characteristic fossil. This sandstone rests, according to Seely, upon different members of division E of the Beekmantown, but usually upon the upper ferruginous limestone of that division. The upper strata of the Chazy, though varying somewhat, bear most often a tough, magnesian limestone, destitute of fossils, and weathering with an iron stain, while just above is a layer of flinty sandstone.

At Valcour Island the Chazy is described as follows (abbreviated):

1. Gray or drab-colored sandstone, usually with thin layers of slate and with occasional thin layers of limestone at the base; passing into massive beds made up of thin, alternating layers of tough slate and of nodular limestone; dark, bluish-gray, impure limestone in beds of variable thickness; gray, tolerably pure limestone in beds 8 to 20 inches thick, separated by earthy seams. Lower Chazy, Group A, 338 feet.

2. Impure, nodular limestone; gray, massive, pure limestone; bluish-black, thick-bedded limestone, usually weathering so as to show pure nodular masses in a somewhat lighter matrix; dark, compact, fine-grained limestone, with obscure bedding; bluish-black limestone. Middle Chazy, Group B, 350 feet.

3. Dove-colored, compact limestone in massive beds; dark, impure limestone in thin beds; tough, arenaceous, magnesian limestone passing into fine-grained sandstone. Upper Chazy, Group C, 202 feet.

Like the Beekmantown, the Chazy throughout its distribution at the present surface shows some variations in characters and thickness of members and at some places only partial representation of the formation.

In addition to the localities given above, exposures of Chazy occur near Balls, MacNeils and Merriams bays, and from Basin Harbor to Button Bay, along the east shore of the lake; at the northern end of Providence Island; on Sawyer's Island; and on Grand Isle, where it is represented somewhat extensively, both geographically and as a terrane.

After the discovery of characteristic Chazy fossils (*Maclureas*) at the surface in the central and western parts of the West Rutland valley fine, although somewhat distorted, specimens were found on polished slabs from the bottom of the deep "Ripley quarry."

South of West Rutland, in the town of Ira, at Day's quarry, which was worked for a time, Walcott found sections of large gastropods, probably *Maclureas,* in a bluish marble.

South of West Rutland in the Vermont valley recognizable Chazy fossils, so far as the writer can determine, had not been found up to the season of 1920. See beyond. Dr. Walcott discovered fossils in the limestones south of Bennington, which were assigned to the Chazy-Trenton, but no sharper distinction was drawn.

Lowville (Birdseye).

In the generalized time-scale for eastern North America the Lowville succeeds the Chazy.

An elevation at the close of Beekmantown time, accompanied by folding, in eastern North America, has been described as probable. This elevation is thought to have raised much of the middle Appalachian region and all of New York State except the northeastern portion above water. In the Champlain region it is held existed a trough at this time in which was being deposited the Chazy. While the Chazy was being deposited in the Champlain region and in another small (Ottawa) basin the lower Stones River was depositing in Kentucky and Tennessee.

After the deposition of the Chazy in the Champlain region it is thought an emergence there occurred, forming land, which was not submerged again until the Black River brought the Mississippian sea into the region. The Lowville, which is regarded as the time equivalent of the Upper Stones River of the south, forms the basal member of the Trenton series (Mohawkian) in New York and ushered in the Black River invasion.

As mentioned in the discussion of the Chazy the Lowville was theoretically included with Chazy and Black River in the Vermont report.

The Lowville was at first described as very scantily represented in Vermont. *Phytopsis tubulosum,* Hall (a fossil which has the appearance of a bird's eye and which gave the early name to the formation), has been seen only in the northwest corner of Benson in a bed about 6 feet thick. Elsewhere this horizon is described as having only a few feet of pure, fine-grained, brittle limestone with fine lines of calcspar, lighter in color than the known Black River strata just above, and without fossils.

Brainerd and Seely maintain that more than one horizon in the Beekmantown and in the Chazy are lithologically similar to the Birdseye, and have been wrongly assigned to that formation. Assuming the rocks and fossils which had some appearance of the Birdseye to belong to that formation they sought localities where the Chazy approaches the Black River, thus hoping to find the Birdseye between. But in every locality so sought they found the Black River resting upon the Chazy, with no room for the Birdseye. Instead they found the so-called Birdseye in places to be underlain and overlain by members of their Calciferous. They found fossils which have been figured as sections of *Phytopsis tubulosum* to be "spongoid" forms, known as *Strephochaetus,* characterizing their middle Chazy. They could find no proof of the Birdseye in Vermont, except the small exposure in Benson.

Black River.

In their description of the Beekmantown of Vermont, Brainerd and Seely frequently refer to the Black River as immediately overlying their Chazy. Northeast of Shoreham village they mention Black River, carrying characteristic fossils, lying in a trough of the Chazy. Half a mile south of this exposure the trough widens and the Trenton appears flanked by the Black River and the Chazy in succession. Again in Orwell, south of Shoreham, Black River is described as resting against the Chazy, the latter lying on the former at one place by overturn. Black River is described at Larrabee's Point, Thompson's Point and MacNeils Bay.

In his paper dealing with the Chazy of the Champlain valley, Brainerd describes and shows graphically in sections the Black River at Valcour Island, Isle La Motte and Highgate Springs, resting upon or in close association with Chazy.

Professor Perkins has mapped five separate exposures of the Black River on Grand Isle, and one on Isle La Motte, and refers to it as occurring at Button Bay Island and at Benson.

The Black River strata are described as fine-grained limestone, bluish at the base and jet black in upper layers. The formation as a whole is nearly destitute of fossils, although some thin layers are full of them.

Except in the vicinity of Lake Champlain the Black River is not positively known in Vermont.

In the Champlain region the Black River has been thought to lie disconformably upon the Chazy, the latter having been elevated and probably somewhat eroded before the Black River invasion.

Trenton.

This formation as identified by fossils differs in lithology and degree of metamorphism at different places. Some terrigenous rocks by reason of association with Trenton limestone or other relations have been described as probably of Trenton age.

The Vermont report shows the Trenton at Highgate, on Isle La Motte, and on Grand Isle in Lake Champlain; in Charlotte on the lake shore; and in the western portions of Addison and Rutland counties.

Mr. Wing later added details of the Trenton in Addison County and also found Trenton localities in the "Eolian Limestone." West of or within the slate belt of the Vermont report he identified the Trenton at localities only a few miles apart in all the towns north of Castleton, including Hubbardton, Sudbury, Whiting, Shoreham, Cornwall and Weybridge; and on the east of the slate belt in Leicester, eastern Cornwall and Middlebury. The presence of the Trenton at Benson, south of Orwell, left little doubt that this formation exists "in long bands stretching down on the west of the two belts of slate from Weybridge southward."

From the relations of the "central slate belt" to the marbles in Rutland County and farther south, Wing believed the Trenton abundantly represented in the marble belt. Fossils (*Trinucleus concentricus*) were described as found in limestones "interbedded" in the slates 10 miles southeast of Sudbury, at Hubbardton, and a mile or two north of the slate quarries at West Castleton.

In the summer of 1887 Walcott found fossils indicative of a Trenton fauna at Pownal, Vt., a mile north of the Massachusetts line, and also on the eastern side of Mt. Anthony about 3 miles south of Bennington Centre.

In the papers by Brainerd and Seely on the Calciferous and Chazy of the Champlain valley, frequent mention is made of Trenton rocks. They are described as forming a wide strip east of Shoreham, running through Cornwall and Whiting on the west of the "central slate belt"; also at Shoreham; at Orwell; at Larrabee's Point; to the east of Balls Bay; at Cedar Branch, north of MacNeils Bay; on Grand Isle, both inland and along shore; at Crane Point, opposite Port Henry, N. Y.; and at Isle La Motte.

Professor Perkins has shown wide exposures of this formation on Grand Isle and has also mapped its outcrops on Isle La Motte.

Small exposures are mentioned as occurring at Highgate and St. Albans, but they are in no cases extensive. The formation is described as not occurring along the lake shore north of Charlotte.

Dale thinks that some of the limestones of the marble belt are of Trenton age. On his map of the slate belt of eastern New York and western Vermont, Ordovician limestone is shown as an interrupted band along part of the western border. In Benson this limestone, with a few small patches of slaty or gritty rocks, is represented as a band 2 miles wide along the shore of the lake. Just east lies the so-called "Benson Black Slate" over an area about 2 miles wide and 5 miles long and this is bounded on the east by an irregular strip of the limestone. These two areas of limestone are shown as separated at the south from another area of the limestone about 2½ miles wide south of West Haven. The latter area narrows southward, and with only one interruption, extends to West Granville, N. Y. Fourteen miles south of West Granville a narrow band runs from North Argyle to Argyle in New York. In the text these areas are referred to as the Trenton limestone. Outcrops are specially mentioned as occurring in Hartford and at Carver's Falls in Poultney River. An area is shown northwest of Hubbardton, surrounded by the slate, phyllite and grit formation. At Carver's Falls and at several other points near the Cambrian boundary, with which the limestone is shown in contact over long distances, according to the map, the limestone yields Trenton fossils. In several places this limestone "may represent the entire Lower Silurian series and should then be regarded as Trenton, Chazy and Calciferous." The Trenton limestone is mentioned as occurring sporadically within the Ordovician areas of the slate belt.

In general as thus far described the Trenton formation is calcareous. Several observers have regarded limestone of this age as interbedded with members of the slate formation. Dale says that the limestone was probably in some places deposited contemporaneously with the "Hudson" grits and shales. In his table and descriptions of formations, those designated as "Hudson grits, Hudson red and green slates, Hudson thin quartzite," are put in the Ordovician and in part referred to or described as probably representing the Trenton limestone, described above as occurring west of the slate belt. Dale describes what appeared to him as indications of transition between Hudson grit and the "Berkshire Schist" of the Taconic range, and from the areal relations infers that the latter is equivalent to the entire Ordovician among the slates and grits and in addition to representing the Calciferous, Chazy and Trenton includes also probably the Lorraine and Utica.

Foerste describes Trenton fossils as occurring in thin blue limestone which forms intercalated bands in the base of the slate formation. He gives two localities near Danby Four Corners, 12 miles south of Rutland, and another on the ridge west of Otter Creek a little northwest of South Wallingford. He mentions branching bryozoa, crinoid beads, and sections of *Strophomena* and *Streptelasma*.

Normanskill.

Graptolite shales "interbedded or associated" with "Hudson" grits in the slate belt are assigned to the Normanskill Zone (Trenton) by Dale.

Utica.

The so-called "Utica" has a wide distribution in the region of the lake. The Vermont report, which separates this formation from the "Hudson River," shows the Utica as forming Alburgh peninsula, North Hero and much of Grand Isle, and on the mainland of Vermont further indicates a strip extending from the shore of Missisquoi Bay southward through Highgate and Swanton to St. Albans Bay; again at the mouth of the Winooski River and from Charlotte on the east of the Trenton limestone south to Shoreham. It is described as pinching out in Orwell near "Chittenden's Mills." A narrow strip is shown skirting the lake on the west of the Trenton in Addison County, and a small patch on the lake west of Bridport.

According to Professor Perkins what was mapped by the Vermont Survey as "Hudson River" is also Utica. According

to Perkins: "Here and there the Utica appears on the Vermont shore of Lake Champlain and in small patches away from the lake." Juniper Island, the Four Brothers and Rock Dunder in the lake are also formed of Utica slate.

Mr. Wing's investigations apparently dealt chiefly with the limestone formation ("Eolian"), and only indirectly with the slate. The slate of the great "central slate belt" of the Vermont report he called "Hudson River" and showed it in sections and discussed it as conformably overlying the Trenton formation. At West Rutland "the Chazy adjoins the slate belt." The limestones containing Trenton fossils "over the interior" of the slate belt had the appearance of being "brought up from beneath by anticlinals."

Brainerd and Seely maintained that all the rocks of the Lower Silurian appear on the Vermont side of Lake Champlain, sometimes showing in their natural order in great monoclinals with Utica slate at the top, lying on the Trenton limestone. They made the slate of the "central slate belt" which Wing called "Hudson River" in the Shoreham section, of Utica age, thus correlating it with the slate formation lying west of the "great fault," or the slate of the Lake Champlain region proper. These observers show the Utica in faulted contact with the Chazy and Trenton at Isle La Motte. Professor Perkins shows the Utica widely distributed on Grand Isle, forming the larger part of the island; also three patches along the east shore of Isle La Motte.

Within the roofing slate belt the Utica is not distinguished. East of the slate belt the Berkshire Schist is made probably to include this horizon.

On Grand Isle Professor Perkins has described characteristic Trenton fossils and so-called "Utica" types occurring on the same slab.

Later Ordovician ("Lorraine," "Hudson River").

The presence of rocks of Ordovician age younger than so-called "Utica" in western Vermont cannot be affirmed from the rocks themselves. Perkins maintains that in the Lake Champlain region all the slate formation is of Utica age (or older perhaps).

In the Taconic range the Berkshire Schist is made provisionally to include Lorraine, and many of the terrigenous rocks of the roofing slate belt are not specifically assigned beyond indicating that some of them are probably equivalent to the Trenton (and the Calciferous and Chazy). They are usually referred to by the non-committal term "Hudson," which term in its present usage, includes Trenton and older and younger terranes.

GENERAL STRUCTURAL CONSIDERATIONS.

Preliminary statement. Throughout their length and breadth in western Vermont, from the Canadian boundary to the Massachusetts line, and in their geographical extensions into Quebec at the north and into Massachusetts and New York at the south and west, the formations just discussed present a wonderfully fascinating field with respect to the secondary deformations which they have suffered. For a bold sweep of the imagination there is no aspect of Vermont geology so inviting as that of the widespread dislocations which have followed the action of compressive stresses in the earth's crust. By these forces the rocks have been piled on each other and shoved from east to west.

In the Taconic region the deformational history is very complicated and difficult to read. Many views of the structure have been given and there probably will always be divergence of opinion.

The present erosional aspects of the region in many particulars seem clearly to be due to structure produced by ancient processes of deformation and as one studies the topography and geology together it becomes apparent that the physiography of today had its genesis in crustal disturbances of a more or less remote past.

Brief summary of various studies that have been made in the deformation of the earth's crust in various parts of the world, and of certain theoretical aspects of the subject. In their work of mapping the areal and structural relations of formations in various parts of Europe and of this country during the past forty or more years, geologists have in some cases readily come to recognize and sometimes have been forced to reckon with the existence of great displacements of the crust in order to account for the field relations which certain regions show. Especially noteworthy is that class of deformations comprising overturned folds, shearing, reverse faults and thrusts.

All these secondary structural features often share with each other the displacement changes of a given region and sometimes apparently have a common general relation to a definite regional deformation. Uncertainties will naturally arise concerning the extent to which the various secondary deformations due to compression, in a given region, are related to the same general episode; or, if there is reason to think that pressure acted intermittently, as to whether it acted in the same direction at various times. Evidence has been offered to show that in certain regions thrust movements have been widely separated in time and have acted in practically diametrically opposite directions.

It is usually not easy to fix the precise, or even the proximate, date for the chief displacement features of a region, or to apportion the various deformations therein among different epochs in those cases in which a region is known or suspected to have been

affected by crustal movements more than once and at more or less widely separated times. The degree of probability rests upon different conditions in different regions. In certain regions where older formations now rest by thrust on younger masses, these relations by themselves may serve to indicate only a general limit of antiquity and other conditions may or may not give an idea of the precise date at which the actual deformation occurred.

Sometimes the evidence points to the formation of a major thrust whose plane was subsequently folded and suffered offsets and other later disturbances. The latter may in certain regions be reduced to a type characteristic of later orogenic movements or other displacements and serve to show at least separate episides of disturbance, while they leave undecided the question of how much earlier the major thrust occurred than did those movements which modified it in various ways.

In certain cases perhaps the existence of a stratum competent to transmit a great lateral thrust may serve to indicate the limit of antiquity of the movement; while the relations at the same time afford no means of telling at what time subsequent to the formation of the competent stratum it was called upon to exercise its influence. The problem might perhaps be further complicated in some cases by the possible former existence of a competent stratum which had been partially or wholly eroded and which by reason of its original relation to the load which it carried could have initiated a thrust which was participated in by a lower stratum, also competent under proper conditions, which obtained relief by the fracture initiated by the more superficial part of the crust, the fracture of the latter changing the relations between the deeper stratum and its load, which had prevented fracture until the relief of the initial fracture was felt by it.

In some cases a thrust movement may not have occurred until erosion had so changed the relations of a stiff stratum with respect to its load that it fractured, in which case the thrust would be thought of as occasioned by reason of erosion preceding or assisting compression. In a case in which erosion preceding any compression seemingly made possible a thrust movement and in which the erosion was apparently carried to a stage of peneplanation prior to the thrust, the date of the peneplain, if ascertainable, might serve to fix the probable date of thrust.

In some regions the fact of different dates of compression might be perceived by reason of the difference in degree of displacement produced as, for example, where it would be possible to associate one class of fractures with the folding of an earlier thrust of relatively large displacement.

While it is possible to imagine the formation first of a major thrust whose plane was subsequently disturbed by folding and thrusts, there are regions in which the conditions seem clearly to indicate that minor thrusting or reverse faulting along many separate planes and apparently involving previous folding, occurred first, piling the strata on each other, sometimes to enormous thickness, and that a later thrust passed beneath the whole and cut off the whole series of earlier minor thrusts whose planes came to lie at oblique angles with the major thrust plane. More than one series of minor thrusts, or reverse faults, and an associated major thrust may exist in the same region, which suggest different episodes, or periods of compression, for that region. Moreover, in addition to these minor and major thrusts there may be one or more later and still more powerful or "maximum" thrusts, so formed that the later of these override the earlier, while all may overlap the previous minor and major thrusts of the region, at one or more places. A very complicated condition is thereby produced. The maximum thrusts carry the older rocks over the younger, but with various degrees of overlapping, and the overthrusting may go so far as to carry the disturbed portion of the crust over on undisturbed strata. While a common direction of movement and a sequential nature in these displacements and therefore their relative dates might be apparent, the question of their geological dates might still remain open.

A condition that might be inferred to be due to folding antecedent to thrusting is frequent in such regions as just described, but it is explained, sometimes at least, as occasioned by friction along the unyielding plane over which the upper material moved, so that there was a tendency for the upper part to curve under and produce inversion of beds.

The outcrops of the maximum thrust planes under erosion resemble boundary lines between unconformable formations because of greater or less discordance between the strata above and below the plane of fracture.

In regions of long-continued and profound erosion and involving at the present surface very old rocks the problem of the dates of various disturbances may shift to one of sheer uncertainty, especially when a region is known or believed to have been involved in two or more mountain building deformations and one or more of these disturbances are also known to have been a long time subsequent to the dates of formation of the rocks which now lie in displaced relations to each other. It is conceivable that a relatively recent orogenic movement might have dislocated and deformed a region involving rocks of much greater antiquity than the date of the movement itself and give results not to be readily distinguished from those which would have followed a compression of those rocks shortly after their formation.

Displacements have been described in the Canadian Rockies in which an original width of 50 miles has been shortened to half that distance by a succession of thrusts along a number of

parallel, longitudinal fractures which have produced a series of huge oblong blocks resting on one another from west to east, and apparently produced without much preliminary bending. Overturned folds were observed along the courses of some of the faults, but were described as usually small and of minor structural importance. Violent folding in the prolongation of a fault line and undulations of major fault planes indicating disturbance subsequent to the main faulting were observed. In the belt of fracture there were recognized seven principal faults of varying throws. *There was observed a very striking apparent conformity between beds widely different in age east of the axis of the region.*

It will appear, either in regions in which strata belonging to epochs approximating in age relations the date of later deformations have never been deposited, or in those in which such strata though deposited have been eroded, as though only those rocks which are now visible were involved; but in one case it will be necessary to recognize that a former load may have controlled or modified the action of the deforming forces. It may be that the only light one may be able to get upon such a possibility will come from considering the whole general region, of which the province under consideration is apparently a genetic part. Late Paleozoic rocks, for example, may be much more sparsely represented today in New England than in the past. The conditions in neighboring New York and the fact that we are probably dealing with an upraised peneplain of a great upthrust segment of the crust should perhaps be remembered in our studies in western New England.

The probability of difficulty in working out the dates of deformations in a region as the result of the fact that nature works, at least to some extent, with the same rock masses at separate epochs and under various conditions is apparent. Such conditions, in efforts to discriminate among the effects of possible different crustal movements, will lead to differences of interpretation almost surely where present relations are greatly involved.

In passing it seems worthy of note that any principle which assumes that the minor, secondary structural features of a region may be taken as replicas of the larger deformations must be used with caution.

The problem of the structure of a region often involves as primary conditions the nature, sequence and thickness of sedimentary formations and the complex nature of the substratum on which these are deposited, such as rigidity, condition of previous strain, irregularity of surface and admixture of crystalline masses. It must further reckon with antecedent deformation of any kind and frequently upon consequent strains in those cases in which the structural features are of different dates. It must take account of the possibility of variations in the strength of the compressive forces at different times, or in different parts of a region during the same episode; of metamorphism and resulting crystallization or re-crystallization of rocks; of erosion at different periods; and of periods of tension stresses and normal faulting.

DESCRIPTION AND DISCUSSION OF FIELD STUDIES BY THE WRITER IN WESTERN VERMONT.

General plan of discussion. For convenience, general reference to field studies in this paper will be given by counties and by towns which are shown on the accompanying map, plate XXII. Observations and citations are based on the topographic, quadrangle sheets of the United States Geological Survey. Close reference to localities mentioned will require the use of these maps. Some assistance may also be had from the map showing physiographic divisions, and from certain landmarks such as large towns or cities, township boundaries and rivers. For the townships of Brandon, Sudbury and Orwell a special map is offered, Plate XXII.

ADDISON COUNTY.

Orwell Township.

(Ticonderoga topographic sheet.)

Topography. The township has a somewhat diversified topography. A spur of the foothills of the Taconic range enters it from the town of Benson at the south. Over this spur the contours of 600 and 700 feet run for long distances. The highest point is 1,000 feet. There are several scarps within the spur.

This high land extends nearly to the lake in southwestern Orwell, but the surface of the northwestern part of the town is a gently-rolling upland with contours at or below the 400 level. The surface of East Creek over much of its length is practically that of the lake. Along the creek and the lake shore are large tracts of Champlain clays, which effectually conceal the underlying rock.

East of the spur described is a valley through which courses the Lemon Fair River and which separates the spur from the Sudbury hills. This valley has a minor ridge running in a general north-south direction through it.

Mount Independence. The flattish position of the strata forming this hill is noticeable. They dip about 10° northerly. Forming the basal members at the southern end are thick-bedded, whitish, quartzitic sandstones which Brainerd and Seely called "Potsdam" and assigned a thickness of 170 feet. Then come dark-gray, siliceous and magnesian rocks, in some cases almost quartzites, and then interbedded dolomites and limestones. The rocks of the hill above the so-called "Potsdam" were called Beek-

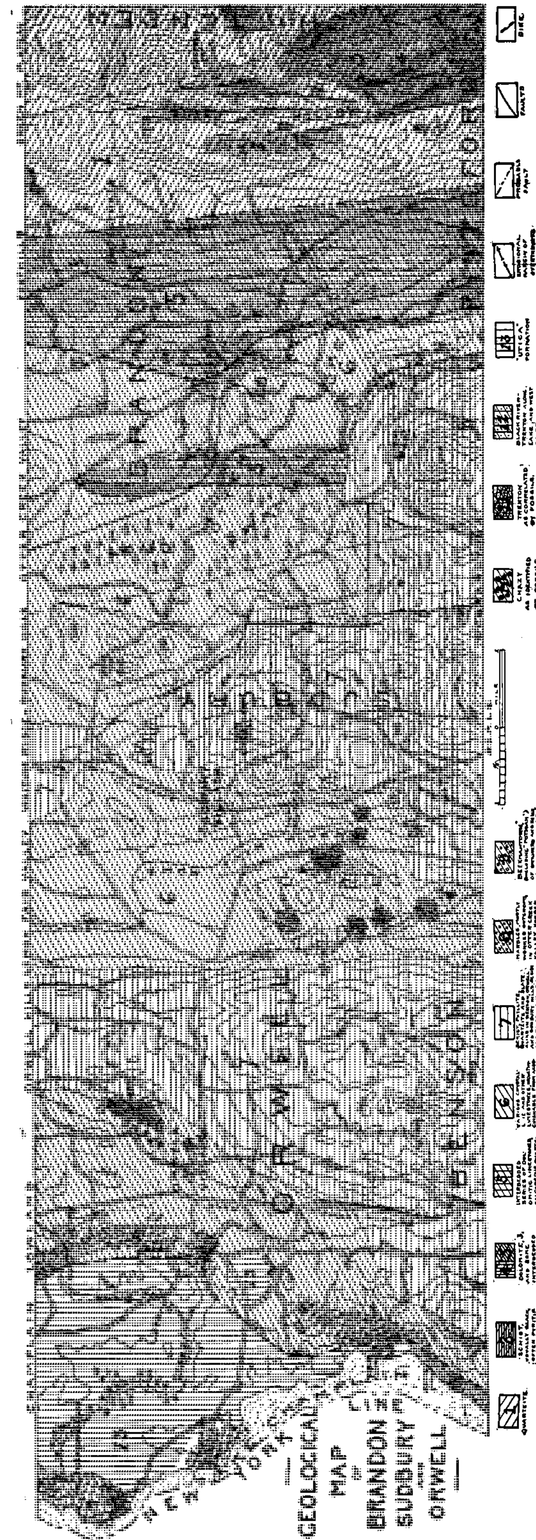


PLATE XXII.

mantown (Calciferous) by Brainerd and Seely and put in their divisions A and B. The writer did not find along the lake shore or at any other part of the base of this hill any contact with other rocks than those which make up the hill. It seemed to be surrounded on the landward portion by the Champlain clays.

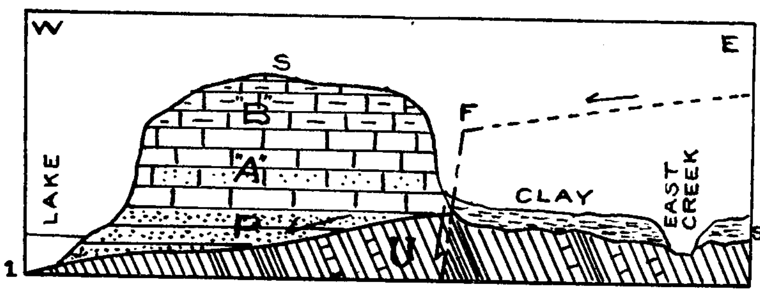


FIGURE 9. Section to show interpretation of the relations at Mt. Independence. U, "Utica" slate; P, "Potsdam"; "A" and "B," lower "Beekmantown." The lower Ordovician has been thrust on the "Utica" slate formation. A possible normal fault, F, is shown which displaced the whole series at the west, including the thrust plane. 1-2, thrust plane. S-S, erosion surface of the hard rock formations.

Chipman's Point. One and a half miles south-southeast of Mt. Independence thick beds of dark-gray, magnesian limestone emerge from the lake north of Chipman's Landing, with general northerly dip and strike of N. 58° E. One-half mile southeast of the landing these beds which seem to have suffered no break within them, disappear into the lake with general southerly dip, thus appearing to form a gentle arch with general direction of its axis east and west. So far as observed along shore these beds are similar to those lying above the "Potsdam" in Mt. Independence. At many places the rocks dip abruptly into the lake. No so-called "Potsdam" was observed. Eastward these rocks pass beneath the clays. No contacts with other rocks were found. The strata indicated only gentle deformation within them.

South of Chipman's Point. South of Chipman's Point are three promontories known by campers along the shore as "The Phoebes." These are composed of black, limy slates and shales with bands of interbedded black limestone. All are much disturbed and show not only a highly-inclined easterly dip as a rule, but internal crushing as well. The shaly members of the southern promontory gave *Graptolithus pristis,* and bowlders of the interbedded limestone at the base of the cliff yielded *Plectambonites sericeus, Dalmanella testudinaria,* and *Trinucleus.*

One hundred and fifty rods south of this promontory a brook enters the lake. Slate outcrops in the bed a few rods from the shore and is succeeded up the brook by a magnesian limestone, dipping easterly and resembling part of the lower Beekmantown of the exposures at the north. In the field northeast of this

brook are dark, magnesian limestones. In lithology and presence of chert, some of this rock resembles division A of Brainerd and Seely's Beekmantown. This is succeeded eastward by other magnesian limestone of general gray color and probably part of the Beekmantown.

South of this brook is a hill known as "Blue Ledge" by the campers. The ledge shows an almost perpendicular scarp from 150 to 200 feet above the surface of the lake. The west face of the scarp to a height of 100 plus feet is composed of slate like that of "The Phoebes" at the north. The shaly layers yielded *Graptolithus pristis.* The summit of the scarp and the eastern slope of the hill is a magnesian limestone like that in the brook bed just north and is probably Beekmantown. The topography shows that "Blue Ledge" is bounded on the north and south by east-west faults of the normal type. The limestone capping the hill dips easterly. See figure 10.

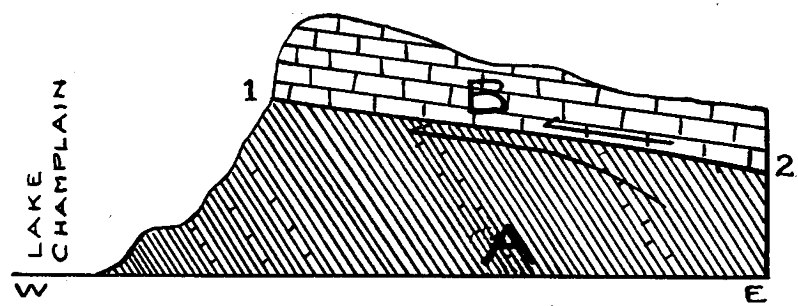


FIGURE 10. Section to show relations at "Blue Ledge," on the Orwell shore of Lake Champlain. A, "Utica" slate formation; B, massive dolomite, probably of "Beekmantown" age; 1-2, thrust plane. Curved arrow indicates folding of "Utica" strata; straight arrow indicates bodily thrust of massive "Beekmantown" on slate formation.

South of "Blue Ledge" is an abandoned farm. Just north of the old barn is an exposure of the "Utica" and not more than 10 yards to the east of the slate is a low scarp in the dolomite, but the contact is concealed. These relations are shown in plate XXIV.

The relations at "Blue Ledge" and at the old farm thus give clear and unmistakable evidence that the slate formation is overlain by the dolomite which is all regarded as forming some part of the Beekmantown of the region, on the basis of the lithology of the rock. The indication is that "The Phoebes" owe their present topographic prominence to a protective covering of the Beekmantown which has been removed at a relatively recent epoch. For the Beekmantown to have its present position on the younger formation an overthrust is assumed.

Questions then arise with reference to the former extension of the Beekmantown in the neighborhood. Is it present beneath the clays between Chipman's Point and Mt. Independence? If not, was it once present there lying on the slate formation and did it also once cover the slates to the east of the lake shore over the areas now largely concealed by clays, but in which along the various stream incisions the slates can be seen to form the surface rock? East of these clays and west of Orwell village, as will presently be described, the Beekmantown occurs again and in apparent overthrust relation to the slates. It therefore appears probable that these questions just asked as to a probable, former, widespread covering of the slates by Beekmantown may be answered in the affirmative.

The conditions at Mt. Independence, at Chipman's Point and at other places indicate gentle flexures in the dolomite formation; while those at "Blue Ledge" and west of Orwell village show that the formation has been fractured. It appears probable that certain structural features permitted the removal of Beekmantown beds over the areas intervening among its present surface outcrops and that Mt. Independence, and perhaps also the dolomite at Chipman's Point, are thrust-erosion inliers in the slate formation. On the whole it appears probable that the present exposures of the dolomite are the downthrow portions of the formation as deformed by normal faulting and that many of the flexures which the formation shows are products of the same deformation.

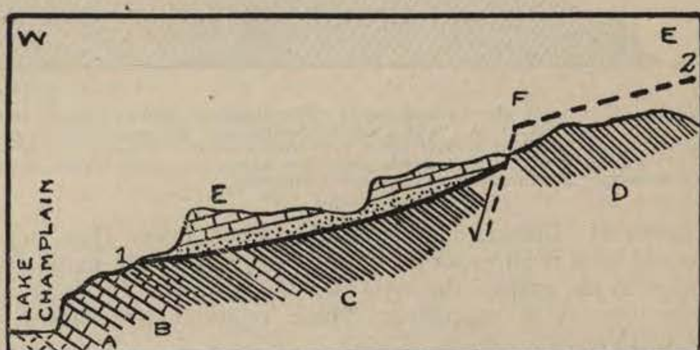


FIGURE 11. Generalized section to show interpretation of relations along the lake shore in Orwell just north of the Benson line. A, Black River; B, Trenton; C, Trenton-"Utica"; D, friable shales probably conformable with C; E, "Potsdam" and "Beekmantown" now lying by thrust on A, B, C, and formerly also on D. A normal fault has dropped the rocks at the left, including the thrust plane. On the upthrow side E has been eroded and also part of D. 1-2, thrust plane.

Southeast of the old farm mentioned above is a very bold precipitous scarp in the dolomite. In the face of this cliff the rocks appear very massive and exhibit little appearance of bedding. The scarp loses prominence southward owing to the drift piled against it; but it was followed through the woods

PLATE XXIV.

Contact of massive "Beekmantown" on the "Utica" slate near the shore of Lake Champlain in Orwell, one-half mile north of the Benson line. The boy stands on the slate; the "Beekmantown" shows as a scarp midway up between the trees.

above the camp of Oscar Neemes to an apparent fault that will presently be described.

Along the shore one-half mile south of "Blue Ledge" and only a few rods north of Neemes' camp, very thick, bluish-black limestone beds appear in the bank and dip into the lake. The water line intersects diagonally the strike of these thick limestone beds and as one walks along the shore one passes from syncline to anticline, rather closely spaced and regular in their succession and probably as strongly compressed as these heavy beds would allow. South of Neemes' camp the beach is covered with many boulders in which *Bellerophon, Trinucleus, Plectambonites* and other fossils are common. Above the bank apparent Trenton beds outcrop and many loose boulders are filled with Trenton fossils.

South of an east-west line passing approximately through Neemes' camp what are apparently Middle Ordovician strata have a topographic level about the same as massive Beekmantown north of that line. South of this hypothetical line, back in the woods about one-fourth of a mile southeast of the old Walker place, a quartzitic sandstone forms a low cliff. The scarp is farther east of the shore than that of the massive Beekmantown just north of Neemes' camp. There may be an east-west fault with an offset, in the vicinity of the camp, and with differential lateral displacement; or, as the topography affords reason for thinking, while there may be a fault the quartzite scarp south of it may owe its present more easterly recessive position to erosion of rocks left at a relatively higher topographic level after normal faulting.

The thick-bedded, bluish-black limestones just described are regarded as probably Black River, both from their lithology and stratigraphic relation to apparent Trenton rocks. It is not wholly certain whether they and the Trenton are part of the overriding mass, or are beneath it like the "Utica" farther north. In figure 11 they are represented as beneath. They may have participated in a thrust, or a reverse fault, and also be overthrust by older rocks.

The evidence afforded by the relations along the Champlain shore in Orwell favors the views:

1. That the Middle Ordovician strata (Trenton-Utica) are overlain by early Ordovician (Beekmantown) or possibly even older ("Potsdam") rocks;

2. That, as indicated by the absence of any but relatively gentle flexures, which indeed were probably due to much later deformation than that which produced its present superposition, the older rock was thrust bodily over the younger strata and now lies unconformably upon the latter along a thrust plane;

3. That a later crustal disturbance deformed the whole series, including the thrust plane, and caused irregular, gentle

flexures in the thick overthrust mass, which as now eroded displays the basal Ordovician and perhaps Upper Cambrian lying on the younger rocks;

4. That, at the time of the disturbance just mentioned, or later, there occurred some faulting with various degrees of displacement, involving the rocks both above and below the thrust plane;

5. That the major thrust plane which parted the thick mass of strata composing the Lower Ordovician of the region did not shear always at the same stratigraphic level, but cut through it so that the rupture was now through the Beekmantown and now through the "Potsdam."

These conclusions seemed reasonably clearly established before the relations in Orwell east of the shore were examined.

Relations west, northwest and southwest of Orwell village. East of the lake in the bottoms of ravines tributary to East Creek are many small exposures of friable slates and shales with easterly dip. Still farther east in the banks and bed of the North Branch of East Creek in various parts of its course the slates again outcrop and show frequent bands of interbedded black limestone. These slates were traced eastward along East Creek and the North Branch to the western margin of the limestone formations west of Orwell village.

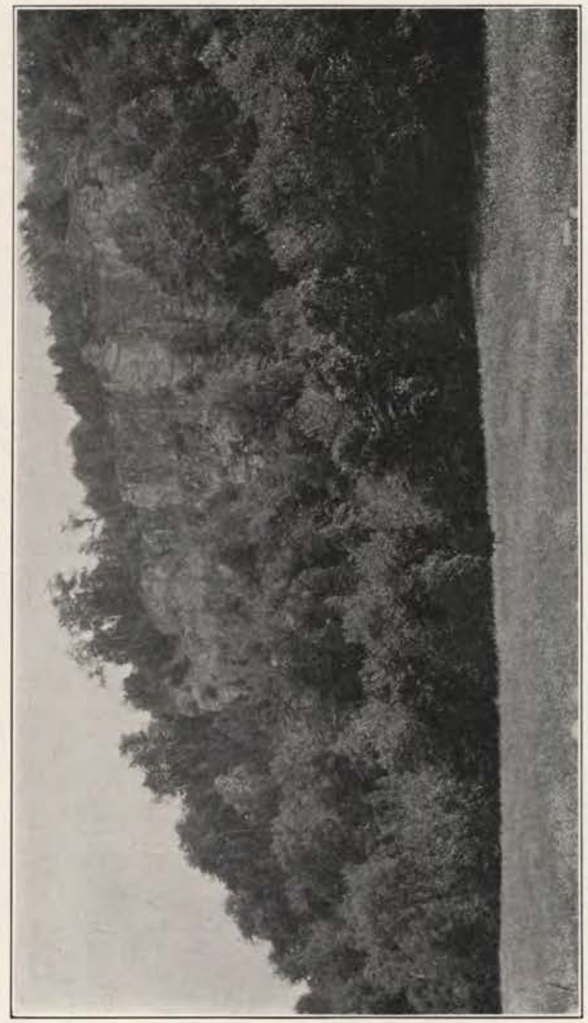
One and a half miles west of the village, East Creek tumbles over the edge of limestone and cataracts across upturned slates. This place is the site of an old grist mill, formerly known as "Chittenden's Mill."

At the summit of the falls the rock is a dark blue or black limestone which breaks into splintery pieces. The beds strike N. about 38° E. and dip southeasterly. This limestone carries number of *Prasopora lycoperdon* on the eroded surface and when broken gave *Trinucleus* and linguloid shells. About half way down the cataract slopes in the brook bed a reading in the slates and interbedded limestones gave N. 77° E. There has clearly been disturbance.

About one mile northwest of Huff's Crossing, a few rods east of the railway track is a high scarp in massive, siliceous dolomite (see plate XXV). At the base are beds like those at the base of Mt. Independence and probably representing the "Potsdam" of Brainerd and Seely; but the slates on which this rock presumably rests, by analogy with conditions farther south on the lake shore, were not seen. Along the road east of the scarp are beds like those overlying the "Potsdam" at Mt. Independence.

In the bed and banks of the North Branch around Huff's Crossing are exposed higher beds of the Beekmantown formation, and three-fourths of a mile farther south some of these latter beds are exposed in numerous outcrops in the fields near the road.

PLATE XXV.



Scarp in the "Beekmantown" northwest of Huff's Crossing, along the erosional margin of the overlap by thrust of basal Ordovician on the Ordovician slate formation. At the base of the scarp, above the talus slope, is massive, quartzitic sandstone like that at the southern base of Mt. Independence, which was called "Potsdam" by Brainerd and Seely.

These exposures have been described by Brainerd and Seely. The blue limestone of their division D appears on the axis of the anticline carrying *Ophileta complanata, Maclureas* and other fossils. This member is succeeded on each limb by the other members of this division, although those on the east limb are most satisfactory for study. In the stream channels near Huff's Crossing divisions D and E appear and in addition the top of division C.

West of the highway bridge at Huff's Crossing the Beekmantown beds, which directly beneath the bridge lie in a flat position, as displayed in the south bank of the stream through a distance of about 300 yards show gentle undulations with apparently slight southerly pitch. Then appears an abrupt change from a moderate dip to one about 65° W. along a strike of about N. 25° E. About 60 or 70 feet of interstratified limestone and siliceous beds are exposed across their strike in the bed of the stream. About 100 paces west of these rocks are similar ones which show a somewhat puddled arrangement which is attributed to the disturbance which these rocks have suffered. Two hundred paces downstream, after an interval of clay, appear the blackish slates with limestone bands like those seen near the grist mill falls, westward at intervals along East Creek, and at the lake shore.

A mile and half south of these exposures, north of the road which runs westerly north of the grist mill falls, along the west edge of the woods and west of Beekmantown beds, were found numerous, well-preserved surface scrolls of *Maclurea magna* at numerous places and other outcrops of striped, bluish limestone like the Chazy as seen at other localities. West of this stratum are limestones carrying hosts of surface markings of fossils and which are regarded as probably representing the Trenton. These various rocks seem more metamorphosed than the Trenton rocks above and the slates below the dam at the grist mill and in some cases, at least, have a highly-inclined westerly dip.

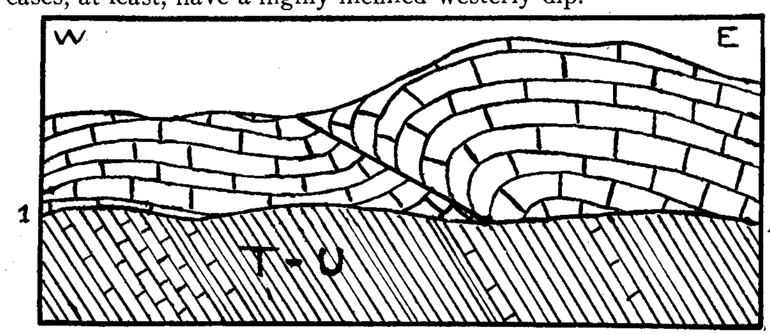


FIGURE 12. A section generalized to show interpretation of structure in the overthrust Lower Ordovician limestones (here largely "Beekmantown") west of Orwell village. The massive rocks were ruptured by reverse faults which were subsequently truncated by a thrust, 1-2. The rocks were carried westward over folded limestones and slates belonging to the Trenton-"Utica" formations of the present lake region. 1-2, thrust plane.

From the general local deformation shown along the western edge of this eroded anticline south of Huff's Crossing it would appear that there was a rupture following compression of the rocks composing it and that along the plane of rupture there was differential movement and friction which occasioned more flexing than these massive rocks usually underwent and which brought about some overturning. So far as observed in the massive strata found overlying the slate formation in this immediate region, strong flexure does not appear to have been their mode of deformation, from which fact the inference is drawn that the structure just described was due to friction and of the nature of a drag rather than one that preceded and initiated the break.

At the grist mill falls the eastern and western walls of the gorge are apparently composed of massive beds lying rather flat, and like those which extend with some interruption westward and southwestward toward the lake, and which form a noticeable scarp along the road to Montcalm Landing. From general field relations and lithology most of these rocks are correlated with the Beekmantown, although their exact position therein could not be made out with certainty. From the discordance in structure in the walls of the gorge it seems most probable that the massive so-called Beekmantown rests unconformably upon the slate formation and that it also once overlay the fossiliferous rocks at the summit of the falls. The conditions did not permit a good photograph. The massive strata seem not to be so severely deformed as the similar rocks lying north of them and it is regarded as probable that an east-west break lies between. The interpretation of probable general structure is shown in figure 12, which does not attempt to show the probable normal faulting just mentioned.

The massive magnesian rocks that extend westerly from the grist mill, about a half mile west of the dam are interrupted along the road and in the fields by slates which in one outcrop showed westerly dip. The field relations indicate that these slates are surrounded by the dolomite and have been exposed by the erosion of the latter. Westward the road to Montcalm Landing descends over a scarp in the dolomite to the Champlain clays that extend to the lake shore. This scarp is on a meridian a mile west of that on which is located the axis of the anticline south of Huff's Crossing. The rocks composing this scarp are apparently in somewhat interrupted surface continuity with other magnesian rocks which form the slopes and summit of a hill about one mile south of it, the upper beds of which are yellowish or somewhat chamois-colored rocks and which grade downward into other rocks which could not be correlated with certainty on account of drift and few exposures, but which towards the base contain cherty dolomites like those of Mt. Independence.

Additional considerations concerning the general structure of the region. From the outcrops and relations just described for the areas inland from the lake and west of Orwell village it seems that further support and suggestions may be drawn as to the interpretations to be put upon the structure of the region along the lake.

1. The structural relations at the grist mill gorge, taken with the general procumbent position of the massive strata; the difference apparent in the metamorphism of the rocks which are now in contiguity; and the patch of slates lying west of the grist mill which is seemingly surrounded with massive magnesian limestone beds and has therefore the character of an erosion outlier, give further support to the idea that the Beekmantown strata, and possibly older rocks, now rest on the slate formation and probably some Trenton rocks included or in addition, along a thrust plane.

2. That the massive overriding strata, either during or prior to translation, were broken along a reverse strike fault and that a slight buckle occurred east of the fracture with some folding down of the edges of the beds along the western margin of the block that was pushed against the adjacent beds on the west; and that possibly some Chazy and possibly still younger beds were involved in the frictional drag along this reverse fault plane.

3. That there may have been some warping or faulting later that dropped the strata between the gorge and the scarp north of Huff's Crossing and left the intervening beds at a lower level than those on each side of these faults, or in the trough of the warp, and thus preserved beds higher than the Beekmantown at the present erosion surface.

4. That the various scarps in the dolomite formation stand primarily for the major thrust relation which this formation bears to the slates; and that some structural features secondary to the thrust favored the erosion of the Beekmantown between the detached masses of these rocks near the lake shore and their sinuous inland margin which is often marked by scarps.

5. That the massive character of the overthrust rocks prevented much heaping up by reverse faulting under the compression.

6. That the plane of major thrust is now and probably was originally one of low angle to the horizontal.

Areas north, east and south of Orwell village. The Beekmantown rocks forming the anticline south of Huff's Crossing were traced eastward by scattered outcrops across their strike to the old stage road to Shoreham village and in places fossils were noted on the weathered surfaces. These fossils appeared as *Maclurea-* or *Ophileta*-like scrolls with others that resembled cephalopods in the shape of the outlines and in the presence of septa. East of the stage road markings are less numerous and distinct and outcrops fewer on account of drift. On the basis of fossils and structure and also certain other exposures that will be described presently lying to the eastward, the beds over an east-west distance of a mile east of the road from Orwell village to Larrabee's Point are regarded as Beekmantown in age.

East of the road from Orwell village to Orwell depot, limestone outcrops are numerous and form a band a half mile wide resting against the western slope of Deignault Hill. *Maclurea magna* was found by the writer near the western edge of this band. East of the beds carrying this fossil the limestone shows abundant fossil markings on the weathered surfaces, but the rock is so altered that nothing distinct could be seen on fresh surfaces. At many places sections of shells both in the plane of the spiral and at right angles to the axis, strongly resemble *Pleurotomaria* and *Murchisonia*. A number of the more robust *Pleurotomaria*-like forms were abraded to the plane of the columella and left little doubt of their generic affinity. Spiral coils at right angles to the axis of the whorls were very common. Crinoid stems were frequent. From these characters the rock is regarded as probably of Trenton age. It bears closest lithological resemblance to other rock that will be described beyond in which still more characteristic fossils were found with those just described.

These limestone beds have a general north-northeast strike and seem to occur in somewhat undulating open folds. There is a prevailing easterly dip due to shearing deformation which has greatly obscured the stratification dip. At some places an apparent flattish position and at others a westerly dip of the bedding were observed.

The limestones just described are succeeded eastward at the surface by phyllites and schists on which they apparently rest, although no contact was seen. Along the road from Orwell village on the west slope of Deignault Hill outcrops of the phyllites intervene between others of limestone, but a short way beyond the eastern margin of the limestone is reached and may be followed in a north-northeasterly direction just west of the road running northerly at the top of the hill. The instance cited above was the only one noted northeast of Orwell village where the limestone has been eroded so as to expose a patch of the underlying phyllite. East of the limestone margin all is phyllite for a mile or more to the valley of the Lemon Fair River.

The limestones just described vary in degree of metamorphism along the strike and present certain interesting characters in their outcrops in proximity to the phyllite. Just east of the main village of Orwell, north of the road to Sudbury, the limestones are strongly sheared and are almost slates. Many surface exposures are "marbly" in appearance. Near the phyllite the limestone is frequently seamed with many veinlets of calcite, a feature which was observed at many places in this general region where the limestone and phyllite are close together in surface outcrops, or where there is good reason to think that the phyllite is only a short distance beneath the limestone.

The limestones northeast of Orwell village continue along the strike south and southwest of the village with prevailing easterly dip which is for the most part a shearing deformation structure purely. One-fourth of a mile south of the village distinct easterly stratification dip is apparent and the rock carries sections of *Murchisonia*-like forms. In general the rock south of the village as far as the old stage road resembles the Trenton at the north.

West of the road the limestone seems to be more metamorphosed generally, is strongly sheared and seamed with calcite in many places, and often takes on a "marbly" appearance. At one place a sort of flow-cleavage structure seemed to have been developed nearly parallel to the bedding and both apparently were subsequently folded. The fold is now cut by two sets of fracture planes.

South of Orwell village the limestones give place easterly at the surface to phyllites, schists and slates which are the southward continuation of those in Deignault Hill. These terrigenous rocks form the high hills in the southern-central part of the township around Sunset Lake and its neighboring ponds, and extend into Benson township at the south. Two miles south-southwest of Orwell village, just east of the Benson-Orwell road, begins a series of scarps, which increase in altitude southward and which mark a normal fault displacement. At numerous places in the hills east of these scarps are cliffs that are interpreted as fault scarps and some of the ponds rest in what are apparently primarily faulted basins.

About a mile north of the Benson line on the downthrow side of the great fault the limestones along the valley of East Creek give place at the surface to phyllites which extend westerly as shown on the map. Over the phyllite lying west of the fault and in the high hills east of it no limestone was discovered.

The wider surface exposure of the phyllite formation at the south in Orwell township is to be associated with its present higher altitude and conditions which favored the erosion of limestone that once overlay it; for the field relations east and south of this spur of high land show that limestone of similar age and character to that which in Orwell rests against or on the schist at the west lies on entirely similar phyllite east of the spur and indicate the former extension of the limestone over the phyllite now forming the spur.

Eastern Orwell township. A strip of country about a mile and a half wide in the eastern part of Orwell township presents many significant features. The northern part of this strip is now very largely buried by Champlain clays, but the southern part is hilly and affords many interesting outcrops which serve to bring out the general relations among the rock formations.

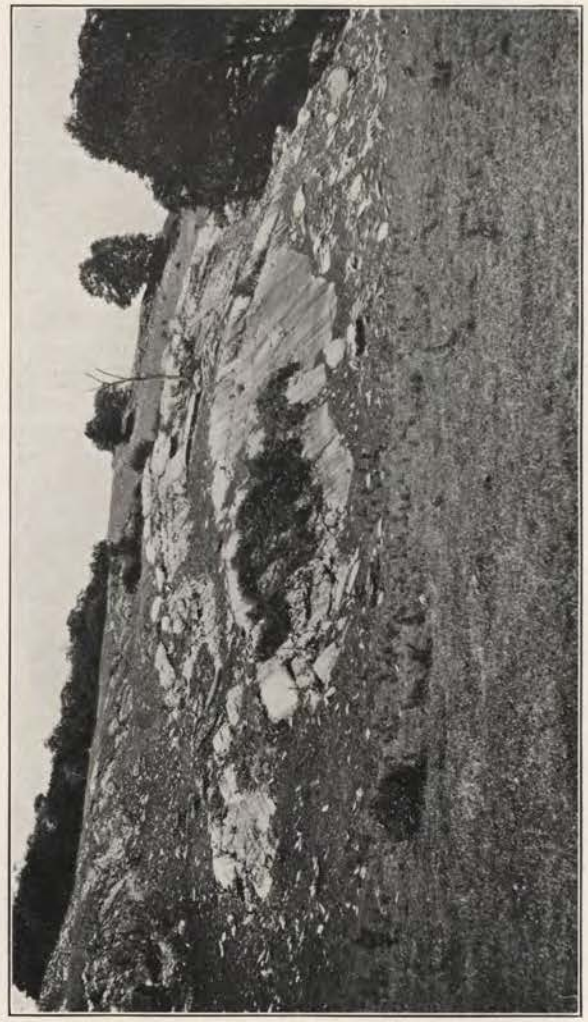
South of the Orwell-Sudbury road are two valleys separated by a low range of hills. Along the western valley extends the road from Abell corner to Bangall and Hortonville. The other valley is occupied by the head stream of Lemon Fair River and along its western margin is another road going also to Hortonville. Along these valleys and over the low range intervening between them the surface rock is largely limestone, which can be seen to have been much disturbed by folding and faulting and to have been severely sheared in most places. The prevailing rock is of a faded blue or gray color on weathered surfaces and dark blue or bluish-gray on fresh surfaces. So far as observed it does not often take on a "marbly" aspect south of the Orwell-Sudbury road. Fossils were found at many places in this limestone on the hills and in both valleys mentioned, chiefly on the weathered surface. They all have a similar aspect and consist of crinoid stems, scrolls representing shells of gastropods like those found northeast of Orwell village, sections in the planes of the axes of spirals resembling *Pleurotomaria* and *Murchisonia, Plectambonites, Orthis,* a doubtful streptelasmoid form, a small and a medium-sized *Orthoceras,* bryozoans like *Stictopora* and, on fresh surfaces, many specimens of *Trinucleus.* The most prolific localities were found on the adjoining farms of George W. Felton and Horton Farnum along a side hill just west of the eastern road mentioned above. Southeast and east of Farnum's, similar rock extends east of the road across the Lemon Fair valley and similar fossils were found at several places nearly to the Hyde Manor road.

For the most part the limestone just described, so far as the shearing structure permits observation, consists of beds of moderate thickness and in this and in general lithologic features as well, resembles the Trenton northeast of Orwell village and, in fact, also that along the lake near Neemes' camp. But it should be noted that metamorphism is clearly more pronounced in the areas east of the lake shore.

In Horton Farnum's pasture were seen some massive beds of limestone which from the field relations seemed to be inferior to the fossiliferous beds lying north and south of them. There was nothing seen to indicate whether the massive beds are of the same age as those surrounding them or older. See plate XXVI.

At various places along both valleys mentioned, on each side of both roads and within the low range of hills intervening, phyllite or quartzite emerges at the present surface from beneath the broken and eroded limestones. The map does not

PLATE XXVI.



A view to show fold in limestone on the farm of Horton Farnum in the valley of the Lemon Fair River in eastern Orwell. The view is towards the northwest. The fold is a north-south buckle with strong easterly pitch and the rock is sheared with easterly dip. The rocks in the fold shown did not yield fossils; but north and south in the fields many outcrops show markings of shells (see text), and excellent specimens of Trinucleus were obtained on fresh surfaces at several places.

attempt to show fully the fragmentary nature of these outcrops of terrigenous rocks. They appear sometimes as patches surrounded by limestone, sometimes as scarps along the strike on hill summits, sometimes but more rarely in sections across the strike in gulleys of erosion, and again as narrow bands, as though infaulted or infolded with the limestone. These terrigenous rocks are entirely similar to those of the Orwell hills and to those of the Sudbury hills lying to the eastward, and it was not possible to draw any distinctions among them on the basis of difference in age, or from their relations to the associated limestones.

North of the Orwell-Sudbury road the course of the Lemon Fair has been constrained and controlled in the process of the river's down-cutting by a few ledges which by the river's work and that of general erosion have been opened to view. Some of these ledges are of much interest.

Outcropping in the west bank of the Fair in the fields about one and a half miles north-northeast of Abell corner and exposed on the dip surface is the light blue limestone seen south of the Orwell-Sudbury road. In the east bank of the stream the beds are exposed along their edges and much of the rock is seen to be a strongly-sheared limestone having the character of a calcareous slate. Practically on the strike of these beds, a few rods north in the same bank and in a somewhat higher scarp, this sheared limestone takes on a "marbly" aspect and is infolded or infaulted with patches of chamois-colored, dolomitic rock. Near the base of the section light-colored, siliceous phyllites like those so frequent in the Orwell and Sudbury hills, and outcropping through the limestones lying between, emerge from beneath the marbly rocks and at one place a large solution hole has exposed the phyllite underlying the limestone. Northerly the sheared rock becomes still more "marbly" and lies above strongly-sheared, slaty limestone.

In this general vicinity the limestone or "marble" is filled with solution holes and channels along joints which give an impression that the limestone lies in disturbed relation to some stratum beneath.

The sheared "marble" extends through the fields eastward from the Fair for several rods and gives place at the surface to a sheared, light-blue rock like that noted on the west of the Fair. It is infolded with gray dolomite mentioned above.

The sheared blue rock and "marble" are thus seen apparently to pass into one another both along and across the strike in these exposures and apparently both have essentially the same relations to the gray or chamois-colored beds. The gray rock is also found south of the Orwell-Sudbury road, but its relations there are not impressive. Conditions similar to those just described for the rocks in the banks of the Fair and adjacent fields, north of the Sudbury road, prevail in the fields east and south and need not be cited in detail. It may be noted that entirely similar types and relations extend through detached exposures southeastward to the west slope of Sudbury Hill below the stage road.

The field relations of the blue limestone or "marble" to the gray dolomite suggests that the dolomite is not interbedded with the other, but that it is usually above it and distinct from it. The examination of some of the exposures in which the two are infolded, or infaulted, might give the impression that the two are interbedded members of the same formation.

For some reason the rocks north of the Orwell-Sudbury road have been more severely altered and fossils in them now seem to be lacking.

RUTLAND COUNTY.

Benson Township.

(Whitehall topographic sheet.)

Topography. Hubbardton River and its head streams have cut their valleys below the level of 300 feet among the hills in the eastern part of the town, and a strip along the lake shore in the northwestern part a mile wide and a mile and a half long marks a small extension of the Champlain lowland into this area. Elsewhere Benson topography is typical of the foothill country west of the Taconic range.

Description of a section from Lake Champlain through Benson village to Bangall, near Hortonville. Extending from Benson Landing for a distance of one and a half miles eastward along the road from the landing to Benson village the section gives siliceous and magnesian limestones of Brainerd and Seely's Beekmantown formation. The beds form a gentle arch and near the lake dip at a low angle to the west.

At Benson Landing the Beekmantown rocks as exposed do not reach the lake shore, but a mile north at Stony Point they dip into the lake. A few rods east of Benson Landing are exposed in a low west-facing cliff in a ravine south of the road about 15 feet of dark, bluish-gray, siliceous limestone or dolomite, weathering light gray, in beds about two feet thick which dip gently to the west. About 20 rods to the east of this outcrop is a somewhat higher cliff in the ravine showing from the base about two-thirds the way up, massive beds of somewhat pitted, magnesian limestone which on fresh surfaces is mottled light and dark gray. Above these beds are a few feet of limestone showing many ridges parallel with the bedding. The dip is gently westward. Above these rocks, in and beside the road and perhaps 20 feet higher stratigraphically, near the junction with the Stony Point road and in the yard of the William White place, are exposed with westerly dip bluish-gray limestones frequently covered with thick, reticulated, gray or reddish brown patches, which often show as shallow, ringed craterlets in relief which give the weathered surface a coarsely-pitted appearance. Among these pits and patches and also on the smoothly-weathered rock are scores of finely-coiled whorls of *Ophiletas* and some *Maclureas*. These fossiliferous beds are interstratified with layers of sandstone. Eastward about 200 yards along the road, dark, bluish-gray rock somewhat like that noted in the first cliff outcrops beside the road and a half mile east similar rock lies flat. Away from the lake the outcrops are few and mere patches in the drift. The precise sequence was therefore hard to determine; but it seemed clear that probably the fossiliferous rock represents the lowest subdivision of Brainerd and Seely's Division D, carrying *Ophileta complanata,* Vanuxem.

The magnesian limestones lying beneath the fossiliferous beds presumably represent Division C. All the rocks appear conformable, but the conditions do not permit minute comparison with similar rocks in the sections of Shoreham and Orwell.

Eastward along the road past the school house at Williamson corner and down the slope to a brook are occasional exposures which are not readily identified or correlated in their restricted outcrops.

South of the brook and the road are mud-colored slates which a few hundred feet eastward up the brook give place to bluish or dove-colored limestones intermingled with chamois-colored dolomite. The dove-colored rock carries dirty, yellowish patches and stripes often soiled to black and on its weathered surface at places afforded many small fragments of indeterminable fossils and two recognizable specimens of *Maclurea magna.* A reading gave the strike as N. 32° E. and the dip as 25° easterly.

East of these rocks a short distance, on the north side of the road, are limestones resembling the Trenton beds near Hortonville, which will be described presently. No fossils were found. East of these exposures, along the road, the rocks are slates, some of which are mud-colored, friable rocks like those mentioned above as occuring at the present surface farther west between probable Beekmantown and Chazy outcrops and which have what appears to be a distinguishable difference from most of the slates of the Benson hills. They have in fact a resemblance to certain slaty or shaly rocks which were noted farther north in Orwell, but which have not thus far been described in a special way. In some of the ravines tributary to East Creek in Orwell the friable shales did not appear precisely like the blacker so-called "Utica" and led to the suspicion that there is a series of beds in the formation that usually goes under the comprehensive name of "Utica" which is marked by less carbonaceous matter and whose members are of prevailingly different color. This idea seemed to receive some confirmation when mud-colored slates were found west of the grist mill on East Creek along the road to Montcalm Landing and therefore lying west of the black, compact Trenton limestone and associated black slates at the dam and in the gorge of the creek and again when similar slates were found on the meridian of those west of the grist mill two miles to the south along the road to the lake that passes through Frank Charleton's farm, and also a mile south of here on the hill east of the Nefong farm (old Walker place) and east of the road from the Nefong farm to Benson Landing.

The mud-colored slates along the road from Benson Landing to Benson village lie on the general meridian of the various exposures of similar slates just mentioned as occurring in Orwell and are now regarded by the writer as the same. Along the Benson road they give place at the surface to black slates which have been called "Benson Black Slates." An actual transition was not noted. Outcrops of the mud-colored, friable slates, however, occur close to those of the black slates; but after the latter begin, going eastward, there do not appear to be any more outcrops of the lighter-colored and more friable slates. A similar relation obtains at the north; in northern Benson township, on the downthrow side of the great scarp along the Benson-Orwell road, a blackish slate is present and westward across East Creek the other slates appear.

The black slates continue eastward through Benson village and east of the village are succeeded by outcrops of lighter-colored, siliceous phyllites like those that are intermingled with the black phyllites of the Orwell, Benson and Sudbury hills. The black slates are not exactly like any of the terrigenous rocks that the writer has seen among the hills just mentioned. They also appear different from the mud-colored slates or shales at the west, not only in color, but in the fact of greater metamorphism. On the strike or meridian of the black slates farther south in Benson at Forbes Hill, however, occur the light-colored, siliceous phyllites and grits so common at the east, but this is not conclusive of similar general age for them and the black slates; for it will be shown that the probability is that terrigenous rocks have been overthrust on other terrigenous rocks in western Vermont and it apparently cannot be affirmed whether the black slates are beneath or on top in the examination of a surface section of such an overthrust. It seems probable, however, that the mud-colored, friable shales are of different age from the phyllites at the east in Benson village and eastward, and that they may belong to the same general formation that contains the black, limy, fossiliferous slates along the lake shore in Orwell, and also some of the Trenton rocks. If this is so, then the map of Orwell which shows the slate of the Orwell hills extending west of the scarp along the Benson-Orwell road should differentiate among the slates west of the scarp and show some of

them in the character used to represent the "Utica," just as was done west of the grist mill farther north. On such an interpretation some of the slates would be part of the mass that has been overridden and therefore probably of different age from the other terrigenous rock. It is, however, not easy to show any sharply dividing line at the present surface.

Continuing the section eastward from Benson village, outcrops are lacking east of the direct road from Orwell to Fairhaven along the road to "Spoke Hollow" or "Howard Hill corner." Due north of this road in the high hills around and west of Sunset Lake in the northern part of the township are phyllites and quartzites which have been described at another place, and south of these hills, across the valleys of the head streams of Hubbardton River, are entirely similar rocks which will be briefly mentioned again beyond. Similar rocks are found on Howard Hill.

On the southeastern slope of Howard Hill are exposures of limestone bearing strong resemblance to rocks which a little way to the eastward and elsewhere carry Trenton fossils. A half mile east along the road through Bangall to Hortonville, on each side of the road just northeast of Hall's corner, are ledges of undoubted Chazy showing the lithological characters of this rock and affording good samples of *Strephochaetus* and several recognizable specimens of *Maclurea magna,* besides fragments of other fossils.

Eastward from these ledges of Chazy, about half a mile, near the standpipe of the Hortonia Power Company, greatly-sheared, blue limestone has been blasted for the big conduit running to the power house, and still further east between Babbitt's corner and Hortonville, north and south of the road, are ledges of faded blue limestone which give evidence of arrangement in undulating folds with easterly dip which is sometimes that of stratification and sometimes very apparently that of shearing in westward dipping beds. Fossils are numerous on the weathered surfaces and include many small spirals and numerous sections in the plane of the axes of the spire of *Murchisonia-* and *Pleurotomaria*-like gastropods. In its fossil contents and in its other characters the rock is like that which at the north and northeast along the valley of the Lemon Fair and north of Horton Pond carries numerous Trenton fossils.

Along the section just described it will be seen that at the present surface there is wide separation by terrigenous rocks of the calcareous rocks near the lake from those near Bangall, but that the latter practically join the limestones of the valley of the Lemon Fair, and actually do join the rocks in the valley along the road that leads from Bangall to Abell's corner. Around Hortonville the phyllite formation frequently outcrops through the limestone by erosion of the latter. The section does not reveal any

Beekmantown rocks away from the lake region at the present surface.

The field relations of the rocks just described indicate that the calcareous strata east and west of Benson village lie on a formation of terrigenous rocks. That these latter rocks are all of similar age seems improbable. The phyllites on which rest the Chazy-Trenton rocks near Hortonville are entirely similar to those of some of the Benson hills and those found in the hills of Orwell and Sudbury; but nearer the lake the Beekmantown-Chazy-(Trenton?) beds may rest in part on phyllites like those at the east and in part on very different slates. See figure 14.

Some observations south and southeast of Benson village. South by east of Benson village along the road from the village through O'Donnell corner, black and lighter-colored phyllites in the association that has been so frequently mentioned outcrop at several places. At O'Donnell corner they occur together in the same ledge in the exposures near the dam. These rocks continue eastward and form the hills east of the road from Howard Hill to Fairhaven. For two miles along the Benson-Fairhaven road, from the junction of the Howard Hill road with it, the hills at the east drop by a high, steep scarp to the plain of Hubbardton River. This scarp is the counterpart of those along the Benson-Orwell road north of Benson. It diminishes in height southward and the Fairhaven road ascends from the plain and crosses the hill to Fairhaven. Near the top of the rise, west of the road, are ledges of greatly-brecciated blue limestone. Fossils have been destroyed, but the rock is lithologically like the Trenton as observed at the north. The apparent dip is eastward.

West of these outcrops, along the road that goes over Forbes Hill to Benson village, and north of it, are other ledges clearly dipping easterly and composed of gray dolomitic beds and light-blue limestone. The blue limestone is much altered and sheared. One much-weathered specimen which was identified as *Maclurea magna* was found and there seems little doubt that the beds belong to the Chazy. Westward and between these outcrops and Hubbardton River there appear to be other ledges of Chazy, but at the time they were examined circumstances did not permit a prolonged study.

Across Hubbardton River, along the road up the east slope of the hill, are phyllites like those in the hills east of the Fairhaven road and believed to be the continuation of them beneath the limestone that intervenes and to have been exposed by the erosion of the limestone. They continue along the road over Forbes Hill for a mile and a half where the limestones appear in the fields to the west of them and then north of them along the road towards Benson village. The latter rocks give place two and a half miles south of Benson village to the phyllites again which continue along the road towards the village. Limestone

was also noted forming detached hills in the plain of Hubbardton River.

The exposures just described south of Benson village, by a somewhat circuitous route it is true, connect the limestones on the Hortonville meridian with those near the lake. They carry the Chazy-Trenton beds nearer the lake rather than the Beekmantown away from it.

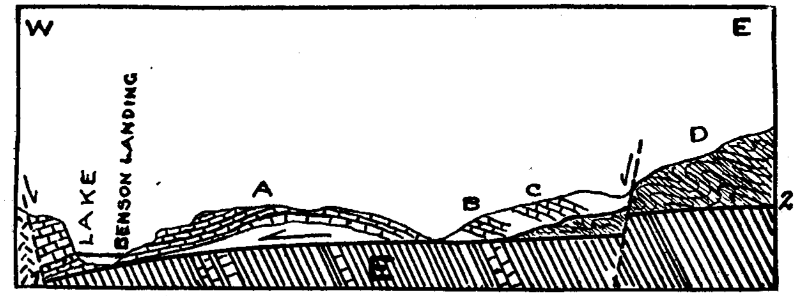


FIGURE 13. Writer's interpretation of relations east of Benson Landing. A, "Beekmantown," forming a low abraded anticline; B, Chazy, separated from A by a brook in which appear shales which are interpreted as exposures of the formations that have been overlapped by thrust; C, probably Trenton; D, black phyllite, probably Lower Cambrian, interpreted as unconformably subjacent to the Ordovician limestones. A thrust, 1-2, has cut through D and from it into the overlying limestones and all have been driven over E, Trenton-"Utica" slates. The rocks near the lake were subsequently dropped by normal faults as shown.

The field relations of all the exposures now described, though briefly, for Benson township indicate that the phyllite formation, as in Orwell, and as will be indicated presently as also in Sudbury and Brandon, once had a continuous covering of limestone strata which was either thrust or deposited upon it. There does not appear to be any essential difference in the terrigenous rocks over all this somewhat extensive area, except as indicated above for certain slates at the west. There seems to be no indication that the limestone appears from beneath the phyllite formation on account of folding and erosion or on account of thrust. On the contrary, the various areas of limestone are either purely erosion remnants, or thrust-erosion remnants, and whether outliers or inliers depends upon the age assigned to them and to the terrigenous formation on which they rest.

Short section north of Benson Landing. Before leaving the Benson area it seems desirable briefly to record some observations made north of Benson Landing.

One mile north of the landing, at Stony Point, siliceous limestone of arenaceous texture forms a cliff rising from the lake and lies nearly flat. Eastward from the shore surface deposits have covered the hard rock to a great extent, but through the sugar orchard east of Sibbald's cottage and eastward to the Chester Bishop place, are scattered ledges and the very gentle dip and rock exposures indicate the northward continuation of the rocks and structure east of the Landing. In the northern section within a distance of about a mile were seen at intervals going eastward small exposures in the following sequence: 1, at the water's edge a rather coarse, siliceous dolomite; 2, tough sandstone, carrying many fragments of fossils looking like trilobite fragments; 3, siliceous limestone with ridges on the weathered edges; 4, blue limestone "conglomerate" with irregular fragments of a hue slightly different from that of the matrix; 5, layer with numerous whorls on the weathered surface; 6, drab or buff-colored dolomites.

From this sequence, although outcrops were usually limited in number except at the east, it was concluded that this flat arch is composed largely of Brainerd and Seely's Division D, with possibly some of C at the west and some of E at the east where the dolomite strongly resembles that associated with the blue limestone of the Chazy. So far as observed the arch was not broken or eroded to expose any slates through it.

RUTLAND COUNTY.

Sudbury Township.

(Brandon topographic sheet.)

Topography. This township includes most of the spur of high land which forms the northern end of the Taconic range. On the west and northwest the spur is bounded by the valley of the Lemon Fair River, which is a southward extension of the Champlain lowland between the Taconic hills. On the east and northeast the spur is bounded by the low, swampy flood plain of Otter Creek, along which the Champlain lowland merges with the Vermont valley.

The spur falls off gradually in altitude northward into the low schist ridge of Whiting, which is flanked on the east and west by limestone. There are certain structural features both within the spur and along its margins which will be described in detail beyond.

General geological features. As one passes eastward from the lake region through the Taconic range towards the Green Mountains the confusion in field relations and the difficulty of interpretation increase. The field worker experiences the need of multiplicity of detail in critical relations in order to feel at all sure of his views of structure and even then it will happen that two persons will arrive at quite different conclusions with respect to the meaning of presumably critical relations or will stress quite different things as being of importance. It soon becomes apparent to the student of the metamorphosed and greatly deformed rocks lying east of the lake that the region must be viewed more or less as one grand unit in order to see into the meaning of its smallest part. Recognition of the direction of the road which one must travel to get anywhere perhaps will be conceded as an important step leading towards the destination.

North and south of Sudbury village. The sheared blue limestones and marble and associated gray dolomite in the valley of the Lemon Fair River in eastern Orwell township that have been described, continue into Sudbury township and give place eastward to the terrigenous rocks of the Sudbury hills, which are practically continuous northward with a low ridge of similar rocks extending northward into Whiting township and southward join with the entirely similar rocks of Hubbardton. The map shows connection across the ridge of the limestone of the Lemon Fair valley with that of Otter Creek. Whether one showed the area, which on the writer's map represents a surface connection of the limestones, as there shown, or as schist, would depend upon what outcrops were stressed, as will be seen presently; for it appears that schist lies beneath limestone in the area and also outcrops through it. It will be convenient to say that both are practically continuous, which, though literally impossible, when so stated conveys important ideas. The schists outcrop everywhere along the road from Webster's corner in Sudbury nearly to Whiting village, also westward nearly to Ketcham corner, where they appear on the meridan marked by the marbles and sheared limestones farther south. Eastward they extend one-third of a mile from Webster's corner along the road to Brandon and are then interrupted by the limestone for a short distance. At this interruption the limestone is really a calcareous slate as shown in pits along the road and in fields nearby and might be mistaken for the schist or phyllite formation if hastily examined. A little farther east the schist appears in the road, east of the school house, but is again bounded by the limestone north and south.

West of Sudbury Hill is an old road across the flats that runs from the village to Ketcham's corner. East and west of this old road are detached, knoll-like patches of limestone or "marble" with associated gray dolomite projecting through the clay of the old "lake" bottom and apparently to be regarded as practically continuous westward beneath the clay with the similar rocks described above as outcropping in the banks of the Lemon Fair; but whether continuous with or surrounded completely by limestone beneath the clay, or whether partly surrounded by schist, could not be determined for they are now simply islands in the clay. These exposures show varying proportions of either sheared blue limestone, or "marble," with gray dolomite. On the west side of the main Sudbury road, on the west slope of the hill below the village, the rock is often a whitish or salmon-pink sheared "marble" and this and the rocks in general along the old road mentioned are entirely similar to those which extend around the northern end of the schist spur and join with others at the east. Directly west of Sudbury church the sheared "marble" is overlain by a mass of thick, blocky, gray dolomite through which the marble peeks at places and the structure was made out as probably that of a local syncline of "marble" holding the superjacent dolomite.

South of the Sudbury church is sheared "marble" and associated dolomite and this association in general continues along the scarp slope east of the Hyde Manor road as far as Hyde Manor. South of the Manor the "marbly" rock gives place apparently along the strike to light blue limestones mostly sheared into slaty-looking rocks and these, except for an occasional tongue or patch of schist near the summit of the slope, and with obvious faults and flexures, are continuous with the sheared blue limestones, dovetailed with tongues of schist and carrying Trenton fossils, north of Horton Pond and extending westward across the upper valley of the Lemon Fair.

Directly east of Hyde Manor, along a brook that descends from the hill, the phyllite formation has been exposed by erosion of the limestone and is continuous eastward at the surface with that of Government Hill. South of the road from Hyde Manor over the hill to the Huff Pond road occur patches of limestone surrounded wholly or partly by schist and the latter outcrops through the limestone at the summit of the scarp slope just west as a gray, pyritiferous rock much like that seen in the valley of Sugar Hollow Brook east of Brandon in association with phyllites quite similar to those of the hill east of Hyde Manor.

An east-west section along a parallel about 300 rods north of Sudbury church gives sheared blue limestone just east of the stage road, which is succeeded eastward up the hill slope by phyllite, and this in turn by limestone. But along this section erosion has left few or no remnants of limestone on the higher slopes, and eastward over the hill for a mile and a half all is schist or quartzite.

At the northern end of the Sudbury spur, about a mile northeast of the church, is an instructive east-west section along which erosion has produced a mutually interrupted series of outcrops of limestone and schist, as now exposed, and which is indicative of what was probably once the condition over all the higher portion of the spur to the southward.

One and a fourth miles north of Sudbury church, in a gulley beside the main stage road, is sheared blue limestone. Eastward up the slope this is succeeded by schist which is the northward continuation of similar rock on the northwest slope of Government Hill where it is often intermingled with patches of quartzite. The schist forms a scarp which is topped by limestone. The scarp is regarded as the northward expression of normal displacements

on the west of Government Hill, of which the one east and north of Hyde Manor is the most clearly defined at the present time. The limestone topping the scarp just referred to is a slaty, sheared, blue rock in places and "marbly" in others. It is succeeded eastward by schist with contact concealed, but with the two rocks only 9 paces apart. Then a short distance eastward is the sheared blue limestone again with "marbly" aspect, then schist once more, then sheared blue limestone with some dolomite mixed with it, then schist, and once more sheared "marble" mixed with dolomite, then "marble" which joins at the present surface with extensive exposures of similar rock lying eastward and northward to the road. On the map the phyllite or schist is shown dove-tailing with the limestone along the section just described, but such arrangement is somewhat schematic. The implication is that the calcareous formation is superjacent to the terrigenous rocks as is the case in the areas lying to the west. This relation seems to be capable of reasonable proof by the means so far employed without paying much special attention to differences of dip and strike in the associated rocks. Many areas of the "marbly" rock at the east of the section just described are pinkish in color like that west of Sudbury church. Dolomite is intermingled with it at various places and it passes laterally into blue, sheared limestone.

East of the section just described, and east of the north-south road that joins the Brandon road ("Otter Creek road"), near the school house, are four large, conspicuous hills which are composed largely of sheared limestones and marbles, and all show, at some places more than at others, gray dolomite resting on the blue limestone or marble in patches and intermingled without any regularity.

It is reasonably apparent that the north end of this spur of the Taconic range in Sudbury now has metamorphosed limestones lying on the schist formation and that the latter has been exposed at many places by erosion of the limestone, while the limestone has been preserved from erosion at certain places by protection through folding or faulting. South of the section at the north end of the spur which was just described to demonstrate these relations, and to show that the conditions prevailing west of the Sudbury hills also occur in them, limestone has not been found by the writer within this spur in the township of Sudbury, except east of Hyde Manor along the lower faulted portion of the western slope of Government Hill, where the limestone which tops the considerable scarp east of the Manor extends easterly to the Huff Pond road.

The question of the age of the sheared, blue limestones and marbles on the western, northern and northeastern slopes of the Sudbury spur apparently cannot be readily affirmed from fossils, as most of these rocks are extensively altered. None was found in them by the writer. The question is complicated by the presence of disturbances, some of which seem fairly easily defined as to character, while others are very difficult to explain. There are, however, some considerations which serve to establish the identity of some of the limestone on the basis of probability.

The fossiliferous Trenton limestones in the southeastern part of Orwell township, as discussed above, pass eastward across the low, hilly land between the head stream of the Lemon Fair and Horton Pond and join at the present surface with the sheared blue and slaty limestones south of Hyde Manor, while these pass northward along the face of and on top of the scarp east of the Hyde Manor road through Sudbury village from which area, when traced northeastward, they join with the limestone exposures at the northern end of the Taconic spur and when traced northwestward they join with the sheared blue limestones and "marbles" in the valley of the Lemon Fair. The latter are to all appearances the northern continuation of the fossiliferous limestones to the south of them. Over this considerable area, therefore, these various rocks may seemingly be traced with unimportant surface interruptions into each other. Added to this is the important fact that at scores of places these various rocks have substantially the same relation to an underlying schist-phyllite formation, which is throughout essentially the same in its characters. Moreover, there is associated with all these various rocks a singularly similar gray dolomite which has held to a more uniform appearance in the different localities, for some reason or other, and which lies on the fossiliferous as well as the metamorphic rocks, although seemingly more abundant at the east. Further, the strong indications of normal displacement on the west of Sudbury Hill afford explanation of any apparent discontinuity at the present surface. The lithological differences among these calcareous rocks require explanation, especially on the assumption that the various rocks are essentially the same; such differences might be seized upon to show that the rocks could hardly be the same. But any effort to explain the differences may be postponed for the present.

Description of an irregular or composite section across the northern end of the Taconic range passing through Government Hill. The section begins for sake of completeness at the Hyde Manor road and extends to the eastern boundary of the township of Sudbury, across the schist formation.

At this point it will be convenient to call special attention to and to discuss briefly certain lithological differences shown by the members of the schist formation. Some of the terrigenous rocks making up this formation are distinctly schistose, but perhaps most of them are better called phyllites than schists because, though obviously altered, crystalline rocks and while generically speaking they are schists, they are prevailingly rather fine-grained

PLATE XXVII.

Trenton limestone beds, valley of the Lemon Fair in Orwell. Sudbury hills in the distance. The limestone beds in this photograph show a structure very characteristic of the calcareous rocks of the region and which has apparently been developed as a result of shearing strain. Here the dip of the induced structure is in the same direction as that of the beds; but in other cases this dip may appear in westward dipping beds. The dip of beds in surface sections is often hard to make out on account of this internal deformation.

and do not show their minerals conspicuously when viewed with the naked eye, except where they carry the large crystals of pyrite which have been mentioned, or other phenocrysts. In the older descriptions of these fine-grained, micaceous rocks they were called "hydromica schists." Many, perhaps most, of these phyllites are black and many are light-colored, fissile rocks, cleaving somewhat like slate, but more brittle and chipping into many small pieces. A coppery-colored stain is abundant in both, but usually more apparent on the lighter-colored variety. The pyrite seems to be much more characteristic of the black phyllites. It occurs, however, in some of the other terrigenous rocks of this formation.

True slates are not abundant at the present surface over the Sudbury hills, although they occur there and in the Orwell hills as well. They have not been found good enough to quarry profitably. Occasionally among these rocks there occurs a very black, carbonaceous phyllite, rich in small pyrite grains, and rather restricted in its lateral and horizontal extent. Quartzite is abundant, sometimes in scattered small patches, but at other places continuous at the surface, or practically so, over considerable areas. In a number of places white vein quartz in irregular seams and patches is abundant within the quartzite. Some of the black, pyritiferous phyllites, gritty schistose quartzites, and more compact or massive quartzites are indistinguishable from similar rocks found east of Brandon in the ridge west of Sugar Hollow and near the base of the margin of the plateau.

While there is thus often a manifest difference in general surface aspect of ledges in close proximity, both in color and lithology, after an examination of hundreds of outcrops over the Sudbury and Orwell hills and in other parts of the Taconic range, the writer has failed to find any positive criteria by which to separate one from another on the basis of age. The structural relations and other considerations seem to afford sufficient explanation of the variations seen at the present surface. In the high scarps on the west of the hills in Orwell and northern Benson, massive quartzite is interbedded with black phyllites and other rocks which could not be satisfactorily inspected on these precipitous scarps; but which together had an aspect very similar to that given by a surface section across the summits of the ranges lying east and similar to the association of phyllite and quartzite east of Brandon.

As may be mentioned again beyond there appears no good reason for regarding the phyllites along the low ridge that extends from Sudbury into Whiting as different from those in the Sudbury hills, although along the Sudbury-Whiting road the light-colored variety is rather in predominance. In a brook two miles northwest of Whiting village occurs the same quartzite with its nests of white vein quartz that is so conspicuous on Government Hill.

One-half mile north of Hyde Manor and east of the stage road is a scarp. The steepest portion of the face near the top is a sheared "marble." This continues over the summit and eastward is covered at places with the gray dolomite. The calcareous rocks extend from the scarp eastward for about one-third of a mile to the Huff Pond road. At the base of the scarp at places near Hyde Manor the dolomite has a position that might suggest an interbedded relation to the "marble," but as the superjacent position of the dolomite is more apparent the relations at the Manor are interpreted as due to faulting as shown in figure 14.

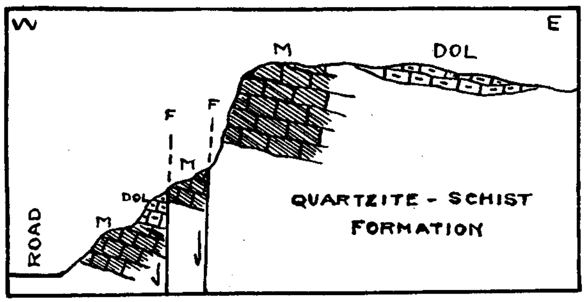


FIGURE 14. Section just north of Hyde Manor, somewhat generalized as to attitude of beds, showing gray dolomite as probably faulted with sheared limestone, which produces appearance of being interbedded. The calcareous rocks are shown as being underlain by the quartzite-schist formation of the Sudbury hills.

A little south of the section as just begun, along the cross-road from the Manor to the Huff Pond road, and also east of the main road from Sudbury village to the pond, on the western slope of Government Hill, are black phyllites with bedding unusually distinct and striking nearly east and west, N. about 70° E., and farther up the slope near the summit thick-bedded quartzite shows much disturbance from the prevailing strike of the rocks roundabout. A reading here gave N. 70° W.

The surface rock on the western slope of Government Hill is prevailingly a blackish phyllite, with some patches of quartzite, but the latter forms most of the ledges north and south along the summit of the hill, and in places carries much vein quartz in irregular seams and bunches.

Government Hill descends over quartzite by a gentle slope of irregular surface on the east about 150 feet through a distance of less than one-third of a mile. Then comes an ill-defined scarp, which does not appear on the topographic map, with the black phyllite at its base and quartzite forming the higher portion and summit. Eastward this hill descends over quartzite by irregular surface to a swamp with a sharp scarp facing west on the

east of the swamp and with the black phyllite at the base and quartzite again at the succeeding summit. Then another easterly slope to a swamp with another scarp, sharper if anything than those just mentioned and exhibiting similar geological relations.

East of the eastern slope of Government Hill, the section as thus far described, is either through a dense, swampy tangle or thick woods and very difficult to traverse, but while the ledges are much covered with decaying vegetation the succession can be made out.

At the east of the spur in the high hill north of Dolan's house, two-thirds of a mile north-northeast of Landon's corner, the quartzite seems thinner than farther west. This hill has a sharp scarp on the east which is clearly visible from the road running northerly from "Pond Hole" school house. Between the base of the scarp and the road are abundant ledges of the black phyllite with patches of quartzitic graywacke and some of the lighter-colored phyllite intermingled with it. The map shows the fault marked by the scarp just described. The schist has been dropped. North and south on the downthrow side it gives place at the surface to exposures of sheared blue limestone and dolomite. At the north the latter lie now in great confusion and in places near the schist are much mashed and broken. Eastward across the road and brook the phyllite is succeeded by sheared and foliated "marble," or blue limestone, and associated dolomite.

From the scarp just described a probable fault extends northwesterly between the phyllite and limestone towards the northern end of the Sudbury spur. This is marked by a scarp for some distance, with a swamp at its base. The limestones east of the north-south fault just mentioned are on a meridian occupied by "Long Swamp" at the north; while those north of the probable fault running northwesterly lie on the meridian of and are identical with those which have been described as forming the high hills northeast of the Sudbury spur.

From the facts now recited, of the occurrence east of Sudbury church along the strike of the sheared "marble" at Hyde Manor of black phyllite like that east of this marble at the base of Government Hill, and of the occurrence of similar phyllite along the strike of the "marble" west of Burr Pond and north of Horton Pond, and of field relations in Sudbury village and northeast of it, as well as at other places, it is apparent that the phyllite is, along the margins of the Sudbury hills, subjacent to limestones that can be rather satisfactorily traced into one another at the present surface and which present similar features and associations. And a field examination leaves a strong impression, almost no doubt, that the different members of the terrigenous formation are components of a formational unit.

Composite section from the phyllites of southern Orwell across the Taconic range to Otter Creek in Brandon. This section, like the preceding one, is a broad band or belt from west to east.

Beginning in the phyllite formation in southern Orwell, for sake of completeness, the section passes from these phyllites over a band of limestone, which is the northern extension of the Chazy-Trenton rocks of Bangall in Benson township, with some irregular outcroppings of phyllite through the limestone, then over phyllites which are the northern extension of those in Hortonville, then over a succession of limestone and phyllite bands dovetailed in with each other, the limestones carrying probable Trenton fossils, to the phyllites west and north of Burr Pond. The black and associated light-colored phyllites forming the hill north-northwest of Burr Pond are succeeded eastward at the eastern base of the hill by massive quartzite with prominent ledges just east of the brook that feeds Burr Pond, between the brook and the road. Across the road is a softened scarp, facing west, then for a mile schists with patches of quartzite to another scarp that faces east and at the base of which is the sheared, blue limestone extending south of "Pond Hole." This scarp is the southward continuation of that which was described in the preceding section as bounding the phyllite and quartzite formation on the east. The fault which this scarp marks can be followed southward with diminished scarp and passes just east of High Pond, about two miles south of "Pond Hole." The map does not attempt to show a number of scarps, which presumably mark fault lines through these hills, because the writer wished to avoid a prejudicial impression which often comes from seeing many such features represented on a map whose area is so small in comparison with that of the actual territory pictured. An examination of the region would be sufficient to show how much these rocks have been disturbed and the extent to which their present surface succession and arrangement may be explained by disturbance.

Taking up the description at a point one-fourth of a mile north of High Pond, along the fault line just mentioned as extending south of "Pond Hole," the section eastward is over black phyllites on the west slope of the hill called "Stiles Mountain"[1] on the map, then over massive quartzite in prominent ledges through the woods along the east slope to the road, then across the road and on phyllites and quartzites over a succession of steep, scarp-like slopes facing west and gentle ones facing east, including those of Stiles Mountain proper, for a mile and a half to an old wood road. East of this road on the west of Castle Mountain is a very steep scarp at whose base a brook runs northerly. In the bed of this brook, perhaps 100 rods from its junction with another brook, massive quartzite rests on black phyllite on the downthrow side of the fault, which is marked by the scarp under which the brook flows. The west scarp of Castle Mountain ascends over phyllites, which are succeeded at the summit and down the eastern slope of the mountain by phyllites and quartzite. Midway down the eastern slope are patches of gray, siliceous dolomite of arenaceous texture. The phyllites with quartzite continue to the base of the hill and are succeeded eastward at the edge of the valley by marble and blue limestone with associated gray dolomite. Along the section just described the light-colored phyllites are frequent at more or less regular intervals, but without any defined order.

[1] The name Stiles Mountain, according to the residents, really belongs to the second high hill east of this one.

Over the high hills along the southern boundary of Sudbury, from Horton Pond to the valley of Otter Creek, which were surveyed with care, no limestone was found by the writer except the siliceous dolomite mentioned as occurring in patches on the eastern slope of Castle Mountain. Further evidence that the limestone once rested on the terrigenous rocks is however obtained from relations shown along the valley of the brook that flows east in the hollow north of Stiles Mountain (proper) and Castle Mountain to join Otter Creek. Along this valley, as shown on the map, and separated by the phyllites and quartzites from the limestones of the valley of Otter Creek, and surrounded by the terrigenous rocks, are patches of sheared, bluish marble. The valley of the brook is presumably a small, east-west trough-faulted basin separating the hills north and south of it, and the limestone has been dropped between them.

The road from Bressee Mill to Brandon, a half mile south of the Dean farm, skirts the eastern base of a scarp in greatly sheared and contorted marble, which at the top of the scarp rests on quartzitic schist, while south of this scarp on both sides of the road to Bressee Mill are ledges of massive quartzite. There is a scarp running west-northwest from the road south of Dean's place and which extends from the edge of the Otter Creek valley to the embayment which is shown on the map as bounded rather symmetrically by fault displacements. This scarp probably marks a normal displacement and, although phyllite occurs on the downthrow side, it substantially separates limestone on the north from the terrigenous rocks of the hills.

The embayment mentioned, in which the limestone now extends southward at the surface between higher masses of phyllite, is bounded at the south by another scarp along the high tension line of the Hortonia Power Company, just north of which is a considerable swamp. South of these faults as just described as bounding the phyllite hills on the north, the limestone has been eroded on the upthrow side, except as shown on the map. North of them the limestone has been preserved, as shown, by downfaulting. On the northeast the Taconic hills are thus separated from the low land west of Otter Creek by well-marked normal fault displacements.

RUTLAND COUNTY.

Brandon Township.

(Brandon topographic sheet.)

Topography. The short spur of the Taconic range which includes "Stiles Mountain" and "Castle Mountain," whose geology was described under Sudbury, really belongs in Brandon township. Bordering this spur on the east is the low, level flood-plain of Otter Creek which extends into the northwestern part of the township and there is largely occupied by extensive, wooded swamps.

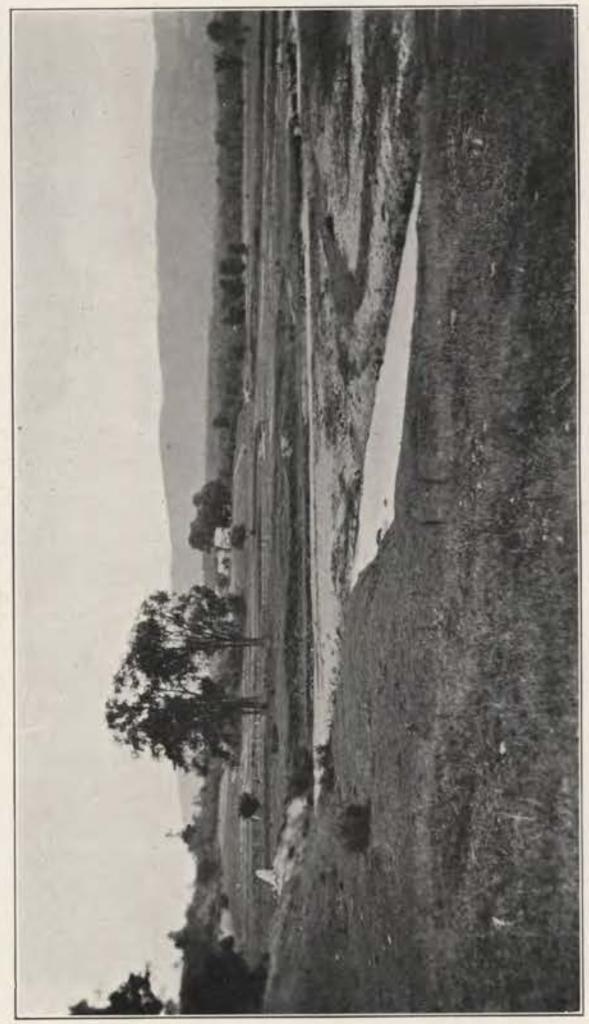
Except for a short distance near Brandon the Rutland R. R. follows the eastern margin of the plain. At various places ledges emerge from the plain as detached knolls, some of which are of considerable size; but for the most part along the creek the hard rock is hidden.

Along the eastern edge of the plain are low hills which offer nearly continuous exposures. On the whole the land rises eastward to form a somewhat rolling upland which, with some interruptions due to ancient dissection of the rock surface, passes into the foothills of the Green Mountain plateau. The Neshobe River and other streams have in recent times terraced an old sand plain that marks a period of glacial flooding or a submergence of the old rock valleys among the hills east of Brandon village. East of these streams the land rises more rapidly to the western edge of the plateau, but east of Brandon a ridge of intermediate elevation is separated from the steep scarps that border the plateau by the valley of Sugar Hollow Brook. In general, however, a strip of hilly and mountainous land about two miles wide extends in a north-south direction through the eastern part of the township.

General geological features. In Brandon township many of the rocks are marked and masked by still greater metamorphism than that shown by the rocks of Sudbury. But this feature is not true of all. In this township appears a series of beds that has not been identified in Sudbury and is the northern continuation of the "interbedded series" of the Lower Cambrian that will be discussed in connection with different parts of the Vermont valley at the south. In their well-preserved, bedded character and in other ways these rocks are in contrast to most of the other calcareous rocks of the Brandon area, which, as exposed both at the surface and in the quarries, give evidence of great dynamic stresses in the flow structures which they exhibit and in the obvious crushing and crystallization which they have undergone.

With the terrigenous rocks in many cases there does not appear to be distinguishable difference between those in the Sudbury-Orwell hills and similar types lying east of Brandon village;

PLATE XXVIII.



Terraces cut by Neshobe River west of Forestdale, near Brandon, in probable delta deposits, made either in a glacial lake or in an inland extension of the sea. These deposits now extend southward and westward through Brandon in rock valleys among hills composed of marbles and overlying interbedded members of the Lower Cambrian series of the region. The meander in the foreground exposes (not visible in plate) and is controlled by the beds of dolomite and quartzite which lie beneath those shown in plate XXXI. Green Mountain plateau in the distance.

but in the scarps of the western edge of the plateau and at other places along its edge, quartzite and arkose have sometimes been sheared into more or less foliated rocks.

General relations west of Brandon village. The sheared "marbly" rocks and sheared blue limestone with associated gray dolomite which compose the conspicuous hills in the northeastern part of Sudbury township in some cases lie in faulted position against the rocks that underlie the plain of Otter Creek, along which a surface area two miles wide with few exposures, separates the rocks on the west from those on the east of the creek, although there are a few detached outcrops, or islands, which serve in a measure to bridge the gap. The easternmost of these islands is at the southern extremity of "Long Swamp" and lies on the meridian which farther north marks the western edge of practically continuous surface exposures northwest of Brandon, which edge is two miles east of the meridian along which lie the conspicuous hills of Sudbury township mentioned above.

South of "Long Swamp" and north of the fault at the northern end of the Taconic hills which lie southwest of Brandon village, a continuous surface section from west to east spans the distance between the two meridians and joins fairly closely with other exposures which carry the limestones to the meridian of Brandon village, while farther south detached exposures, similar to those at the north, outcrop in the plain of Otter Creek, which owing to the course of the creek is here two miles or more east of the plain in the northwestern part of the township, and carry the section in limestone to a meridian which passes a mile east of Brandon village.

The above-described relations may assist somewhat in understanding the geological features around Brandon village.

The calcareous rocks of the islands along the plain of Otter Creek and along the continuous east-west exposure south of "Long Swamp," except some rocks which will be mentioned later, are entirely similar to those which have been described for the northern end of the Taconic spur in Sudbury. Making due allowance for such disturbances as these rocks have experienced since their present general relation to the phyllite formation had been established, it has seemed possible to trace rather satisfactorily the counterparts of the fossiliferous beds on the west side of the Taconic spur around its northern end into the Brandon area. Two considerations seem especially to warrant the propriety of such procedure:

1. The invariable occurrence of a similar association of gray dolomite with marble or blue limestone in all fairly extensive exposures.

2. The fact that if we view the transition area from Sudbury into Brandon broadly, that is, so as to include an east-west section as wide as the township of Brandon is long from north

to south, we have rocks on the eastern side of the Taconic spur having the same relation to the terrigenous formation as that which obtains on the western side and at the northern end, and not to be disguised by any faulting which has occurred on the east.

The latter consideration seems to give further indication that the same terrigenous formation that composes the Taconic spur is present at depth beneath the marbles and their associated dolomite beds of the Champlain lowland around Brandon village. On such an assumption it becomes easy to account for the similarity of the terrigenous rocks east of Brandon to those of the Taconic spur and to support certain ideas of the down-faulted character of the Vermont valley around Brandon and in other places which will be offered later. If such an assumption should prove plausible it must have far reaching significance in the interpretation of the structure of the region.

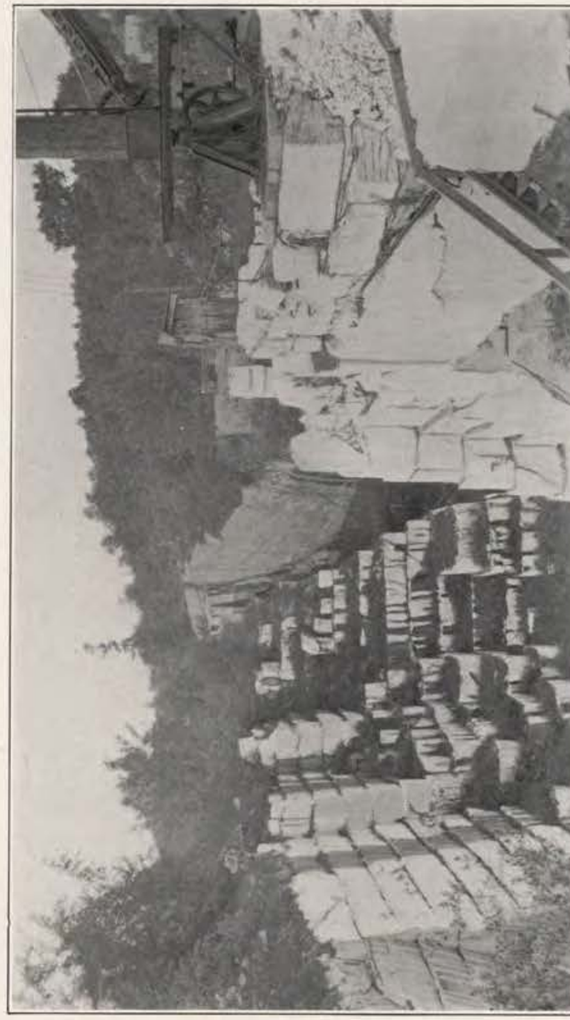
The gray dolomite which has so frequently been mentioned as occurring in association with the sheared blue limestone or the marble rocks west of Brandon seems to be quite distinct from any member of the interbedded series which, as will be described later, consists of interbedded dolomitic limestones, calcareous quartzites, and quartzites, and perhaps other dolomite not strictly interbedded, like those occurring throughout the Vermont valley; and this distinction holds even in those places where the interbedded series also is now clearly present above the marble.

In the Brandon area there are exposures in which this gray dolomite is associated with a dove-colored rock, which is striped precisely like the Chazy rock seen at Bangall in Benson township, where it carries well-defined, probably middle, Chazy fossils, and like that seen west of Bennington in southern Shaftsbury, and elsewhere. One of the places near Brandon where this striped rock may be seen to good advantage is one and a half miles north of the village, about 300 rods west of the old race course. The rock here is so greatly altered that all traces of organic remains have been obliterated and do not appear with any definite characters even in weathered outcrops. The stratum showing this association continues southward to the angle of the roads and across the west road. It also occurs a mile south, west of the village, north of the "Otter Creek road," and at other places west of the village.

This association had also been noted at places in Sudbury, and at other places less distinctly in the Brandon area; but what now seems its probable significance was not grasped until the examination of the Brandon area was well under way and until the Brandon region had been reviewed in the light of relations which are shown at the west.

If this association of dove-colored rock and gray dolomite is the Chazy, as now seems to the writer likely, it appears to be

PLATE XXIX.



View of the "Brandon Italian Marble" quarry one-half mile south of Brandon village, showing in the east face of the quarry the smooth and rounded surface of an included mass of dolomitic limestone.

significant that it so often lies apparently on the marble, or above the sheared blue limestone, as the case may be. In the vicinity of Brandon, except where the interbedded series of dolomite and quartzite has overlapped it, the dove-colored rock and its dolomite roughly alternate across the strike with the marble, with the result that each of these strata forms an indistinct band or "vein" running somewhat parallel with the other north and south. A greater width of the marble "veins" is now seen along the meridians where this rock is quarried.

The marble bands are not, however, homogeneous in their composition. Every quarry of any size in this area shows some dolomite, either on top of the marble or as infolded blocks or other involved fragments in the quarry rock. Where these dolomitic or "flinty" masses are discovered in the course of quarrying they usually halt the work at that point and drive the quarrying in a new direction. In Huntley's quarry at Leicester Junction, where the rock is burned for lime, pink marble just like that northeast of the Sudbury spur has sheared each side of a huge block of dolomite which shows in the north and south faces of the quarry. This dolomite is often a drab-colored rock and frequently occurs in close association with interbedded dolomites and quartzites. In the quarries generally all bedded structure is greatly obscured or obliterated and profound dynamic effects, such as mashing, flowage and crystallization, are everywhere manifest.

The explanation of the relations of the gray dolomite and its associated dove-colored rock to the marble around Brandon seemingly must account for the present apparent superposition of the former in so many places on the assumption that the former is Chazy and the latter probably Trenton. The agency of reverse faulting or thrusting at once comes to mind. The effect of such deformation would be to elevate the Chazy against the younger rock and carry the former over the latter. If this deformational process was repeated at intervals across what is now the general line of strike of these rocks the immediate effect would be to ease the stress, at least for a time, which was felt by the mass of rocks in which these ruptures occurred and to heap the rocks by piling some on others. Account must be taken of the possible former presence of other limestone strata beneath what is called "Chazy" and also of strata above what is called "Trenton" at the time of this postulated faulting. The rough regularity of the relations between the two strata, as now exposed, might be accounted for on the basis of certain primary structural relations which the mass of which they were a part had to the stress sustained by it.

Certain assumptions have clearly been made as the premises for the considerations just offered; but it will be remembered that effort was made to give a foundation of probability to the ages of the rocks in the Brandon area which have been discussed by tracing the less altered rocks at the west into them through more or less continuous surface exposures and by careful lithological correlation and by general field relations.

The greater metamorphism of the rocks at the east in Brandon might be explained as due to several factors. These rocks might have been involved in primary, or at least antecedent, relations different from those at the west at the time they came under kinetic stresses; or they might have been subjected to continued or repeated compression after new conditions, such as a loading due to overthrusting, had been imposed; or they might be thought of as having been involved in the zone of most severe crushing in the region. These rocks at the east give evidence of having sustained pressure under confinement, whether this condition was a special one present only at the east when the rocks at the west were sheared into their present condition, or whether it was a condition antecedent or subsequent to the operation of those stresses which sheared the rocks at the west.

The deformational structure of the limestones west of Brandon, as far east at least as the present western margin of the "interbedded series," is that of shearing chiefly. This shearing seems to increase eastward towards the areas in which the rock has taken on the characters which are shown by the marble of the Otter Creek valley. It is practically along the meridian on which falls the present eroded western margin of the "interbedded series" west of Brandon village that the commercial marble runs out westward at the surface southwest of Brandon, and even the quarries, including the "old Goodell quarry," opened at this western limit south of the "Long Swamp road," one-fourth of a mile east of M. F. Phillip's house, were soon abandoned. One of these quarries shows very well the gray dolomite folded as a small patch with the dove-colored rock and both of these driven as one mass over the marble. The latter shows its bedded structure much more distinctly than does the more severely crushed rock farther east, which is a feature that falls in line with other characters to mark a transition zone between the rocks at the west and those of Otter Creek valley. South of the "Long Swamp road," between it and M. F. Phillip's place and about one-fourth of a mile southeast of Martin Ketcham's place, is a cliff in the limestone facing north. In the face of the cliff great irregular blocks of limestone rest against others along irregular contacts and where two come together, big chunks fall away, while the rock is broken throughout into small, irregularly shaped pieces, usually with good faces, but with much irregularity of shape, and the whole mass indicates beyond a doubt that it has been greatly crushed and brecciated, but apparently not under the same degree of confinement as the marble and other rocks farther east. The surface exposures roundabout, particularly to the southward, show intermingled dove-colored rock and its gray or chamois-colored associate, with occasional patches of marble. Each is deformed by shearing, a feature which the dolomite shows least, and all are much disturbed and involved with each other.

A number of considerations make it appear that there is a progressively increasing metamorphism from west to east in the calcareous rocks in passing from Sudbury into Brandon; but whether the relatively moderate shearing shown by the rocks at the west was a structure antecedent in the rocks at the east to the greater deformation now shown by them, or whether the two are different expressions of stresses acting at the same time but under different conditions is a question involving other considerations. In general it appears that all the various calcareous rocks which have just been described, were obliged to accommodate stresses by some molecular adjustment as well as by movement *en masse;* but accommodation by mashing and flowage differed at different places and was much more pronounced at the east, in those rocks which presumably are represented at the west by the blue limestones and their associated dolomites and dove-colored rocks.

On the assumption that these various calcareous rocks just mentioned are in general equivalent over wide areas and rest on essentially the same terrigenous formation throughout—an assumption that seems to the writer to have gained a considerable degree of probability—the thoughts arise as to how this relation came to be established and as to what is the age of the terrigenous rocks. Some of the latter have been called Ordovician and some of them Cambrian; but a field examination will show that it is hardly possible to separate them as belonging to different terranes on the basis of the lithological features of the rocks themselves, although certain types easily impress one as being of Cambrian age from a likeness to those which have been assumed with considerable positiveness to be Cambrian and the same might be claimed for other types with respect to their inclusion in the Ordovician. Whether we call them Cambrian or Ordovician, or both, the problem remains of accounting for the calcareous rocks above them, and the postulates which are formulated to explain the present relations will differ in the large for the different cases.

It was about at this point in the writer's studies that the need of certain more definite working hypotheses which could be further tested in the field appeared. Certain similarities in field relations insisted upon recognition; the terrigenous rocks called for a more definite status concerning possible or impossible division and for a more definite assignment as to age; and the accumulated evidence for the action of powerful compressive stresses throughout a wide region and for clearly-defined thrusting in certain parts of that region made it necessary to ponder as to the extent to which thrust movements were involved in the entire region's history.

The following are examples of some of the questions which came to mind:

1. Is there any evidence to show that the calcareous or the terrigenous rocks which have been described were first broken and heaped up by repeated reverse faulting and then carried westward as a mass over other rocks along a low-angle thrust plane so that they now rest by thrust unconformity on other rocks? In this connection what emphasis is to be put upon the apparent present contact surfaces of the calcareous rocks and the terrigenous formation on which they rest or the contact surfaces where the conditions are reversed and terrigenous rocks rest on limestone?

2. Is there any evidence to show that while the calcareous rocks have been disturbed in position their superjacent relation to the terrigenous formation was primarily due to normal marine overlap on a floor of eroded older rocks?

3. What explanation is to be offered for the apparent absence of middle and later Cambrian in the general region?

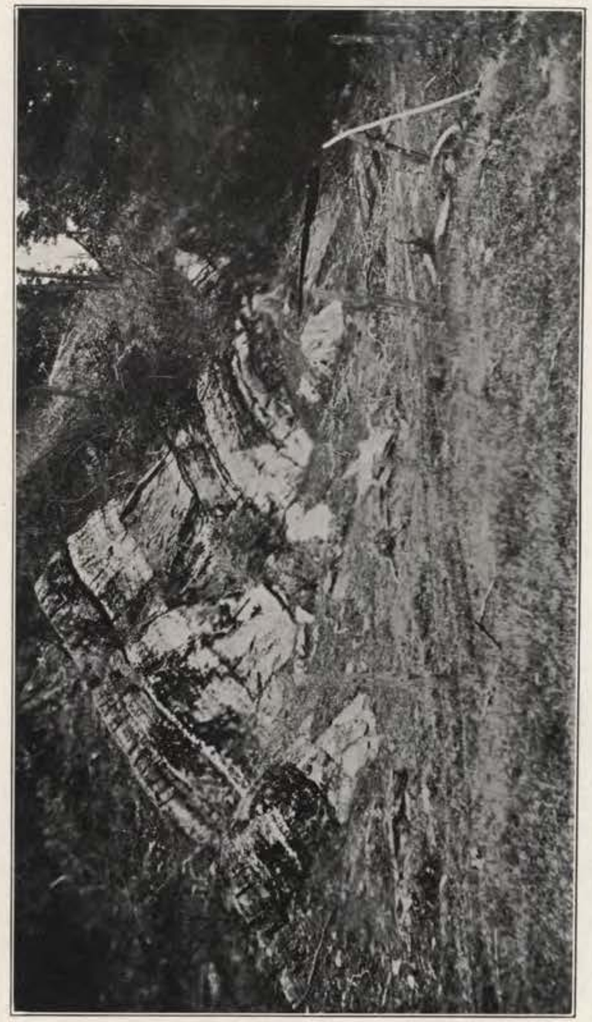
4. Is it likely that the Beekmantown as known near the lake is now present at depth or at the surface around Brandon and in the Vermont valley or the "slate belt"? Is it likely that it was ever deposited at the east and is there any evidence on this point?

These questions and others grew out of a study of the field relations in western Vermont and the possible answers to them are part of the problems of the region. They will have to be considered again.

The "interbedded series" of dolomitic limestones and quartzites in Brandon. This series is present in great force in Brandon township, north, east and south of Brandon village. In contrast with the marble and for the most part with the dove-colored rock and its associated gray or chamois-colored dolomite, the bedded structure of this series is well preserved in Brandon, in which feature it resembles other exposures of the series in the Vermont valley. The field relations at Brandon perhaps indicate its age less decisively than at other places, as at Bennington, for example; but the resemblance of the series to the entirely similar rocks at Bennington leaves no doubt of the similar age of the two and little doubt of the Lower Cambrian age of the series.

In the Bennington region a certain thickness of dolomitic limestone intervenes between the quartzite and the interbedded series. In Brandon neither the quartzite nor the dolomite are in the same simple relations to the interbedded series. In some places a dolomite is associated with the marble, as alluded to above, and this rock does not appear to have the characters of

PLATE XXX.



Interbedded dolomites and quartzites of probable Lower Cambrian age on the limb of a fold dipping westerly. These rocks lie a mile west of Forestdale village and near the west bank of Neshobe River. The photograph illustrates well the general appearance of the interbedded series in Brandon. The contrast with the marble of the region is made clear by comparing this plate with any of those showing the marble.

the striped rock that has been described or those of the gray rock associated with it. The dolomite referred to may be seen at most of the quarries around Brandon lying on or in the marble. It often separates the marble from overlying, interbedded dolomites and quartzites. As first studied by the writer it seemed to him to be a part of the Lower Cambrian series, but the field relations are much involved and not conclusive on this point. The probability of its inclusion with the Lower Cambrian would seem to depend to some extent upon the interpretation put upon the present structure of the rocks of which it is a part.

In a few places members of the interbedded series seem to lie directly on the marble. Such relation was noted in the field just west of the old Goodell quarry in Brandon along the old stage road to Leicester and Salisbury, where stringers of quartzite, irregularly disposed along the strike lie directly on marble. In places this quartzite thins out to nothing along the strike and at others widens out beyond any probable thickness of any of the quartzite beds of the series. These stringers look in fact like eroded remnants of members of the series which lay in a rather flattish position upon the marble. East of the road a few feet of dolomite lie on the marble in the old Goodell quarry and above it is the interbedded series again. A few rods west of the exposures showing the quartzite stringers is a ridge composed of the gray dolomite and the dove-colored limestone on which no recognized traces of the interbedded series is now present. Northwest of this ridge, across the road, are outcropping ledges of a band of marble which is succeeded westward by another ridge at the south end of which, in the open pasture just east of the back road to Morgan's Stock Farm, is an abraded anticline of what is interpreted as the interbedded series. The western limb descends across the back road to the plain of Otter Creek. Traced northward along the axis of the fold the interbedded rocks give place to the gray dolomites and associated dove-colored rock, but farther north on the northern side of a crossroad appear various eroded exposures of what appears to be the dolomite-quartzite interbedded series. The relations as thus described show the marble and its associated gray dolomite and limestone to be overlain by an eroded mass of the interbedded dolomites and quartzites northwest of Brandon village.

After an examination of the rocks in Orwell these relations were reviewed. While the interbedded rocks northwest of Brandon bear some resemblance to members of the Beekmantown west of Orwell village, they do not seem to be sufficiently like them to change the writer's earlier assignment of them to the Lower Cambrian. Moreover, they showed no traces of fossils. They have some differences at places from the interbedded rocks east of Brandon village, which seem, however, to be due to a shearing more nearly parallel to the bedding. Rocks like those just described as probably Lower Cambrian also occur just north of the Rutland R. R. track, and two miles south an "island" in the plain of Otter Creek shows these rocks prominently exposed again on precisely the same meridian as those at the north, and farther south, still on the same meridian, northwest and west of the Seager farm, they outcrop again. They may thus be traced north and south through a distance of about three miles.

In places at the north, near the axis of the fold, there is pronounced shearing structure developed across the bedding, but at other places along the axis where the beds lie more nearly flat and along the slopes of the western limb of the fold, shearing seems to be more nearly with the bedding, producing thin, sheeted structure, and at many places these thin sheets are distinctly crinkled. Stringers and patches of salmon-yellow calcite mixed with quartz occur abundantly over the eroded exposures of these thinly-sheared beds.

Northeast, east and southeast of Brandon village, west of the road from Forestdale to Pittsford, the interbedded series is disposed in regular and irregular folds, often closely compressed, frequently overturned, and ruptured at many places along the strike, and probably also across it. A rupture along the strike may frequently be seen passing into a fold. Over these parts of the Brandon area the marble is wholly covered by these interbedded rocks, which are generally marked by higher altitude and greater thickness than elsewhere near Brandon.

Some of the ruptures in the series, just referred to, seem clearly to be reverse faults, which are best shown at those places where members of the series stand on edge, or are inclined at high angle with easterly dip, while contiguous members at the west dip at a moderate angle to the westward. One of these localities is a mile east of Brandon village, at Cheney corner. See section, figure 15.

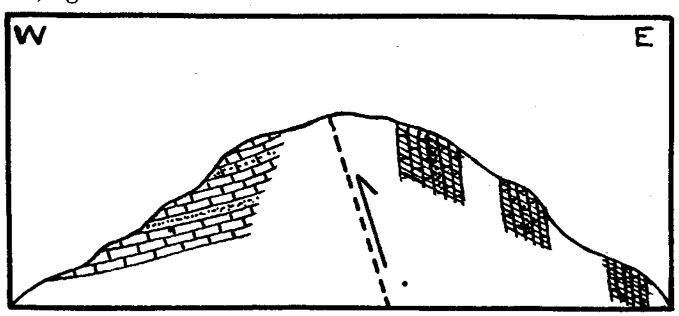


FIGURE 15. Structure shown by members of the interbedded dolomites and quartzites east of Brandon village, near Cheney corner; close folding and reverse faulting.

East of the Forestdale-Pittsford road. The interbedded series as described for the area east of Brandon village is succeeded on the east by terraced sand plains of old delta deposits and east of the Forestdale-Pittsford road by heavy bowlder drift which conceal outcrops. The heavy drift forms the lower western slopes of a series of high, ridge-like hills which begin in Forestdale and extend southward through Coxe Mountain in Pittsford. This range of hills is separated throughout most of its length from the steep, scarped slopes of the Green Mountain plateau by the valley of Sugar Hollow Brook.

The exposures in these hills from Forestdale southward present many features for comparison with the rocks forming the Sudbury and Orwell hills of the Taconic range. It is possible to identify some of the types in these foothills of the plateau with characteristic ones of the range. In the eastern hills there occurs a dolomitic limestone in association with the quartzite and phyllite which is now apparently wholly absent in the Taconic hills of southwestern Brandon, Sudbury and Orwell, except for some doubtful rocks on the eastern slope of Castle Mountain which have been mentioned.

Southeast of Forestdale are ledges of massive, brown quartzite which are separated at the present surface by a space of nearly a mile from the most eastern exposures of the interbedded series east of the village. Four miles to the south, however, the interbedded rocks are separated by only one-fourth of a mile from the drift slope of the range of quartzite hills. Southeast of Forestdale, back in the woods, is a considerable scarp and west of it, in the open fields just outside the village, is a succession of smaller scarps dropping off westward. West of the second of these dolomitic limestone apparently rests on the quartzite, but elsewhere in the vicinity the dolomite was not seen. Due north of these ledges, along their strike, on the road to Goshen, just east of Forestdale, are ledges of black phyllite and quartzitic schist entirely similar to those seen in Sudbury and Orwell and also at other places in this eastern range that will presently be mentioned.

Going southeast from Forestdale, ledges of quartzite are numerous at many places and it is possible to trace this rock through the woods and clearings along the low range of hills to Coxe Mountain. Exposures are chiefly found along the higher western slopes and summits. There are a number of significant associations which should be mentioned.

The hill road going east from the Forestdale-Pittsford road about two miles south of Forestdale crosses the summit of this range of hills and descends to Sugar Hollow. The summit point is known locally as "Birch Hill."

On the ridge north of Birch Hill, massive, brown quartzite forms the higher part of the western slope and is in contact with schist or phyllite which overlies the quartzite and extends eastward and northward along the ridge. The black phyllite or schist forms large exposures, but is roughly intermingled on a large scale with quartzitic schist, or schistose quartzite, in which at places are large, chunky veins of quartz which have been opened by zealous seekers for gold. In one of the pits was noted a black, graphitic schist carrying pyrite and quite like that seen at places in Orwell. The dip of the rocks, which is probably cleavage structure in part, is easterly. The western slope of the ridge north of Birch Hill has scarps above the drift-covered portion and the eastern slope is abrupt and regarded as marking a fault displacement. No dolomite was found along the top of the ridge; but northeast of Churchill's house on Birch Hill, on the eastern slope, are small patches of dolomite, apparently in place. South of Churchill's house, across the road, an east-west section gives massive quartzite at the west, then eastward quartzitic schist with a small patch of dolomite.

South of Churchill's house and west of the Sugar Hollow road, patches of dolomitic limestone occur sparingly as remnants of erosion on the eastern slope of the ridge. At places also the same association of quartzitic schist and phyllite with massive quartzite noted at the north occurs along the southern extension of the ridge. East of an old road which joins the Sugar Hollow road with the Birch Hill road, on the east side of a gulley, is quartzitic schist carrying pyrite and overlain by dolomite, while west of the gulley are big ledges of massive brown and granular quartzite which continue on the strike to join the exposures north of the Birch Hill road.

South of Churchill's corner the Sugar Hollow road descends for a mile over a gentle slope nearly to the brook. The old road over the ridge passes through a sort of col which may mark a structural sag, for directly south of the point where the old road joins the Hollow road the quartzite gave a reading of N. 72° E. and a dip of 36° N., which is a marked deviation from the prevailing north-south strike of the rocks. Directly north of the place giving this anomalous reading, dolomite rests on the quartzitic rock and its presence here leads to a suspicion that the low pass just north may be due to erosion of dolomite lying in an irregular sag.

Just south of the point where the old road joins the Hollow road a scarp appears west of the Hollow road and continues southward.

Two miles south of Churchill's corner a small basin in the hills holds Sugar Hollow Pond. The basin is a faulted one. Scarps bound it on the east, northeast and probably on the south. East of the pond is a succession of low ridges broken by strike faults which are marked by westward-facing scarps and intervening swampy gullies.

The terrigenous rocks composing these hills of the ridge or range just described present many similarities to those west of Brandon in Sudbury, both in their lithology and structure. They are evidently broken by numerous faults as well. Massive quartzite is more abundant at the east and a dolomite is present at places, but otherwise the student will be impressed by the very strong similarities, amounting to identities so far as distinguishing among them is concerned.

It has been suggested above that the terrigenous rocks of Sudbury pass beneath the marbles of the Otter Creek valley to join others at the east. This should be construed as only a general statement; no implication was intended that the terrigenous rocks at the east may not have been greatly disturbed in position.

East of Sugar Hollow Brook. East of the brook the topography is marked by sheer precipices, steep slopes and a rugged surface generally. Displacements by faulting are very evident. The western scarps which were cleared by glacial action were too high and extensive to be banked and covered with drift and now offer a somewhat imposing view when observed nearby.

In common with other portions of the western edge of the plateau the total displacement now apparent between general upthrow and downthrow areas has often been effected along several distinct planes. Along what appears as a single plane the amount of displacement will vary at different places along the strike. A scarp will often pass into a monoclinal fold and at some indefinite distance across the strike will be replaced by another scarp which will perhaps overlap the former along the strike and perhaps also another which has in its turn replaced the second. This arrangement impresses the observer of the topography east of Sugar Hollow Brook.

From the junction of its head streams the brook flows at the base of a prominent scarp on the west of the Chaffee Mountain mass. The considerable height of the scarp may be seen very clearly where a recent slide has cleared it of trees and other vegetation. This scarp is replaced eastward by another higher precipice at whose summit is a shelf that on a clear day gives one of the finest views in the Vermont valley.

Chaffee is best ascended along its northern slope from the valley of the eastern tributary of Sugar Hollow Brook. Massive quartzite forms the bed of this tributary and its valley and the ascent of Chaffee is over similar quartzite, dipping easterly, which can be followed to the shelf above mentioned and from the latter place to the summit where the easterly dip still prevails.

The ascent of Chaffee was made by the writer under trying conditions; the summit was enveloped in clouds and the rain came down in torrents. The atmospheric conditions caused some bewilderment so that observations could not be made with the desired accuracy in the thick woods of the mountain. About a mile, as estimated, south-southeast of the summit of Chaffee

Mountain, along the upper portions and summit of an eastward slope is dolomitic limestone, which here from the field relations apparently lies on the quartzite. A sort of col here permits an easy descent on the west side which is made over dolomite and quartzite by zigzagging down slope among a number of small scarps to the valley of Sugar Hollow Brook.

On a subsequent trip along the western slope of the "Moonshine"-Nickwaket range, along an old wood road that ascends to the col mentioned above, black phyllite was found in a scarp overlain by massive quartzite which was succeeded up the slope by exposures of dolomite. There is a small settlement on the mountain side above the contour of the scarp and at the base of Nickwaket and in the cleared fields of these farms the dolomite is extensively exposed. On the east side of a road through the settlement, near its northern termination, the dolomite dips eastward at a moderate angle, but farther east up the slope the dip is westward at a high angle.

A half mile southwest, west of this back road, the surface rock shows undulating not much compressed interbedded dolomitic and quartzitic layers which resemble the interbedded series. These are bordered by a scarp on the west, at whose base is a black, sheared quartzitic schist, which southward passes into massive quartzite. Then westward the dolomite again forms the surface rock which farther south on the slope and in the valley of the brook can be seen grading downward into quartzite and arkose, all dipping easterly at a moderate angle. West of these outcrops is Sugar Hollow road and then the quartzite of Coxe Mountain.

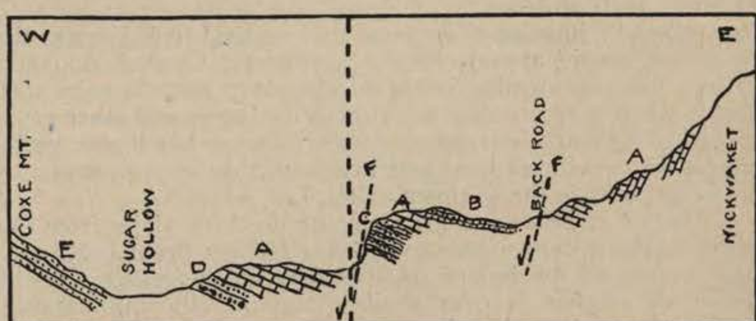
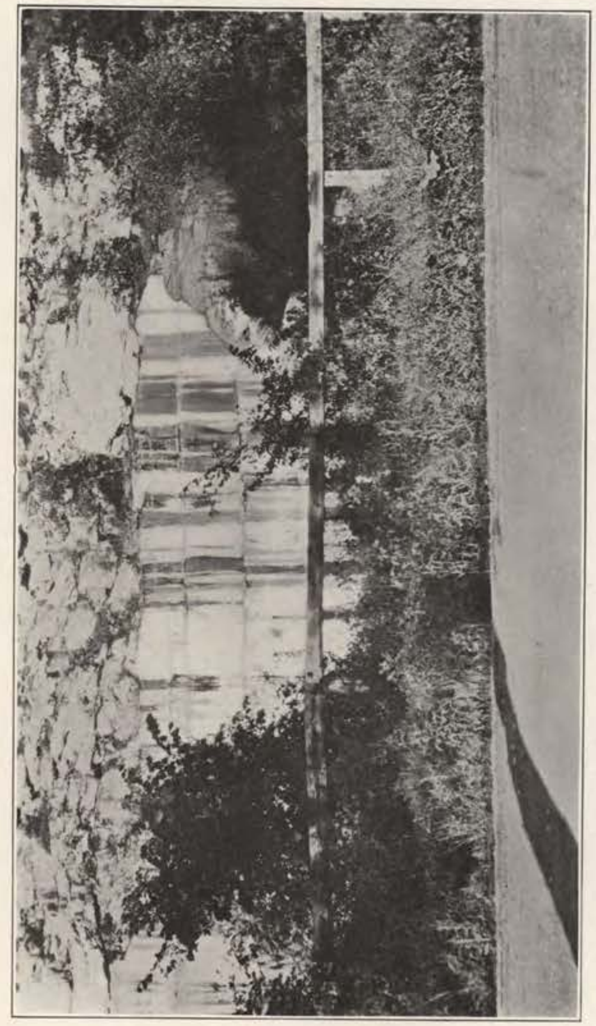


FIGURE 16. A generalized surface section of the margin of the Green Mountain plateau southeast of Brandon village, from Nickwaket Mt. westward through Coxe Mt. with offsets along the strike. Principal offset shown by dotted line. A, dolomite; B, "interbedded quartzites and dolomites"; C, quartzitic schist; D, quartzite and arkose; E, quartzite; F, probable faults.

The observer passing northward along the Sugar Hollow road, from the point where the back road referred to above joins the Hollow road, would hardly fail to notice the conspicuous

PLATE XXXI.



Contact of dolomite and marble in the old Goodell quarry at Brandon village. A common association in the quarries near Brandon.

ledges of dolomite on the east side of the road and would hardly fail to see that the beds are always folded and sometimes overturned to the west. Throughout the same distance on the west side of the road the quartzite of the ridge extending northward from Coxe Mountain is broken by a scarp on the east. Some dolomite occurs on the west side of the road. The scarp ends at the north at the place where the anomalous strike in the quartzite was noted. East of the road at this point dolomite dips at a gentle angle easterly, but on the west side of the road it shows much confusion.

East of Sugar Hollow Brook then are found:

1. Massive quartzite forming the prominent scarps;
2. Dolomitic limestone at places on the summits and in large exposures on the western slope of this mountainous strip, apparently resting on quartzite;
3. Black phyllite and quartzitic schist in scarps overlain by massive quartzite;
4. Apparently some representatives of the interbedded series, whose relations are not clear, but which presumably rest on the dolomite.

This whole series has clearly undergone much disturbance, in fact more than one deformation, but it seems reasonably clear that the rocks all belong to one series and that they are of Lower Cambrian age by analogy with other rocks having similar characters and relations in other parts of the Vermont valley. The original depositional sequence is not clear from the interrelations shown east of Brandon. From the relations at Bennington we have:

1. Massive quartzite, at the base;
2. Dolomitic limestone;
3. Interbedded series.

The relation of the schist is not wholly clear. It seemed to be a part of the basal quartzite formation and interstratified with it. In explaining the present field relations, account must be taken of erosion as well as deformation.

General structural relations of the interbedded series and the rocks of the plateau east of Brandon. The interbedded series just east of Brandon clearly shows within itself deformational features of several kinds, most of which are due to compression and some of which are the result of normal faulting. The effects of compression may be summarized as follows: (a) buckling, with frequent formation of tightly compressed folds, which are often overturned; (b) shearing across the bedding of the folds; (c) reverse faulting along the strike, which is indicated clearly at several places.

The field relations which the interbedded series has to the other strata with which it is now associated around Brandon village, in the writer's opinion, could leave little doubt, after a careful field inspection, that the former is superjacent to the marble and the dove-colored limestone and its gray dolomite associate. The interbedded series has been worn through over many large and small areas, with the consequent exposure of the other rocks on which it lay. The more or less detached exposures of the interbedded rocks along its western portion west of Brandon are inliers of this formation on presumably younger rocks, or are in process of becoming such. This relation makes the marbles and their associated rocks outlying belts in an older series. The number of contacts and outcrops that reveal this relation is manifestly reduced by concealment under drift or by difficulty of correlation of certain dolomites lying on the marble. There may also have been some deformation of all these various rocks, including their plane of contact, subsequent to that which superposed the older series on the younger strata. The evidence may be summarized as follows:

1. The contrast in metamorphism and deformational features which the two formations show when in proximity;

2. Ragged erosional remnants of the resistant quartzitic members of the interbedded series on the marble and its associated rocks at various places;

3. The interrupted outcroppings in bands of the marble through the interbedded series and a probably related dolomite.

From the east-west width of the area in which the marble outcrops through the interbedded formation we may infer with some reason that the marble underlies the interbedded rocks east of Brandon; but how much farther east the marble extends at depth is a question whose answer would depend a good deal on the interpretation given to the relations of the rocks of the plateau to those of the valley.

There is little hint of what lies at depth beneath the sand plains and drift that occupy the space of varying width along the Forestdale-Pittsford road between the interbedded series and the range of quartzite hills east of the road. Farther north, east of Lake Dunmore, a prominent scarp marks a normal fault and this scarp falls precisely along the line of the projection of the Forestdale-Pittsford road northward. The great pile of drift that extends along the western slope of the ridge south of Forestdale suggests that a cliff has afforded a convenient place in which to pile this débris. The slighter development of drift at the north around Dunmore, in contrast with conditions east of Brandon, is quite in consonance with the variability in this respect shown by other portions of the Vermont valley. It is close to the line of this assumed displacement east of Brandon that the kaolin mine at Forestdale with its deposits of lignite and limonite occurs.

Prominent scarps bound the interbedded series on the east, southeast of Brandon village, west of the Pittsford road. Their significance is not clear. They suggest displacements. Preglacial and base-levelling forces and glacial plucking, evidently availed themselves of a general line of crustal weakness along the region of the intervening surface space just described. The map brings the interbedded series and quartzite in contiguity; but the implication is general rather than precise, for there are indications at Forestdale that schist or phyllite lies beneath quartzite and it is not unreasonable to think that the presence of more friable schist, interbedded with the quartzite, might have been the primary contributing cause of the space that has been mentioned.

The quartzite of the ridge south of Forestdale, which is overlain and possibly underlain by phyllite and therefore interbedded with it, joins at the present surface with the quartzite of the higher plateau slopes east of Forestdale which affords some reason for regarding them of the same age and therefore for regarding the terrigenous rocks of the Orwell and Sudbury hills as in part of the same age as the plateau rocks. But it seems that too much reliability should not be placed upon the present surface continuity alone, here or elsewhere in the Vermont valley, in view of unquestionable deformation of more than one kind and the probability of lateral as well as vertical displacement of the rocks now forming the edge of the plateau.

It is not easy to fix the precise relation of the schist in the ridge south of Forestdale to the associated quartzite by reference to these rocks alone. It appears to be conformable. It is even harder to be satisfied of the relation which the patches of dolomite along this ridge have to the schist and quartzite. It seems rather likely that the formation which forms the probable basal member of this series of quartzite and phyllites, dolomites, etc., as a depositional mass varied originally in composition, both laterally and vertically, not only as a result of overlap, but from other causes as well and that a vast mass of sands and muds of different kinds was finally spread over the sea floor.

In general it would appear that the quartzite-phyllite formation is basal to the dolomite and that the former has been elevated against the interbedded series by reverse faulting and that a lateral thrust has carried the latter over the marble and its associated rocks at the west. It does not seem possible to account for the present superposition of the interbedded series on the marble and its associated rocks on any other basis, if the conclusions regarding the relative ages of these formations are in general correct. Apparently the lateral thrust drove for some distance above the schist and through the dolomite, for the schist appears nowhere in the Brandon region between the marble and the interbedded series, although it is entirely possible that the marble extends at depth beneath the quartzite-schist ridge east of the Forestdale-Pittsford road.

It seems reasonably clear that the interbedded series and the quartzite-phyllite formation belong to one terrane from the relations which they have to each other throughout the Vermont valley. If the interbedded series has been thrust on younger rocks we may reasonably infer that probably the quartzite has also. The field relations of the interbedded series give the clue to the meaning of the position of the quartzite and schist east of it; the latter have been brought up by reverse faulting as the result of rupture following compression and probably a low angle thrust plane cuts the reverse fault plane somewhere at depth. It is not so apparent whether the quartzite with its overlying dolomite east of Sugar Hollow Brook, which now form the rugged edge of the plateau, are separated by a reverse fault from the quartzite-phyllite west of the brook, because normal faulting obscures the relations between the two; but while the peculiar pattern of these normal displacements, in which the faults pass at the present surface into folds, suggests that except for normal faulting these various terrigenous rocks east of the interbedded series are not broken except by tension faults within the area of the map, conditions at other places may lead to another conclusion.

Approaching the question of the correlation of the terrigenous rocks on the west and east of Sugar Hollow Brook from the viewpoint of their general associations, their similarity in age and common membership in the basal formation gains considerable increase in probability, in the writer's opinion. So far as the writer's observations go there is no reason to suppose that the quartzite of Chaffee Mountain, "Moonshine" and Nickwaket, and certain quartzites and arkoses in the valley of Sugar Hollow Brook are any older than the quartzites and phyllites of the ridge of hills west of the brook. The rocks west of the brook are dismembered portions of the plateau, dropped down by faulting, in the formation of a great downthrow region. In this downthrown mass the interbedded series, of course, also belong.

How far east the marble may extend beneath the rocks of the plateau is a question whose answer rests wholly upon the answer to the prior question of how far does the thrust plane, whose existence seems to be established by the present relations of the interbedded series, extend east of the present western edge of the plateau. If the thrust arose in a reverse fault near the present margin, then presumably on the basis of the relations which the marble seems to have to these terrigenous rocks and the equivalence of the latter to each other, the marble would not be found at depth east of such a root fault. The thrust plane cannot be traced eastward beyond the exposures of the marble and its associated rocks from beneath the interbedded series because its trace must be made from the surface. There does not appear to be visible at the present surface any transection of the plane. Reconnaissance trips by the writer in the plateau have failed thus far to give anything that could be construed as the root of a great thrust. Its eastward extension is wholly problematical.

It was suggested above that probably a lateral thrust in carrying the interbedded rocks over on the marble had sheared above the basal formation into the calcareous members of the Lower Cambrian rocks. An important principle seems to be involved here. Probably we are inclined to look for too much regularity in the manner in which a great lateral thrust would drive through a mass of rocks. Because the thrust has apparently cut in a certain way through the rocks now near Brandon is no positive indication that the shear would have been just like it at other places, while the general fact of an elevation of Lower Cambrian rocks and overthrusting by them would still hold for many places. In other words, we might expect that in some cases the plane of thrust would have been such as to carry the terrigenous rocks of the east over on the marble and its associated rocks. The recognition of such a possibility in the presence of evidence for general overthrusting might greatly affect the interpretation of relations at many places and such possibility will be called to mind in dealing with certain relations farther south in the Vermont valley.

In considering the ideas and possibilities which have just been discussed, the question continually arises in one's mind as to what extent these various rocks were covered by others at the time of overthrusting. Did the overriding Cambrian carry with it a heavy load of younger rocks? Certain other questions arise: Did the marbles which are now found west of the plateau once extend over it to the eastward? Is there more than one thrust plane, one by which the marble and its apparent counterparts at the west, together with their associated rocks, were heaped up and carried westward and another along which the Lower Cambrian rocks broke through the marbles and overrode them? Did the latter rupture occur first and so bring an extra load on the calcareous rocks now represented by the marble and thus cause their greater metamorphism? Were the marbles and their counterparts ever covered with other rocks, especially with terrigenous rocks? They have been assumed to have been and the marble has been assumed to have been thrust through the younger terrigenous rocks or exposed on anticlinal folds through them. Why do not terrigenous rocks appear between the marbles and the interbedded series around Brandon, not by overthrust of lower members of the Cambrian, but because the marbles were overlain by terrigenous rocks? Is it because these were eroded before the thrust of the Lower Cambrian? Was the thrust which we now see evidence of around Brandon an erosion thrust, that is, one consequent upon previous erosion of the various rocks? If the terrigenous rocks that are found at places lying above the marble and which have been described as Ordovician are such, why do not similar rocks appear above the less metamorphosed Chazy-Trenton rocks that have been described by the writer on previous pages? Why are such rocks absent north of the Taconic range in Leicester, Salisbury, Shoreham and neighboring towns? Must we discount or discard the ideas that the various calcareous rocks, which were described as lying on a terrigenous foundation common to all, are actually in such relation and essentially equivalent? Again in this connection what significance has the similarity of the terrigenous rocks east of Brandon to those of the Sudbury and Orwell hills? If some of the latter are of different general age than others, why does not some pronounced structural arrangement appear among them so that they may be separated? If it should prove more than probable that rocks carrying fossils in Sudbury have been crushed into marble in Brandon does it appear probable that difference in degree of metamorphism among the terrigenous rocks is any sure criterion of difference in age? Is there anything in the lithology of the various terrigenous rocks that is positive enough to separate them into different terranes? Has account been taken of possible overthrust bringing schists into contiguity with less metamorphosed terrigenous rocks; or of an overthrust margin separating rocks of one age from those of another on each side of it, except possibly where rocks which have been overridden now appear through the overthrust mass on account of erosion? In a region of thrust displacements, how much value can be assigned to apparent surface transition? What relations have the overthrust phenomena along the lake to those at the east? Are there field relations anywhere in western Vermont that show the Ordovician rocks resting or probably resting on Lower Cambrian strata?

Allusion has been made to the presence of a great downthrow region bordering the Green Mountain plateau for a long distance on the west. In the writer's judgment recognition of the reality of this great structural feature is all-important and it seems to him that failure truly to appreciate the extent of the region and the significance of the principle involved has been an element of confusion in his own thinking and that of others.

At the present time the Green Mountain plateau structurally appears to stand as a great upthrow block of the crust with reference to certain rocks that lie to the west of it. This relation holds irrespective of whether the plateau has been thrust up or the other area has sunk; but enough has probably been said already to show that it is the writer's idea that this present manifest relation of upthrow and downthrow regions was produced by a deformation quite separate from any of the great overthrusts which have been described. It is necessary to appreciate that the genesis of this relation is of much more ancient date than any purely physiographic relations that now obtain between the two, and that although crustal warping and other disturbances may have caused minor movements and changes in their relations, in a primary and larger sense the present general relation of upthrow and downthrow areas probably antedates the destruction by erosion of a loftier region, although one cannot be so positive about how long after the great thrust movements of the general region the relation of upthrow to downthrow by normal faulting was produced, because the date of the thrusts is so uncertain.

The part of Vermont lying west of the Green Mountain plateau includes the other physiographic divisions described in a preceding section of this paper. From consideration of the ways in which rock deformation is known to have occurred it will appear that there are several purely theoretical possibilities as to the relations which the rocks of these divisions might hold to one another.

1. The Taconic range, Vermont valley and Champlain lowland might all be interpreted as parts of a general downfolded region with respect to the Green Mountain plateau and as owing their present physiographic contrasts entirely to differential erosion of a region of relatively simple folds, in which region the rocks west of the plateau constituted a compound, structural synclinorium and those of the plateau the complemental anticlinorium. Faulting and particularly thrusting played only minor parts at any time in the history of the region. In connection with this view the rocks at the west might be considered as originally members of a great geosynclinal of deposition, while those of the plateau belonged largely to a contemporaneous positive segment of the crust. Sedimentation might have been interrupted without changing the essential relations of these two regions, but eventually produced a great thickness of rocks which were later compressed without being profoundly displaced with respect to one another.

2. The rocks lying west of the plateau might all be regarded as parts of a great downfolded region without having suffered much deformation by thrusting, as postulated under 1. At some subsequent time great trough faults were formed producing the structural outlines of what are now the Vermont valley and Champlain lowland, which stand as downthrow regions with respect to both the plateau and the Taconic range. The present physiographic relations are thus primarily structural in their genesis and secondarily due to erosion. The rocks of the Taconic range and the plateau have the same general relations to each other that they had originally and prior to normal faulting, except for folding.

3. On the basis of known overlap at certain places in western Vermont of older on younger strata the rocks at many other places within the region might be considered as now remote from

their original places of deposition as the result of deformation of the crust by great thrust movements carrying the masses of one segment of the crust over on those of another for considerable but indeterminate distances, with or without much folding, thus bringing into juxtaposition rocks of widely different ages. At some time subsequent to such deformation by thrusting, normal faulting occurred and produced the structural outlines of the Vermont valley and Champlain lowland. These faults literally chopped these overthrust masses along many planes and introduced a confusion calculated to baffle any attempt to explain the present structural relations. If in addition to these deformations there were others, such as folding of irregular thrust planes and repeated normal faulting a very tangled aspect would undoubtedly be produced. Normal faulting in laterally thrusted masses conceivably might give relations that would have strong resemblance to such as would be produced by reverse faulting.

RUTLAND COUNTY.

Townships of Danby, Mount Tabor, Wallingford, Tinmouth, Clarendon, Rutland, Proctor and Pittsford.

(Pawlet, Wallingford, Castleton and Rutland topographic sheets.)

Topography. The areas which will be described in the townships mentioned in the heading for the most part lie in the Vermont valley in its extension north of Dorset Mountain. The rocks along the edge of the Green Mountain plateau at the east and a few in the Taconic range will be briefly mentioned.

The Vermont valley north of Dorset Mountain is marked by a ridge which extends northward from Danby to Rutland. The place of this ridge is then taken by two shorter ones; one of these separates the valley north of Center Rutland from that at West Rutland and the other forms Pine Hill northwest of Rutland.

Otter Creek enters Danby from Dorset at the south and flows in a valley between the edge of the plateau and the ridge that runs north from Danby; but at Rutland the stream turns westward to Center Rutland and flows in the Center Rutland valley west of Pine Hill as far as Proctor, where it enters the wide valley in Pittsford.

By the ridges mentioned the main valley is thus broken into several minor ones which have been excavated in softer rocks than those which compose the ridges. The surface topography of this portion of the Vermont valley therefore differs from that south of Dorset Mountain, but the main outlines of the valley between the plateau and the Taconic range are maintained throughout, except for the interruption by the Dorset Mountain mass.

PLATE XXXII.

A photograph looking northeasterly across the Vermont valley from the lower portion of the northeastern slope of Danby Hill, showing a terraced modified drift or delta plain in the foreground and a characteristic view of the marginal portion of the Green Mountain plateau in the distance.

General note. North of Dorset Mountain the Vermont valley in its extent from Danby to Pittsford, including the detached ridges that have been mentioned in the brief discussion of the topography, presents a great number of most remarkable and illuminating field relations that can be truly appreciated only after an examination of them. An adequate discussion of the geology of this part of the valley would speedily pass beyond the limits of a general paper like the present one. All that can be done is to give what appears to be essential. Outside the Bennington and Brandon areas the writer spent more time in this than in any other part of the valley and devoted parts of five days to a careful inspection of the region.

General description. North of Dorset Mountain lies Danby Hill which, as will be discussed, is separated by an east-west fault at the south from the mass of Dorset Mountain and which northward joins the ridge which extends through Tinmouth, Wallingford and Clarendon to Rutland.

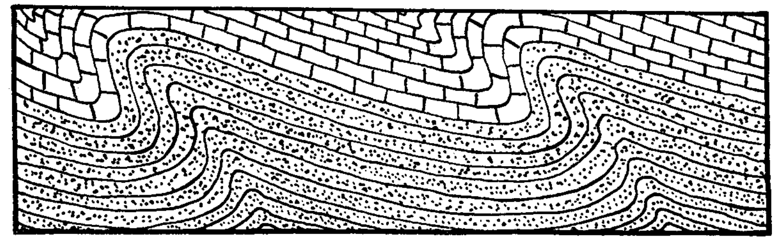


FIGURE 17. Composite drawing designed to show structure of quartzite at the foot of the plateau between Danby and South Wallingford and that along eastern slope of the Danby-Clarendon intermediate ridge; also that of the overlying dolomite. The overturning is westward.

On the east, Danby Hill slopes rather gradually to the plain of Otter Creek. North of Danby Hill the eastern slope of the ridge is often much sharper and sometimes, near the base, abrupt.

Danby Borough is on the eastern edge of Danby township. Danby station is in the adjoining township of Mount Tabor. A mile and a fourth east of the station begins the steep slope of the plateau which is cut east of Danby by the gorge of the "Big Branch." In the bed of this stream at Mount Tabor village the compact, massive quartzite outcrops. Thence it may be followed in the valley northward to large ledges along the railroad track three miles north of Danby station. The boundary of the quartzite then bends easterly away from the track at South Wallingford and its place is taken here along the meridian of the ledges farther south by members of the interbedded series and by limited outcrops of marble. The ledges of quartzite along the track are only a little over a mile, if that, east of quartzite-phyllite outcrops on the northeastern slope of Danby Hill. Except for difference of present altitude of Danby Hill and the erosion of its eastern slope, the relations of plateau, narrow valley, and western ridge at some places in Danby is like that farther south, east of Dorset Mountain.

The structure in the quartzite of the ledges along the track, just referred to, is generalized in the accompanying sketch. See figure 17. A mile west of these ledges, on the west side of the creek at a sharp turn in the main road, dolomite shows the same structure. We see the quartzite and the superjacent calcareous beds buckling under compression to form overturned folds.

The marble outcrops on the northeastern and northern flanks of Dorset Mountain give place northward under drift to quartzite and to members of the interbedded series of the Lower Cambrian in Danby Borough and along the eastern slopes of Danby Hill. In the bed and banks of Mill Brook in Danby Borough, beds of dolomite have a flattish position with very gentle arching, slight easterly dip and apparently a slight southerly pitch. A mile and one-fourth southwest of these outcrops along the brook road from Danby Borough to Danby Four Corners, at the bend in the road, what appear to be dolomitic members of the interbedded series have been folded into a small anticline and overturned so as now to form an acute, recumbent fold. East and west of the dolomite is quartzite. Along the meridian of these outcrops about one and a half miles north of them on the eastern slope of Danby Hill the interbedded members of the Lower Cambrian series outcrop and here apparently mark the eroded edge of a more extensive covering of these rocks. On Danby Hill they extend eastward to join those in the valley of Otter Creek. Further discussion of them may be given after following the section as begun along the brook road and after noting certain other exposures lying north and south of the road.

Westward along the brook road the outcrops of quartzite west of the recumbent dolomite give place to a black schist, well exposed in the bank at the second fork in the road and which continues northward over the top of the hill along the same meridian and joins the schist exposures along the higher eastern slopes of Danby Hill. West of the schist outcrops in the bank of the road in both of the high walls of the gorge of the brook is somewhat massive quartzite. This quartzite was not carefully traced northward at the surface, but on the meridian of this quartzite in the gorge of the brook, on the southern slope of Danby Hills, occurs the black schist or phyllite, and the latter occurs westward along the road to Danby Four Corners. Southward towards Dorset Mountain along a back road are fine exposures of massive, brown quartzite which are surrounded by drift and whose actual extension could not be followed. A mile west of these outcrops the bed of Mill Brook, which flows eastward, is strewn with quartzite boulders. Hosts of big quartzite boulders fill the drift south of Danby Hill, which is a feature doubtless associated with the action of the ice in stripping the slopes and summit of the hill and parts of the ridge at the north.

One-third of a mile south of Danby Four Corners and east of the hamlet on the southwestern slopes and northward along the lower western slopes of Danby Hill is a bluish-gray or bluish limestone, weathering gray and appearing in many outcrops. Fossils were not found in this rock by the writer, but they have been reported by Foerste,[1] and regarded by him as having a Trenton aspect. A mile and a half north of the Corners a crystalline limestone shows a brecciated condition on the gray, weathered surface, but is quite healed and without obvious fragmentation on the fresh surface, which is of dark blue color. From the writer's acquaintance with other areas this blue rock would have been tentatively correlated with Trenton and certainly not with the Cambrian.

Above the blue limestone outcrops at the base of Danby Hill, along the path up the hill traversed by the writer, outcrops are lacking until about half way up when black phyllite or schist appears which continues over the summit and outcrops at intervals therefrom down to about the 1,100 feet contour, when the topography changes somewhat in passing from the schist to some outcrops of sheared, bluish marble standing on end and then a short distance eastward appears the characteristic association of the interbedded series of the Cambrian, which is traceable south by west as the eroded edge of the Lower Cambrian series along the slope of Danby Hill alluded to above. Some conspicuous ledges of massive quartzite also standing on end appear just west of the margin of the interbedded rocks. The surface succession is thus within a fourth of a mile or less across the strike from west to east, with slight offsets to include outcrops: 1, schist; 2, sheared, blue marble; 3, massive quartzite; 4, interbedded series.

A half mile north of the exposures just described the schist outcrops east of the marble. There is, in fact, at this place a confusing intermingling at the present surface of marble, schist and quartzite.

North of these ledges, bearing to the west across Baker Brook, the schist or phyllite forms most of the surface outcrops, with occasional patches of limestone or marble, to the summit of Clark Mountain. Here on the summit and western slopes massive, heavy quartzite forms a continuous outcrop over large areas with the phyllite or schist lying to the east. Thick quartzite dipping about 30° westerly was traced for a mile along an old lumber railroad at the summit of the western slope. The western surface slope of the mountain is fairly steep and bevels across the westerly dipping quartzite. Across the road at the western base of the mountain the interbedded members of the Cambrian were noted dipping 66° westerly along a strike of N. 19° E.

[1] Amer. Jour. Sci., 1893, vol. 46, pp. 435-444.

West of Danby Hill and Clark Mountain is the Tinmouth valley, much of which is low, swampy land. It joins at the north with the valley of Clarendon River.

At the southern end of the Tinmouth valley, one mile west of Danby Four Corners, black phyllite or schist outcrops along the road to Tinmouth for a mile and a half north of the Pawlet road. Between the schist and Danby Pond there appears to be some "marbly" limestone. About two miles southwest of Danby Four Corners is blue limestone. The phyllite is precisely like that which occurs in the ridge at the east and in the various localities described on previous pages.

Three miles north of the road from the Corners to Pawlet, and 75 rods west of the Tinmouth road, and along the same general contours northward are exposures of strongly-sheared limestone or marble. At many places these ledges of marble do not at all appear like the outcropping edges of thick masses of the rock, but rather as a broken covering to some rock on which it lies. Two miles west of the Tinmouth road, within the main range, at the southern end of Harrington Hill, is what appears to be an isolated patch of marbly rock lying on the terrigenous formation. On the trip which was made to inspect these relations there was not time to map the country with the care necessary to show the extent to which the marble or its probable equivalent occurs in scattered exposures over the hills, or to ascertain to just what extent it is interrupted at the surface by the phyllite along the western edge of the Tinmouth valley. It was hoped that there would be another opportunity to investigate the relations within the hills at the west. There are indications of considerable massive quartzite on the west side of the Tinmouth valley in the general vicinity of Tinmouth.

On the eastern slope of Clark Mountain are patches of bluish limestone not so severely metamorphosed as the marbles of the region usually are. They appear to rest on the schist. In the valley of Otter Creek on the west side of the stream at South Wallingford are exposures of the heavy marble, including a quarry. Adjacent to these and extending eastward from them are the interbedded rocks of the Lower Cambrian, and east of these, less than a mile away, is the quartzite of the plateau.

The interbedded members of the Lower Cambrian continue northward from South Wallingford on the east side of Otter Creek, forming conspicuous hills two miles north of the village. In these the beds have been compressed so that they now stand on end. Northward between these exposures and the village of Wallingford the quartzite of Green Hill comes down close to the railroad track with a low but good scarp on the west.

Westward across the creek and its flat flood plain, near Wallingford village, three-fourths of a mile away, is a sharp ascent from the level of the plain which the writer at the time of inspection put down as a probable fault. It runs along the eastern base of the ridge that extends northward from the Clark Mountain portion for 4 or 5 miles. The rock along this slope is schist or phyllite; but northward, southwest of Clarendon village, the place of the sharp slope is taken by a more gentle one and that of the phyllite by quartzite. The base of the sharp slope referred to is marked by swampy land for part of its extent and southwest of Wallingford by Fox Pond.

Westward from Wallingford village over the ridge the surface rock is largely schist or phyllite, with some quartzite. The boundaries of these two rocks were not traced along the ridge for 4 miles north of the road that crosses the ridge from Wallingford village to Tinmouth village, except on the west slope where the road descends diagonally across massive quartzite.

Clarendon village in the Otter Creek valley is 4 miles north of Wallingford village. West of the former the eastern slope of the ridge that lies to the west rises rapidly but gradually from the level of the creek over quartzite which shows the structure given in figure 17. About 300 or 400 yards up the slope from the main road, members of the interbedded series of the Cambrian apparently lie on the quartzite as they do on the eastern slope of Danby Hill. The prevailing surface rock over the ridge to Chippenhook is quartzite; but on the west slope east of Chippenhook appears the interbedded series which continues westward into the valley of Clarendon River. At Chippenhook, in the valley and east bank of Clarendon River, the beds of the interbedded series stand at a higher angle than farther east. A similar relation was noted between the quartzite of Clark Mountain and the interbedded series lying west of it. It appears that these rocks, both in their larger and smaller folds, show overturning westward.

Southeast of Clarendon Springs, east of the road that ascends from Chippenhook over Boardman Hill, black schist or phyllite ledges are intermingled with others of gneissic-looking quartzite, and the two are often together and in contact in the same ledge. Northward down the hill to the bed of a brook is massive, thick-bedded, jointed quartzite, dipping easterly at a low angle. Eastward along a road that follows the brook to Otter Creek is quartzite dipping easterly and apparently extending to the eastern base of the ridge. The rock is often gneissic at the east.

East of Clarendon Springs at Flat Rock and northward, east of the road over Boardman Hill to Center Rutland, is quartzite, often gneissic in appearance, having essentially the same relations to schist or phyllite as noted above, but with the resistant ledges of the quartzite often forming knolls of higher elevation than the adjacent schist and giving a strong impression of quartzite pushed over on schist.

The road from Chippenhook to Center Rutland over Boardman Hill makes a steep ascent diagonally across the western slope of the ridge. The outcropping rock along it is phyllite or schist, specimens of which at most places would not be distinguishable from similar rock at scores of places in the Sudbury hills. The schist outcrops appear in the road about a mile north of Chippenhook and thence continue along the road and east of it and farther north also in ledges west of it, to a point about a mile and one-fourth north of Flat Rock. Here the quartzite, which was mentioned above, crosses the road to Boardman Hill whence it continues northward west of the road and along it towards Center Rutland. Some outcrops of the phyllite appear east of the western outcrops of quartzite. The dip of the quartzite and the apparent dip of the schist is easterly. The boundary between schist and quartzite is in fact irregular and modified somewhat by promiscuous intermingling or interchanging of areas of schist and quartzite. Near and on Boardman Hill the ledges of quartzitic schist or thin-bedded quartzite show severe crumpling with small folds in more or less recumbent position, but more massive beds farther east have not been deformed so much, although the quartzite has taken on frequently a gneissic structure.

West of Flat Rock and Boardman Hill the western slope of the ridge descends to the valley of Clarendon River, first over schist, then on marble. Outcrops of the latter were noted near Austin's house between the 900 and 1,000 feet contours. Marble outcrops occur east and west of the stream and at one place along the road to West Rutland the rock is quarried (Clarendon Marble Co.) and at other places east of the stream it has been opened. But northward along the road the phyllite appears and intervenes between the marble exposures just mentioned and the great quarries of the Vermont Marble Co. at West Rutland along the valley of the head stream of Castleton River. To what extent, if any, the marble is interrupted in its north and south surface extension between Clarendon Springs and Center Rutland was not investigated.

Along the ridge north of Boardman Hill the quartzite was traced to within a mile of Center Rutland, but was not followed down the northern slope of the hill where it presumably occurs; for the rock was noted in the bed of the creek at Center Rutland.

About a mile north of Tinmouth village a gap in the range leads to Middletown Springs. Along the road the terrigenous rocks at the northern end of Tinmouth Mountain are precisely like those in the hills at the north in Hubbardton, Sudbury and Orwell, and while lithological distinctions may be drawn among the rocks in both places any separation on the basis of age seems impossible at the south as at the north, as well as between the two. About a mile west of the Tinmouth-Chippenhook road, "marbly" limestone appears. Its boundaries were not traced. It seemed surrounded with terrigenous rocks, at the surface. No limestone was found at Ira, although it is reported from there and undoubtedly would have been seen by careful search.

As previously mentioned, east of Otter Creek near South Wallingford the steep slope of the Green Mountain plateau bends northeastward. The edge is marked southeast of Wallingford by a high scarp known locally as the "White Rocks." While the valley thus widens out between the plateau and the ridge that extends northward from Danby Hill, the western boundary in the eastern quartzite swings to the valley and is now marked east of Otter Creek and south of Wallingford village by the western edge of "Green Hill" which has the same general relation to the plateau that the valley quartzite has at Bennington, except that at north there are scarps in the valley as well as in the plateau. The scarps at the north have been freshened by ice action.

The rocks were not examined north of Wallingford village east of Otter Creek, between that town and Rutland. In the valley of Otter Creek no marble was seen between South Wallingford and Rutland; nor was any noted between South Wallingford and Danby. But the interbedded rocks were frequently seen from Danby Borough northward to Wallingford village, more particularly east of Otter Creek.

The quartzite which was noted in the bed of the creek at Center Rutland was found two-thirds of a mile north in the cut of the Rutland R. R. Later on a trip from Rutland city over Pine Hill to Proctor village this rock was traced from a point about one mile north of the outskirts of the city, from outcrops just west of the Pittsford road, up the eastern slope of Pine Hill along the cable line to the schist outcrops on the summit and higher western slope at the northern end of the hill. Schist was noted, apparently in place, while ascending the eastern slope along a wood road to the cable line.

The quartzite on the eastern slope dips easterly and eastward is overlain apparently conformably by dolomitic limestone, in which one reading gave the strike due north (magnetic) and the dip 42° easterly. As examined just east of the Pittsford road the limestone at places contains many grains and sometimes larger patches of silica. The quartzite apparently has some interbedded schist.

North of Pine Hill there is apparently a structural break, Pine Hill occupying the upthrow side.

At the northern end of Pine Hill the sharp descent on the west is over schist for a distance and then over calcareous rocks that apparently belong to the dolomite and dolomite-quartzite members of the Lower Cambrian, which around Proctor and southward, east and west of Otter Creek, are in association with marble. The interbedded rocks were traced northward into Pittsford, where their relations to the marble is the same as it is around Brandon; outcrops of the marble occur east of the western margin of the interbedded rocks. South of the Brandon township line, except for a brief distance in Pittsford, the western margin of the interbedded rocks was not minutely traced in its relation to outcrops of marble. Around Proctor the interbedded rocks will often be seen in almost vertical attitude as has been described for the areas both north and south. Two and a half miles north of Proctor they were seen lying in an almost flat position. South of Proctor marble outcrops and has been opened along the lower western slopes of Pine Hill east of Otter Creek. Between these exposures and other marble outcrops farther west the calcareous members of the Lower Cambrian intervene, affording, apparently, another instance of exposure of marble by the erosion of its covering of Lower Cambrian rocks.

Otter Creek has clearly availed itself of structural features in its course, particularly around Rutland. At the city it turns from a northerly course to a westerly one as far as Center Rutland, whence it again flows northerly west of Pine Hill through Proctor and on to Pittsford.

The marble and the dolomite and interbedded rocks of the valley of Otter Creek, north of Center Rutland, lie between the mass of Pine Hill and a ridge of schist and phyllite. This ridge northward is broken to a slight extent topographically, but geologically joins with the quartzite-phyllite rocks in eastern Pittsford township, which in turn join with those of Brandon on the north and Hubbardton on the west. On the ridge west of Proctor village are some patches of "marbly" rock and a mile west of Fowler, farther north, is another patch of calcareous rock surrounded by the schist. Northward the terrigenous rocks are faulted at places west of Brandon, as has been described on previous pages, against the sheared blue limestones and marbles and finally disappear under these rocks in northern Sudbury township.

West of the schist ridge just mentioned lie the marbles of West Rutland between this ridge and the main mass of terrigenous rocks lying to the west in Castleton. In these marbles have been found bluish-gray rocks with abundant specimens of *Maclurea magna*. The calcareous rocks of the West Rutland valley extend as a narrow band about five miles long and terminate at the present surface at the north and south against the phyllite formation.

Westward the phyllite rocks along the Castleton River valley give place at the surface to the slates of Castleton and Fairhaven, but the slates are more or less associated with phyllite rocks just as they are north of Castleton in Hubbardton and Sudbury and north of Fairhaven in Benson, as described on previous pages.

Summary. Some of the details and some of the general relations which have just been given in the preceding description of certain portions of the townships now being considered have been noted by other writers. The studies which have been only in part briefly presented by the writer, were made for the purpose of gaining from direct observation first-hand knowledge by which comparison could be made with the rocks and their relations at other places and really represent only a part of what it was hoped to make. They are offered for their general bearing on the question of the interpretation of the broad structural features of western Vermont.

In general it appears that the structural features of the different portions of the Vermont valley will have to be reconciled with each other. The assumption of similar genesis with respect to the main features of the valley throughout would seem to rest upon strong probability.

It further appears from features which have been and will be cited that the general structural relation of plateau to valley is the same all along the contiguous margins of the two. The Vermont valley now in its relation to the plateau is a downthrow region and a dismembered portion of the plateau. Probably this statement expresses only a portion of the truth, however, as it appears probable that the western side of the valley is faulted also, so that the valley is primarily a great structural trough between the plateau on the east and the mountains on the west. If this is the fact then in our thinking we must in imagination by taking account of probable displacement and erosion restore the valley floor to its approximate original position and in such way strive to visualize what the former relation of the plateau and the masses west of the valley would have been through the connecting mass which was displaced.

It may be asked, what evidence is there that the western side of the valley is faulted? West of Brandon there is evidence to show that the sheared limestones and marbles north and east of the phyllite hills are downfaulted, the fault being sometimes in the marble and sometimes between the phyllite and the marble. There is evidence on the east of Mt. Anthony in Bennington and Pownal of downfaulting of the valley rocks. It happens that along the west side of the valley it is not so easy to tie up some formation in the valley floor with one in the Taconic range as it is in the case of the valley quartzite with respect to similar rock in the plateau. At Dorset Mountain, however, we see the marble at its high level there and find its counterpart beneath the surface of the valley. With the fairly satisfactory evidence at the east of downfaulting why assume that Dorset Mountain has primarily been thrust up with respect to the valley? Dorset Mountain presents evidence by itself of displacement between it and adjacent rocks on the north and south. This fact rather argues against any such idea as that the whole region west of the plateau margin is downfaulted with respect to the plateau, which view might permit the explanation of the valley as an erosion feature purely. There is no reason for selecting Dorset Mountain out of the Taconic region and assuming for it upthrow displacement with respect to adjacent rocks. On the whole it seems most probable to the writer that in view of the displacement between plateau and valley there was also displacement between the valley and the masses now at the west and that such is the significance of the relations shown at Dorset Mountain and at other places.

The marble is at different levels. In the valley it appears to be at about the same level at most places, but varies somewhat even there. In the Dorset Mountain mass it is much higher and perhaps repeated. In Tinmouth valley it is intermediate between its level in Dorset and in the main valley. This general statement of the levels at which the marble occurs refers only to the general Vermont valley region and its extension into the Champlain lowland and passes by for the moment the detached patches in the hills at the west.

The surface of the Vermont valley is controlled at various places by the peculiar structural conditions which there prevail. North of Bennington and through to Manchester, and in fact practically all along its eastern border, the Lower Cambrian rocks shape its surface. North of Dorset Mountain the main general valley widens and new features appear.

The steep northern slopes of Dorset Mountain, except as affected by general weathering, stream incision, and by drift, pass rather abruptly to a more gradual and gentle slope, which except for the incision of Mill Brook and the lateral erosion consequent upon it, continues without important change of level to the summit of Danby Hill and northward to Pine Hill and the schist ridge west of it in Rutland. This somewhat varying level marks a surface of intermediate altitude in a ridge intermediate between the plateau and the main mass of the Taconic range. This ridge is bounded on the east for most of its length by the Otter Creek valley and on the west by the valleys of Tinmouth Channel and parts of Clarendon and Castleton Rivers.

North of Dorset Mountain a region marked out by an east-west line just north of the mountain, a north-south line running probably along the western edge of the Tinmouth valley and its extension, another north-south line at the east, and an irregular line at the north, represents an area of downthrow in which the displacement has been differential. The intermediate ridge just mentioned is on the downthrow side with respect to Dorset Mountain, the plateau and the main mass of schist at the west, and on the upthrow side with respect to the rocks underlying Otter Creek. Its relation to the narrow valley on the west of it may be discussed later. Pine Hill is probably on the upthrow side with respect to the area in Pittsford north of it and potentially so with respect to the valley of Otter Creek south of it.

One of the first efforts at a restoration, such as has been suggested, of the original conditions prevailing between plateau and the mountains at the west would be to get the surface of the valley quartzite back at its former level, so to speak. If this were done all along the valley and lowland, beginning at Bennington and extending to Brandon, a great mass of rocks would be lifted. Along the eastern portion of the valley at least the calcareous members of the Lower Cambrian that now lie at places on the valley quartzite would be elevated to a level some distance above the eroded surface of the plateau and would in effect restore a part of the surface now gone from the plateau. Some account would have to be taken of erosion of the plateau, but the quartzite is a resistant rock.

Passing for the present what particular effects would be produced in the southern portion of the valley and in the region of the Champlain lowland, and considering only what would be the results in the regions of Dorset Mountain and the part of the valley north of it to Pittsford, the elevation of the upper surface of the valley quartzite even to the present sky line of that formation in the plateau would bring it to about the level of the schist-quartzite mass that partially caps Dorset Mountain. The calcareous members of the Cambrian would be above the quartzite. What is now beneath or adjacent to the quartzite which would be elevated with it?

In such an attempt at reconstruction there must necessarily be a large number of elements of uncertainty. This number should be reduced as much as possible.

We may assume, but only assume, that there has been no displacement between the marble of Dorset and that in the valley other than that which dropped the latter; or in other words, that the plateau and Dorset retain their relative positions practically unchanged since the displacement of the block between them.

If now we take the relations shown at South Wallingford of interbedded rocks resting on marble at their face value, and recall the conditions east of Brandon and those which apparently obtain around Proctor and Pittsford, it appears that in the neighborhood of Dorset Mountain we have probable overlap of the calcareous members of the Lower Cambrian on the marble. At Pine Hill we see a terrigenous mass consisting of a sort of conglomerate and a quartzite with interbedded schist, overlain by dolomitic limestone and interbedded rocks lying against marble at the west with the interbedded series apparently lying on the marble just west of the hill. The sequence which we have from the plateau through Pine Hill and the Center Rutland marble strip is not very different from that which is present east of Brandon; but at the south, west of the Center Rutland marble strip, we have conditions different from those near Brandon in the presence of a ridge of schist intervening between the marble of the Center Rutland strip and that of the West Rutland strip.

In restoring the conditions in the valley east of Dorset Mountain it would appear that between the quartzite as elevated and the mass of Dorset there should intervene a narrow block of marble with interbedded rocks overlying it. In Dorset Mountain, schist with thick beds of quartzite tops the marble and the relative meridional positions of the different rocks are made to correspond between the restoration of plateau to Dorset Mountain and what now prevails near Pine Hill.

The schist on Dorset Mountain and northward has usually been regarded as younger than the marble. The fact that it lies on the marble probably by itself is not a sure indication that it is younger; for it now appears practically certain that the marble is at many places in the valley overlain by Lower Cambrian calcareous rocks. The argument assumes that the marble is younger than the interbedded series of the Cambrian, evidence for which is had in the specimens of *Maclurea magna* of the West Rutland quarries, if the evidence as deduced from surface continuity for the Brandon region and as afforded from other relations is not conclusive.

On what does the marble of Dorset Mountain rest? It is sometimes represented as passing beneath a schist formation as though it continued indefinitely westward from the Vermont valley in that relation to the mass of schist composing the Taconic range and its foothills, and as though it passed at depth disconformably, or otherwise, into other calcareous rocks with Cambrian dolomites at their base. When the marble is found among the terrigenous rocks of the hills west of the valley it is explained as emerging from beneath, or as interbedded with the schist.

Examination of some of the patches of "marbly" limestone within the terrigenous rocks west of the valley often does not convey the idea of its being beneath, or of its being interbedded; but gives the distinct impression that it rests on the phyllite formation. In fact it would appear that marble rests on schist and that the latter rests on marble. The point would naturally be raised as to whether the schist above is the same as or like that below: that is, are limestone and phyllite usually really interstratified?

At West Mountain in Shaftsbury and at many other places within areas which are mapped as "Berkshire Schist," the prevailing terrigenous rocks are not distinguishable at all from those of other areas on which fossiliferous limestone, sheared, blue limestone, or "marbly" limestone now rest or certainly did rest at one time. In Brandon, Sudbury, Orwell and Benson are terrigenous rocks having to limestone the relation just mentioned, which the writer regards as so like the phyllites and schists of Danby, Clarendon and Rutland, that it is not possible to make

a sharp separation. They in fact join with each other at the present surface. These terrigenous rocks in Sudbury, Orwell and other places consist of interstratified schists, phyllites and quartzites. The schists which top Dorset are interbedded with thick beds of massive quartzite. Those which form the ridge from Danby Hill northward also seem to be.

If we accept as valid the evidence that has been offered on previous pages for a wide extension of calcareous rocks, including the marble along the Vermont valley and the Champlain lowland, over a terrigenous formation that is over large areas quite similar in its general characters and of probably similar age, and if on this basis we accept the idea that a section from the plateau westward is essentially the same, whether it is along a parallel passing through Leicester, Whiting and Shoreham, or along one through Dorset Mountain, Rupert and westward, except for differences of metamorphism of the limestone or the terrigenous rock and for differences in the present attitudes of the rocks, with consequent scarcity of limestone on schist at the south and consequent small exposure of schist through limestone at the north, and perhaps also for differences due to original lateral variation in the terrigenous rock, then if we think of the phyllite of the Sudbury hills passing beneath the marble of Brandon we may also think of it as passing beneath the marble of Dorset Mountain and that of the valley east of the mountain. In connection with conditions in the Vermont valley, we especially recall that at places among the hills at the west masses of limestone which rest on the terrigenous formation have also been preserved through protection by downfaulting.

The Vermont Report (page 412) states that "the limestone from West Dorset is continuous, through a notch on the west end of Mount Eolus, with the limestone and marble in the central part of Danby, upon the west range of the limestone formation." The map so shows it. Along the valley of the Mettawee a few miles due west from Dorset Mountain, as discussed on a subsequent page, limestone (here the dove-colored rock with gray dolomite) rests on the phyllite. The Vermont Report (page 412), apparently on the authority of the elder Hitchcock, gives the limestone as extending from Dorset over the mountain to Sandgate.

Accepting the idea of overlap along the eastern edge of the valley, from such evidence as we have, we have nothing to tell us how far the marble extends eastward beneath the older rocks. The important fact is that of overlap. If the marble lies on a quartzite-phyllite formation and practically the same kind of rocks now lie on the marble at any place in or west of the Vermont valley, one of the ways in which this relation might possibly be explained, involves an extension of the quartzite-phyllite formation on which the marble lies eastward beneath the margin of the overlap.

An effort has been made to get before the reader a certain amount of evidence which goes to show a widely-prevailing relation between apparently related calcareous rocks and a terrigenous formation that is similar over wide areas and which indicates that the normal position is limestone on the phyllite formation. Attention was then called to the resemblance, as it appears to the writer, which such terrigenous formation has to similar rocks that have an inverse relation to the limestone and that now at certain places rest on it, that is, on marble.

It seems to the writer that a certain amount of assumption is involved when the schist on the limestone is called younger. We have seen that superposition may not be regarded as conclusive evidence in this region. The age of the "Berkshire Schist" seems to have been determined indirectly in all cases, either from field relations or in some other way. From relations which it has to limestones at many places it would seem clearly on such a basis to be older and in no wise interbedded. It has apparently been assumed that the Cambrian dolomite and dolomite-quartzite series passes directly beneath marble along certain parts of the Vermont valley and that the calcareous rocks thus make up a conformable or disconformable "Cambro-Ordovician" limestone series on which lies a conformable "Berkshire Schist." Such views, in the writer's opinion, leave in the air the explanation of such relations as overlap of the Cambrian rocks on the marble at numerous places; the undoubted superposition of related limestones including marbles on terrigenous rocks which are similar to and many of which are correlated with the "Berkshire Schist," and the relations which have been described in more or less detail for Orwell, Benson, Sudbury and Whiting. They further seem to ignore great thrusts, or at least, the wide extent of obvious movement of older on younger rocks, which the region everywhere exemplifies.

Even if the general and normal superposition of the limestone on the terrigenous formation over a wide region is admitted, it is not of course necessary on that account to give up the idea that the schist resting on marble is younger than the marble, because it is conceivable that conditions of deposition permitted the succession from limestone to terrigenous rock, or from terrigenous rock to limestone and again to terrigenous rock, perhaps over a wide region. Nothing in this summary has been said about the age of the quartzite-phyllite formation except that it often appears to be older as a whole, as now eroded, than the limestone which rests on it, including the marble. Further than the suggestions offered on previous pages the consideration of its probable age may be postponed.

One of the things that is perhaps confusing in explaining the relations along the Vermont valley on the basis of overlap by thrust of older rocks on younger ones is the fact that erosion apparently nowhere has uncovered a clear overlap of Cambrian quartzite on marble; something sharp and distinct like that of the quartzite on the "Utica" at Burlington. Another thing that is bound to be confusing, if it occurs, is overlap of terrigenous rocks on other entirely similar rocks, by thrust.

It has been implied above that the marble which underlies the valley, for example, that at South Wallingford, has been dropped from a higher level. North of Rutland the marble on the meridian of that of South Wallingford is apparently covered by the quartzite-schist and its overlying calcareous rocks in Pine Hill. At South Wallingford only the interbedded series can be seen to have any relation like that of overlap on marble.

The marble along Otter Creek north of Dorset Mountain has been assumed by some to pass beneath the intermediate ridge lying to the west and to emerge in the Tinmouth-Clarendon River valley. This is the view given in the Vermont Report. By others the intermediate ridge has been regarded as an anticline underlain by the basal Cambrian quartzite and the underlying pre-Cambrian and overlain by the "Stockbridge" limestone and "Berkshire Schist." Overthrust of Cambrian quartzite on schist is described and indicated and inclusion of limestone and schist in the older rocks is shown as occurring by the younger rock being faulted down into the older rock.

The structural pattern of the valley north of Dorset Mountain is unquestionably complicated and hard to analyze. It seems, however, that one of the first steps would be to try and make a restoration on the basis of the valley being a downfaulted region. Along the eastern side the Cambrian quartzite and interbedded schist could be thought of as elevated, carrying the Cambrian calcareous rocks above it and presumably at places at least, as at Pine Hill, the subjacent marble to a higher level. In other areas with more or less indeterminate boundaries on account of irregularity of early overlap the interbedded rocks of the Cambrian and its subjacent marble could be imagined as elevated. In still other areas, probably in different measure according to amount of displacement, the schist-quartzite masses of the intermediate ridge would be elevated, and by assumption, subjacent marble with it.

By these imaginary processes it would seem that we should get an extensive mass of marble over the area north of Dorset Mountain, approximately back to former levels one of which is now marked by the marble of the Dorset mass. It would seem, too, that the quartzite-schist of the intermediate ridge would be restored to a higher level and on this quartzite-schist with probably some overlying "marbly" limestone we should find a capping of dolomite and interbedded rocks, which we have come to associate with the Lower Cambrian, the whole mass of Cambrian showing the buckling so characteristic of the interbedded series, as has been described so many times. We should recall that the same kind of deformation exhibited by the quartzite on the intermediate ridge is shown also by the quartzite east of Otter Creek, and that in fact one is the replica of the other. At places we now find lying on the schist of the intermediate ridge, small patches of limestone younger than the Cambrian, sometimes fossiliferous, sometimes "marbly," and it would appear that some of these were formerly overlain by quartzite, which in turn was and is now at places, overlain by the interbedded rocks of the Cambrian. In some places we now find all these various rocks within the space of a few acres, intermingling at the present surface, but in relations which suggest that the schist is lowest, the "marbly" or other limestone next, the quartzite next and finally the interbedded series. Underneath all, presumably, is other massive marble. Farther west in the Tinmouth valley are some indications that the interbedded series rests on massive marble, but this is not so certain; the massive marble may be deeper down. Except for erosion or lack of it, and minor details, this brief description would seem to apply to the whole ridge from Danby Hill north to Center Rutland. At Center Rutland the massive quartzite apparently swings to Pine Hill and does not touch the West Rutland ridge; but the latter presumably gives marble at depth, then the schist and on top of the latter, patches of marbly limestone, with possibly some of the interbedded rocks along its eastern base.

It would seem from such a restoration as has been attempted that north of Dorset Mountain there would have been overlap of Cambrian rocks as far west as Tinmouth valley, with younger rocks underneath. Sometimes this overlap apparently carried the interbedded rocks on the marble with no quartzite or schist intervening. Sometimes interbedded quartzite may have been carried over on schist with limestone or "marbly" rock intervening. Sometimes quartzite with overlying calcareous rocks may have been carried over the schist with "marbly" limestone intervening.

On the general idea of overlap of Cambrian rocks as just developed, recalling the conditions north of Dorset Mountain, it would seem that a restoration at Dorset Mountain would involve an overlap on its summit of calcareous members of the Cambrian series, perhaps on younger limestones that have been eroded.

The ideas developed up to this point clearly depart from the view that the Cambrian rocks of the valley, as now exposed, are members of a series that is subjacent to the schist-phyllite formation, and suppose rather that a portion of the Cambrian floor has moved from the east over on younger rocks and now lies by unconformable thrust overlap on younger strata. Overlap seems fairly plain; its extent is less certain. From what has been said

above it is further regarded as probable that the normal position for the marble is above a terrigenous formation like that which caps it. On this view the terrigenous formation is also beneath the marble of Dorset Mountain and extends eastward beneath the margin of the overlap of older rock and also beneath the valley marble, for an indeterminate distance, but perhaps not very far. How far is wholly problematical.

Now it seems possible to imagine that the conditions which seemingly would be present, after such a restoration as has been attempted was made, over the region under discussion, could be explained by a series of thrust displacements. The quartzite-phyllite formation and its overlying probably younger limestone were broken by reverse faults which probably were usually minor thrusts, and along the planes of these thrusts the quartzite-phyllite formation and the overlying younger limestone were driven westward through and over similar rocks until they came to overlie the younger limestone at the west. Or the plane may conceivably have cut in such way as to carry the phyllite against other but similar terrigenous rocks—cutting downward, for example, at places beneath the limestone, or into the terrigenous rock, and pushing the sliced-off portion on the "toe" of the thrust. It seems not difficult to imagine that there may have been several such thrusts, some of which may now be covered eastward and some of which may have been wholly or partly eroded westward. On meridians farther east a series composed of quartzite-phyllite with overlying dolomite and interbedded rocks was broken by reverse faults and finally, after ease of stress had been partly accomplished in this way, along an extensive, irregular plane, which truncated earlier planes within the series at depth and cut through different members of it, a great mass of rock was driven westward over previous thrust masses at the west and may possibly at places have overlapped several earlier thrusts. During these deformations probably some folding occurred as a result of compression and some perhaps as the result of friction along the surface of movement. On the hypothesis of repeated thrusting, as thus outlined, the possibilities of some of the marbles being separated from each other by thrust planes should be considered. During this overriding may have been the time when the marbles acquired their particular metamorphic characters which distinguish them from the apparently related rocks which carry fossils, or are less metamorphosed, and which lie, so to speak, west of the probable margin of the thrust overlaps from the east.

In the section from the plateau westward through Pine Hill apparently we should have, after restoration by elevation, quartzite-schist with overlying dolomite elevated along a reverse fault against the interbedded dolomites and quartzites, and the whole series cut by and resting along a thrust plane which had cut through what is now marble overlying phyllite which together by a minor thrust had been previously and independently pushed over other calcareous rock now represented by the marble of the West Rutland valley, which may have its normal position on the terrigenous formation. These various rocks are probably now much disturbed from their thrust relations on account of later normal fault displacements.

Whenever the schist which had thus been thrust was brought by thrust or by later normal faulting against phyllite or schist which had been overridden it would probably not be possible, oftentimes, to tell the two terrigenous rocks apart, except possibly by difference in metamorphism of the moved rock.

South of Pine Hill minor thrusts would have broken and dislocated parts of the Lower Cambrian series with respect to each other and another deeper thrust would have truncated these; but the various thrusts, cutting and thrusting here in different ways from those at the north, would presumably have produced the peculiar minor features present at the south. The overlap of Cambrian on the marble would, however, have been produced.

If at some subsequent time these overthrust rocks were broken by differential tension faulting and dropped, as has been argued, the marbles under the overthrust would have been carried down, except at Dorset Mountain, perhaps, and at other places south of it, and after erosion we should see the conditions as they are today. It seems possible that portions of the main part of the Taconic range may be overthrust masses that are now protecting younger limestone (marble) at depth. West of the preserved overthrusts the limestone, because unprotected, has largely disappeared by erosion.

BENNINGTON AND RUTLAND COUNTIES.

Townships of Shaftsbury, Arlington, Sunderland, Manchester, Dorset, Rupert and Pawlet.

(Equinox, Londonderry, Wallingford and Pawlet topographic sheets.)

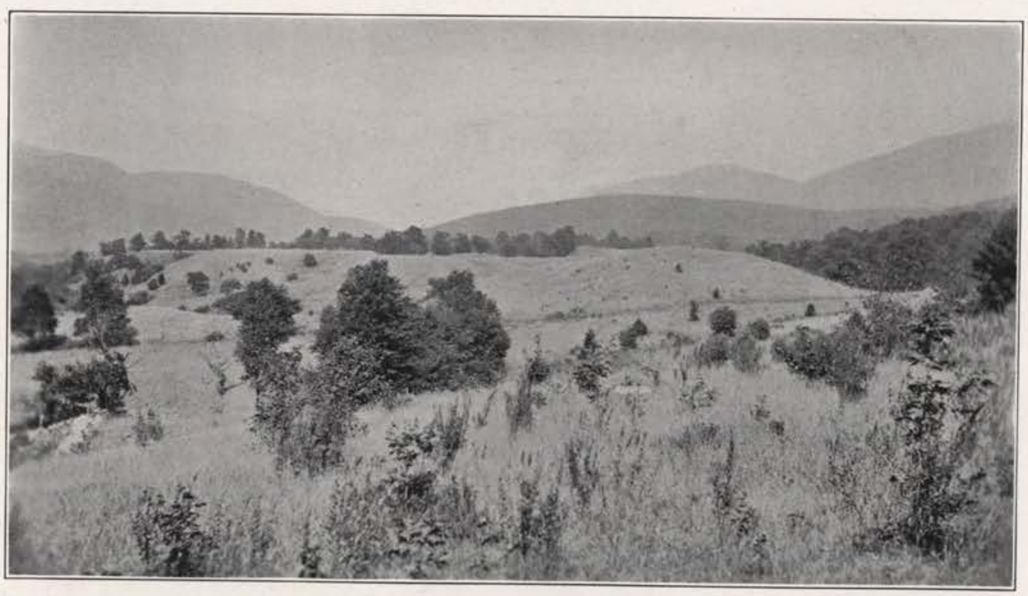
Topography. The areas examined in these townships lie mostly in the Vermont valley or that of the Mettawee River. For the most part the topography has been sufficiently described in speaking of the physiographic divisions of western Vermont.

Observations in certain parts of the Vermont valley through northeastern Shaftsbury, Arlington, Sunderland, Manchester and Dorset. The observations of the writer to be noted of the exposures and relations of the rocks in the towns mentioned in the heading of this section were made chiefly along the eastern part of the Vermont valley. The rocks along the western part were only casually inspected. It was the purpose to make a more

PLATE XXXIII.

Small fold illustrating structure frequently seen in the interbedded and dolomitic rocks of the Lower Cambrian series along the east side of the Vermont valley, but less plainly shown in larger folds on account of abrasion. This view is two miles east of Arlington. Equinox Mountain in the distance.

PLATE XXXIV.



Terraced plain and kame deposits a mile and a half northeast of Manchester Depot, east of the Batten Kill, showing the occasional character and the thickness of the modified drift covering in parts of the valley. The deposits were probably marginal and in part a delta-plain formation in a lobe of the ice sheet. View looking north up the Vermont valley. Photograph taken from the west slope of a kame.

critical examination of them later during the same season (1918), which illness prevented, in connection with the mountain rocks on the west side of the valley.

The surface covering is heavy along the eastern side of the valley most of the way from Shaftsbury to Manchester. On this account it did not prove possible to work out much concerning the precise interrelationships of the hard rocks.

The interbedded dolomite-quartzite series of the Lower Cambrian as seen in the eastern parts of Bennington and Shaftsbury was traced northward into Manchester and it was noted that the rocks continue to show northward at many places the characteristic topographic form of elongated arches which will be described for the areas at the south.

East of Shaftsbury village the folds of members of this series exhibit overturning to the west as was noted so often farther south and which is a very characteristic attitude which has been acquired by these interbedded rocks along the valley. Plate XXXIV shows this overturning on a small scale and in this case is a perfect replica of what occurs all along the valley on a larger scale, but which in the larger folds is obscured by abrasion. Any further description of these hills of the interbedded rocks throughout their extent from Shaftsbury to Manchester would be largely repetition.

It should be noted that the hills of these rocks do not lie snugly along the base of the slope of the Green Mountain plateau that fronts the valley on the east, but are separated from it by a space of varying width in which there is much modified and other drift material.

East of East Arlington village, north of "Kansas," streams have worn through from 75 to 100 feet of sand and gravel without exposing the basement rock. Plate XXXIV shows the present character of some of the kame and terrace covering that surrounds the hills of Lower Cambrian rocks and apparently overlies other parts of the series. Other areas are bowlder strewn and have apparently a relatively thin covering of bowlder drift. The quartzite and overlying members of the Lower Cambrian, in relations like those in Shaftsbury and Bennington, doubtless underlie the drift and the series probably extends all along the eastern side of the valley through these towns.

Quartzite was traced at several places up the steep slopes of the plateau. All the relations indicate that the valley rocks are dismembered portions of the plateau as is the case at the south near Bennington and at the north near Brandon. Although the quartzite was not noted in the valley between Bennington and Manchester in actual surface outcrops, southeast of Manchester the abundance of quartzite bowlders over certain areas suggests that the quartzite is not far below the surface there.

The Vermont valley widens out in Manchester and about 4 miles north of Manchester Center, marble outcrops extensively at the surface and is worked in quarries at South Dorset. Other quarries have been opened between South Dorset village and the southern base of the Dorset Mountain mass and still others high up on the southern slopes. While the quarries at South Dorset are in some cases below the 1,000 feet contour, some of those near Owl's Head on Dorset Mountain are about on the 1,900 feet contour.

The different elevations at which the marble is worked on the south of the Dorset Mountain mass and the topographic outlines suggest a probable displacement by which the marble of the valley has been dropped from a higher level.

At the old Norcross quarry (see plate XXXV) a certain thickness of dolomite now rests with sharp contact on the marble and is well exposed in the north face of the old part of the quarry. The dolomite is infolded somewhat with the surface of the marble. The rock has much the same relation that a similar rock has to a marble in Swinington's quarry at Leicester Junction, which is right on the western margin of the calcareous members of the Lower Cambrian series in the township of Leicester.

In the quarries examined around South Dorset the marble shows the same internal deformation in the form of flow structures that marks the marble nearly all the way along the Vermont valley. It is in contrast to the interbedded series of the Lower Cambrian just as it is near Brandon. It is more metamorphosed in most cases than the dolomite that at certain places lies on it.

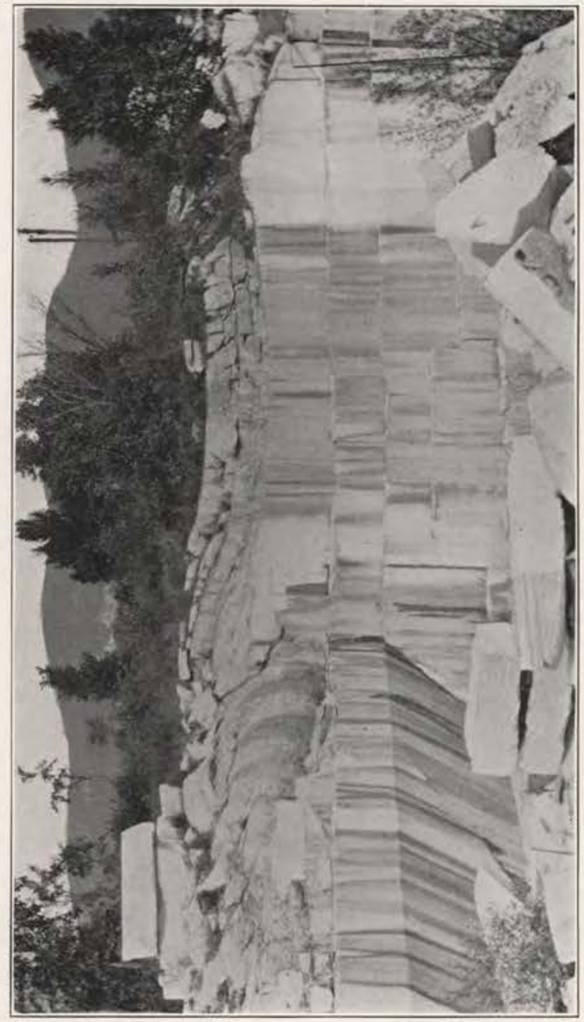
Observations along the valley of the Mettawee in Dorset, East Rupert, North Rupert and Pawlet to Granville, N. Y. Scattered observations were made along the valley of the Mettawee from South Dorset to Granville, N. Y. Some features of interest were observed.

Limestone or marble was noted along the road a mile east of East Rupert.

From East Rupert to North Rupert the hill slopes along the valley road were only casually inspected, but no difference was noted between the terrigenous rocks that compose them and those which have been described on previous pages for the hills in the northern part of the range.

Northwest of North Rupert the hill slopes on the south side of the road were more carefully examined. Here are the black and light-colored phyllites, the crinkled and more massive quartzites, making up precisely the same assemblage as to be found in the Sudbury and Orwell hills. They cannot be told apart. Two and a half miles northwest of North Rupert, south of the valley road to Pawlet, at the end of a short, blind road, limestone rests on the phyllite. A mile north, south of the main road, are excellent exposures of dove-colored limestone with gray patches of dolomite and other exposures in which the gray rock makes up practically the entire visible mass. More careful examination than

PLATE XXXV.



A portion of a stratum of dolomite now seen resting upon and folded with marble in the old Norcross quarry at South Dorset.

the writer was able to give on a day's tramp would undoubtedly disclose more extensive outcrops of the calcareous rock in a relation to the phyllite similar to that which has been noted at so many places.

From the outcrops last described, the hill slopes along the road through Pawlet give the phyllites. At Indian Hill and a mile east of it along the road are crinkled quartzites and light-colored, siliceous phyllites.

From North Pawlet a fine series of scarps can be seen bounding Burt, Cleveland and Lincoln hills and Pond Mountain on the west, and an east-west scarp on the south of Haystack Mountain.

Summary. Whatever its meaning may be, a section from the Green Mountain plateau east of Manchester carried northwesterly through Dorset along the valley of the Mettawee to Granville gives a repetition of the section from the Green Mountain plateau east of Brandon carried over the Sudbury and Orwell hills with certain differences that are less impressive than the resemblances. The Lower Cambrian rocks have practically the same relation to the marble, the calcareous rock rests on essentially the same terrigenous formation, and the latter presents the same difficulty of division into parts on the basis of age or other characters. More slate appears in the southern section (west of North Pawlet) and because of size of exposure permits easier arbitrary field division and mapping, but similar slate occurs in the northern section at several places.

The Vermont valley and eastern slopes of Dorset Mountain in Dorset and southern Danby. The valley narrows north of Manchester between the plateau and the mass of Dorset Mountain. The interbedded series continues northward in the narrow space between the steep western slope of the plateau and the abrupt eastern slope of Dorset.

In East Dorset village along the road and just above the buildings of the East Dorset Marble Co. are beds of dolomite. At the later place they pitch in a northerly direction. The writer was unable to decide what this dolomite represents, unless it is below the interbedded series and a part of the Cambrian.

North of the road from East Dorset village up the eastern slope of the mountain (Green Peak) and some distance up the slope the interbedded series is plainly visible. The writer's notes give a westerly dip for these beds at a point well up the slope. Schistose limestone with some slaty rock were noted a short distance up the eastern slope from East Dorset station near the road.

The eastern slope of the mountain impresses one as being bounded by normal faults. The great apparent thickness of calcareous rocks that appears along the slope may be due to displacements along more than one plane as the rocks now in the valley at the east and south were dropped, leaving the marble and associated rocks after erosion in view at the higher levels and the interbedded rocks at the surface on the lower slopes and in the valley where the marble is now concealed beneath them. The idea of faulting is borne out by the general relations roundabout as well as by the aspect of the mountain slope itself.

The marble on the east face of Green Peak and northward is quarried at about the same level as that at Owl's Head. The fact of the same general level for the quarries may be made out from the valley road. At the Dorset Hill quarry the same features of metamorphism that have been mentioned for the marble elsewhere were noted, as also the facts that while bedding is now largely gone and flow structure and crystallinity have been induced, the marble stratum or mass lies in a flattish position as a whole, indicating that the metamorphic structures which it shows were probably induced under confinement of the mass and suggesting that similarity of relations or conditions prevailed over the wide area in which similar marble now occurs while these features were in process of formation.

Overlying the marble in Green Peak and northward practically continuously to Dorset Peak, is the so-called "Berkshire Schist" which, it is here interesting to note, is really a mass of interbedded schistose and phyllitic rocks with thick beds of quartzite and which as a whole, except for their aspect of somewhat greater metamorphism, do not look conspicuously unlike the quartzite-phyllite assemblage of the Hubbardton, Benson, Orwell and Sudbury hills.

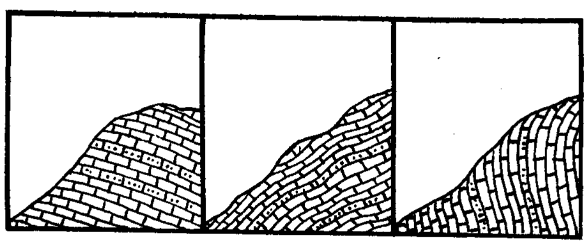


FIGURE 18. Sections to show different attitudes at different places of the interbedded series of the Lower Cambrian along the summit of an anticlinal ridge in the valley between Dorset Mt. and the plateau.

In the valley two miles north of East Dorset and east of Dorset Pond, on the strike of the northward-pitching dolomites at at East Dorset station, light-gray dolomite of the interbedded series forms a ridge. The rock is rather thinly-bedded at many places. Along the summit or upper portions of the western slope the beds may at one place be seen dipping rather gently easterly, at another westerly, and still another standing on end or dipping easterly at a high angle (figure 18). There has clearly been overturning to the westward, as is indicated by the variations in the dip of these anticlinal beds along and near the axis of the

fold. The same structure in these interbedded rocks is shown in the narrow valley here as in the wider portions at the south and north.

North of North Dorset a clear scarp defines the basal portion of the eastern slope of Dorset Peak. The ridge of interbedded rocks described in the preceding paragraph continues northward east of the railroad track for two miles north of North Dorset and then drops gradually off into the lowland of Otter Creek. Near its northern termination it is marked on the west by a moderate but steep scarp. West of the track and the highway, a hill of the same rocks rests against the scarp at the base of Dorset with a low scarp on the south. These rocks appear greatly crushed.

In the Vermont valley in Dorset one finds in the same rocks evidence of strong compression and also of displacement by normal faulting. Along the lower contours some of the scarps have been cleaned apparently at a relatively recent date. Erosion prior to the glacier had so softened the outlines of the higher eastern slopes of Dorset that although they are now steep, the probable fault planes do not now emerge as pronounced scarps even after ice action.

The observer is impressed in Dorset, as elsewhere, with the contrast between the plainly-bedded although withal strongly-folded Lower Cambrian rocks and the severely altered marble, and, in addition, senses some important structural significance in the presence of the high mass of this Taconic mountain flanked by Lower Cambrian quartzite so close to the plateau, and the narrow valley in between surfaced with the upper members of the Lower Cambrian series which also extend up the eastern slope of Dorset Mountain.

BENNINGTON COUNTY.

Towns of Pownal, Stamford, Bennington, Woodford, Shaftsbury and Glastenbury.

(Bennington and Hoosic topographic sheets.)

The geological relations in southwestern Bennington County were examined by the writer in 1912 and made the subject of a paper entitled, "Notes on the geology in the vicinity of Bennington, Vt."[1] The map and descriptions therein given included the township of Bennington, the major parts of Pownal and Shaftsbury, and portions of Stamford, Woodford and Glastenbury. It will therefore be convenient to review under one heading certain relations described in the paper mentioned which bear upon the present discussion, as well as to place on record some later observations made in the region and to offer some modifications of conclusions previously offered.

[1] Ninth Report of the State Geologist, 1914.

Topographic features. This area includes the southern portion of the Vermont valley, which is hemmed in on the east by the steep slope of the plateau except where this is cut by the valley of Walloomsac Brook. East of Bennington and north of Walloomsac Brook the western margin of the plateau is offset to the west about two miles from its course south of the stream.

The valley narrows south of Bennington and is intercepted by a ridge of schist which separates it from the valley of Hoosic River that enters Vermont from the Berkshire valley in Massachusetts. This schist ridge abuts against the plateau in Pownal. Thence it extends northwestward and terminates in Mt. Anthony in Bennington. The valley which comes down from the north through the towns of Manchester, Sunderland and Shaftsbury is bounded on the west by a high range which terminates west of Shaftsbury Center in West Mountain. Between West Mountain and Mt. Anthony is a wide open valley area which marks the extension of the Vermont valley into the Hudson valley region.

Relations southeast, south and southwest of the town of Bennington. In Stamford Mountain a gneiss that is believed to be of pre-Cambrian age is exposed at many places. Flanking this gneiss on the west and also extending around the southern end of the mountain into Massachusetts and then northward into Vermont again on the eastern side of the mountain is quartzite, which at many places in what appear to be basal beds is a massive, coarse, white, granular rock or a massive, compact, thick-bedded, brown formation. This passes upward into thin-bedded, schistose quartzite.

Glastenbury Mountain, north of Stamford Mountain, is also flanked on the west by scarps of quartzite. Faults separate these mountain masses from each other and bound them on the west. At the bases of the scarps on the west of the plateau lies a series of rocks which, when all members are present, has a quartzite at the base, essentially similar to that of the plateau, overlain by a certain thickness of dolomitic limestone, which is succeeded by an interbedded series whose members are sometimes dolomites, sometimes calcareous quartzites, and sometimes almost pure quartzites. Unless disturbed these rocks apparently are conformable.

When the series just mentioned was first described by the writer, owing to the limited time which was spent in areal mapping and lack of opportunity to check up certain portions of the area, it was not possible to speak positively respecting the westward extension of the series and its present western surface boundary. Much of the calcareous rock outcropping in limited exposures through the heavy surface mantle, in the western half of the valley, both north and south of Bennington, was simply termed limestone, in the absence of certainty as to correlation with the interbedded series or its subjacent dolomitic limestone, or of any fossil evidence as to age.

As surface outcrops this interbedded series is present in greatest force and is best exhibited northeast of Bennington. As first mapped by the writer it was shown as a rather regular strip about two miles wide along the eastern side of the valley northeast of Bennington and as a somewhat narrower strip southeast of Bennington, with its western boundary and the relation of the calcareous members to the quartzite not clearly defined. South of Bennington a strip about two miles wide was shown as "limestone formation," with only two rather limited exposures of the inbedded rocks at somewhat widely separated places along the eastern edge of the strip. At one of these places, which is southeast of Barber's Pond, the rocks are overlain by a black, shiny, graphitic-looking phyllite, which appeared conformable to the underlying beds. This is the only place in western Vermont which the writer has noted where the interbedded series is overlain by a schist or phyllite.

In Pownal the calcareous rocks of the valley are intercepted or interrupted at the present surface by the schist of Mason Hill and by the quartzite of the plateau which come together along a fault plane.

From their relation to the quartzite in which Lower Cambrian fossils have been found the calcareous rocks of the series just described are regarded as of Lower Cambrian age.

Some revision of the writer's previously-held ideas has proved necessary for the extension of the Lower Cambrian rocks around Bennington. Observations which were made during a short trip in the season of 1920, after a further acquaintance with Vermont rocks had been gained, may be offered here as some of them have an important bearing on the present paper.

Just south of Main street in Bennington, near the cemetery, dipping easterly at an angle of about 54°, are beds which were originally called simply limestone, but which now are regarded as members of the interbedded series. Similar beds outcrop along the road leaving Main street for Camp corner and again in a quarry besides the road three-fourths of a mile south of Main street. In the latter place the beds can be seen to be greatly disturbed and standing at a high angle, apparently overturned. One-half mile south of this quarry, on the northern slope of the hill, the same rocks lie in a flattish position, showing hardly any buckling and apparently pitching slightly to the south. One mile south-southeast of these flattish beds the interbedded rocks stand on end about 40 or 50 rods west of the old lumber mill on South Stream.

Within less than a mile therefore, east and west across the strike, allowing for a few offsets north and south within a mile, the interbedded rocks pass from a closely-compressed fold through almost flat position to highly inclined beds. It is certain that the drift conceals disturbed structural relations among these beds. Along the hill road from Bennington to Morgan's corner and in the fields outcrops are few. Along the east-west road from Morgan's corner to the main road from Bennington to Pownal were observed some westward-dipping beds which were also apparently members of the interbedded series.

About two and a half miles south of Bennington, just south of Robinson's cross-roads and west of the main Pownal road, a hill shows a series which was examined and finally assigned to the interbedded stratum. The rocks are largely dolomitic but carry some siliceous beds. They dip westerly on the east side, but westward within the distance of half a mile the rocks show confusion and brecciation and then a marked change in the character of the rock, which will be described beyond. The confusion and brecciation are approximately on the line of strike of greatly brecciated rocks two miles to the north near Bennington.

It further seemed to the writer that certain calcareous beds and associated rocks, two and a half miles south of these outcrops in the hill just described, north of Pownal Center, at the base of the hill road running westward to Petty Corner, also belonged to this interbedded stratum. Perhaps a hundred and fifty yards up the steep hill, in the bed of the brook, south of the road, are quartzite, schistose quartzite and sericite schist or phyllite, apparently all conformable with each other and dipping easterly at a low angle near the top of the hill. At the top of the hill along the road to Petty Corner and northward along the road west of Carpenter Hill are ledges of sheared quartzite and quartzitic schist which the writer now considers to be of probable Lower Cambrian age from their resemblance to other rocks in the region. When first described and mapped in 1912, these rocks were simply designated as a part of the terrigenous formation that forms the Mt. Anthony-Mason Hill ridge.

The writer would now draw the western boundary of the Lower Cambrian calcareous rocks of the valley, from Pownal Center north to the Pownal township line, close to the base of the schist ridge.

The observer passing along the main road from Pownal Center towards Bennington would hardly fail to note the low but steep, eastern, scarp-like margin in the ridge which extends from just north of Pownal Center north to Carpenter Hill. At Pownal Center the schist-quartzite formation crosses the highway to join the schist of Mann Hill. The scarp just mentioned is low at Pownal Center but increases in height northward. At some places the members of the calcareous series give a false impression of passing beneath the quartzite-schist formation of the ridge, but at other places they seem rather clearly to be faulted against it. The rocks at the surface of both valley and ridge from Pownal Center to Carpenter Hill now appear to be members of the Lower Cambrian series of the general region. It is the writer's opinion that an east-west section at the surface in the northern part of Pownal township from the quartzite of the plateau across the valley to and including the terrigenous rock of the eastern part of the ridge probably gives only Lower Cambrian rocks.

In Pownal Center along the road to North Pownal is a schistose quartzite, which from the coarseness of its laminations might be called a quartzitic gneiss. To the writer it appeared quite the same as other rock found in the plateau and at other places in the Taconic hills. This rock gives place westward to blackish, pyritiferous, gritty schist or phyllite. The latter, greatly crumpled and jammed and carrying much quartz in seams and bunches, occurs along the western slopes of Mann Hill and is particularly well shown along the highway and trolley road from Pownal to North Pownal and in cuts along the road from Pownal to Pownal Center. The rock at the summit of Mann Hill is a silvery, often greenish, sericite schist. Its apparent counterpart was observed, one and a half miles north of Pownal Center in the beds of the brook coming down from the hill south of the road from Petty Corner to the valley road, and was there apparently interbedded with schistose quartzite, (see above).

The schistose quartzites, gritty schists and black, pyritiferous phyllites of this ridge, at least from the latitude of Carpenter Hill southward, bear close lithological resemblance to rocks which are very common in the hills of the northern portion of the Taconic range and which are described above. The lighter-colored, finer-grained, more homogenous, siliceous phyllites common at the north were not so frequently observed in the exposures examined in Pownal.

It is very hard to decide on the basis of lithology alone whether all the schist and phyllite belong to one formation. It seems clear that field relations among the various rocks may simulate something very different from what they really are on account of complex deformation and that in the absence of definite criteria, assignment must be made on the basis of probability. It has been particularly noted above that in the Taconic hills farther north in Benson, Orwell, Sudbury and Brandon the black phyllites, finer-grained, light-colored, siliceous phyllites, grits and schists appear to pass into one another at the surface and that it becomes practically impossible to discover any particular arrangement or field relations among any of them that could be used to separate them as belonging to different formations or terranes. Moreover, in the Bennington region on West Mountain in Shaftsbury, the schist formation carries the lighter-colored phyllite with the other members and it appears to be still an open question whether the schist formation of this mountain is in whole or in part Lower Cambrian as mapped by Walcott, or Ordovician as mapped by Dale and formerly suggested also by the writer (1914).

East of Pownal Center, on the northeastern slope of Mann Hill, limestone rests on the schist in patches and the two show much intermingling of outcops and great confusion. It was not possible to make any correlation of the limestone on the basis of lithology. The dip of schist and limestone often seem the same. Near Irish corner some early notes indicate the presence of a bluish or dove-colored limestone carrying gray patches like the rock to be described beyond.

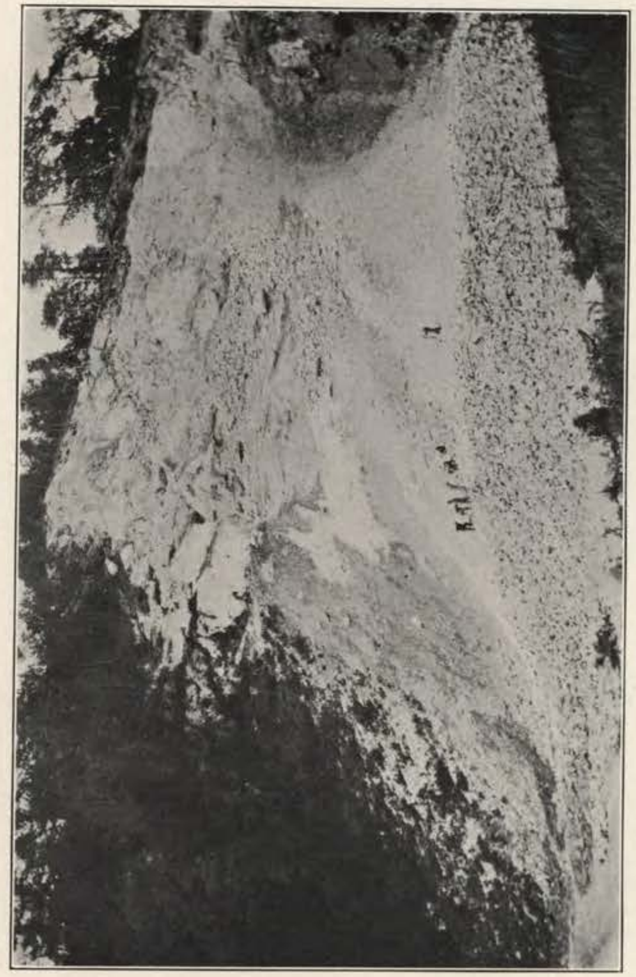
At North Pownal village a scarp of limestone begins a short distance south of the mill of the Pownal Lime Co. and runs northerly parallel with and east of the main road through the village to Whipple's corner. In the quarries of the Pownal Lime Co. the limestone is without definite bedding, appears mashed and shows black, pyritiferous phyllite overlying it and jammed in with it. Plate XXXVI.

Under the highway, between it and the raiload track, in North Pownal village is greatly crumpled schist and the limestone seemingly rests on it. Although no contact was observed here two miles south, west of the Hoosic River, limestone and schist were found in relations which permitted no other interpretation than that the limestone rested on the schist formation. East of the high limestone hill in North Pownal village there are occasional areas in which limestone and schist outcrops intermingle at the present surface. Except for some outcrops of dove-colored rock carrying wavy stringers or layers of quartz one-half mile north of Wright Bridge corner, nothing was observed in the limestone in the vicinity of North Pownal that assisted in its correlation. In the writer's first description, from the general field relations and apparently isolated character of this limestone, it was regarded as a faulted inlier. It will be referred to again in the discussion of the possible general structural relations of the Bennington region.

The rocks southeast of Bennington present some further features of structure and arrangement which should be mentioned.

The writer's first map showed the valley quartzite southeast of Bennington as bounded by a fault on the west and there is still reason to think from the flattish position of the interbedded calcareous and quartzitic rocks in the bed of South Stream, as shown near the lumber mill and nearby, that there is a rupture between these flat beds and the closely-compressed similar rocks that lie just west, as above described. What was shown on the map as valley quartzite southeast of Bennington may and probably does have at various places some of the calcareous members of the series resting on it, as is the case in the bed of South Stream; but east and southeast of Bennington stream deposits,

PLATE XXXVI.



Photograph to show the structure of the limestone at North Pownal. The picture shows how the limestone has been crushed. At the right, phyllite, a black, pyritiferous rock, is shown resting on the limestone and lower down as jammed in with it.

carried into the valley at the time of glacial flooding, largely conceal outcrops except as exposed in the beds of streams.

West of Harmon Hill the valley quartzite from a scarp in the gneiss dips gently westward and passes beneath this mantle of stream deposits, but southward on the east, along a strike fault plane within the valley quartzite, a scarp appears which continuing southward rises in altitude and seems to form the main displacement that separates the quartzite of the plateau from that of the valley.

No apparent distinction is to be drawn between the quartzite of the plateau and the valley. They are the same in all essential characters and one in fact merges into the other where a strike fault scarp, for example, along the edge of the plateau dies away into a slope or monocline of the plateau quartzite. In the writer's first descriptions of this region the obvious displacements along the western edge of the plateau were regarded as reverse faults by which the gneiss and its overlying quartzite were thrust up into younger rocks, with repeated breaks along the strike. The valley quartzite was also thought of as having been elevated independently against younger rocks at the west and dropped later by normal faulting.

While there seem to be probable ruptures in the rocks of the valley by which they now stand in displaced relations to each other, some modification of the original description, which the map therewith attempted to show, is necessary if the Lower Cambrian series has the westward extension suggested in preceding paragraphs.

In the first description of the region a sort of assumption was made that in the vicinity of Bennington there is now a considerable but unknown thickness of Ordovician terrigenous rocks at the surface. For the pre-Cambrian gneiss and its associated Lower Cambrian quartzite to have their apparent present relations to the so-called younger masses, reverse faulting was assumed to have occurred along what is now the western edge of the plateau and also along planes that now lie within the valley. To the writer there still appears much field evidence to bear out the idea of an elevation of the pre-Cambrian floor; but the deformation by which the rocks of the Bennington area, and of western Vermont generally, came to be as they are, seems to be capable of comprehension, if at all, only through the study of a wide region.

Southwest of Bennington town are numerous puzzling relations which bear upon both the stratigraphy and structure of the region.

In an area just southwest of Bennington, bounded by South street, Dunham avenue and the Pownal road, occurs a bluish or dove-colored limestone carrying many small streaks and patches of gray or chamois color, and associated with beds of gray or light chamois-colored rock. These rocks have been noted elsewhere near Bennington, as will be discussed beyond. In one outcrop what appeared to be a few encrinal stem fragments were found. This rock is greatly sheared and near the Pownal road carries bands of brecciated limestone. On account of the sheared structure it was usually not possible to decide whether the eastward dip is that of shearing or bedding, in the sheared rock itself; although in one place the dove and gray seemed clearly to be interbedded and to dip easterly. In another place, perhaps two hundred yards south of mixed sheared and brecciated rocks, and along their general strike, were somewhat thick-bedded, gray limestones dipping westward about 20 degrees.

On the east side of the Pownal road, just south of the junction with Dunham avenue, dark, bluish limestone forms a ledge beside the road and the bedding planes can be distinguished standing at a high angle, sinuously bent along the strike and apparently slightly overturned. Strong shearing along many planes close together has greatly obscured the bedding and produced a sort of slaty limestone, (figure 19).

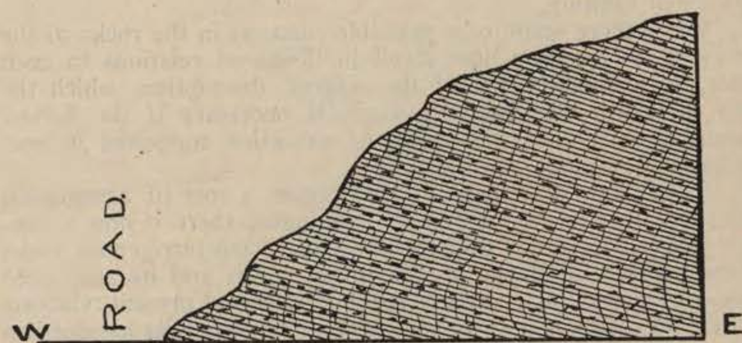
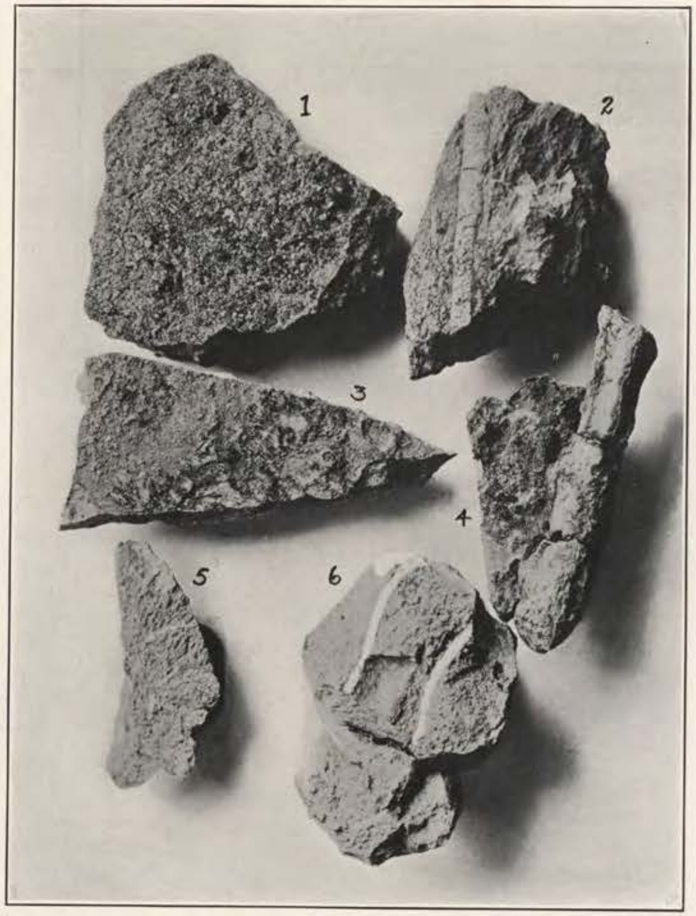


FIGURE 19. Schematic section of limestone as shown in a ledge near the junction of the Bennington Center-Pownal road and Dunham avenue in Bennington. Limestone is close to or involved in a zone of crushing and an easterly-dipping shearing has nearly obliterated bedding.

The general strike of the rocks just described is approximately north and south. Just east of the Bennington Center-Pownal road, in the fields between Dunham avenue and the next road north, are many ledges over an area several acres in extent, in which the limestone is greatly brecciated, some of the fragments being several inches in diameter. West of the Pownal road, a few hundred yards northwest of these brecciated outcrops, the limestone shows a strike of N. 81° W. and a dip of 24° southerly which correspond in general with the strike and dip of the heavy limestones and marbles that form the northern slope of Mt. Anthony.

PLATE XXXVII.



Various fossils found in the vicinity of Bennington. Numbers 1, 2, 3 and 4 collected in South Shaftsbury about 2 miles north of North Bennington village. Numbers 5 and 6 found 3½ miles south of Bennington town near Carpenter Hill. The forms are described in the text and are regarded as probably of Chazy age.

The sheared blue or dove-colored limestone described above is traceable, with long interruptions, from the outcrops north of Dunham avenue for two miles south-southwesterly to some ledges just west of the road over Carpenter Hill and one mile southwest of Robinson's cross-roads. At this place the sheared, patchy, dove-colored rock and its gray associate occupy a prominent knoll and form conspicuous ledges. In the blue rock were found distinct fossil markings, including a much-worn spiral of the size of and identified as *Maclurea magna*, a smaller probable *Maclurea* about two inches in diameter (fig. 5, plate XXXVII), and two specimens like that shown in number 6, plate XXXVII. On the basis of fossils and the resemblance of the rock to Chazy beds examined elsewhere in Vermont these rocks are put in that terrane and regarded as probably Middle Chazy. These rocks may be represented east of Pownal Center near Irish Corner, (see above).

North of these outcrops, along the eastern slope of Mt. Anthony the relations are very obscure. At some places, particularly towards the northern end, thick-bedded marbles dip westerly into the mountain. The dip changes northward to southwesterly and then to southerly. The mountain gives the appearance of being of synclinal structure with southerly pitch and of being composed of thick limestone or marble beds at the base, which are capped with schist. In a quarry in the woods on the east side of the mountain and west of the Everett mansion, and also in Colgate's quarry on the northwest side, along the North Pownal road, a blue, crystalline limestone stratum is seen to lie just beneath the schist. This rock is of uncertain thickness, but its strike and dip seem to indicate that it is conformable to the marbles below it. It has not been identified in the region in any other relations than those just described.

Notes taken in 1912 indicate absence of noticeable crushing in the schist at Everett's quarry and describe the contact between it and the limestone as apparently conformable. The phyllite contact was described as disturbed at places in Colgate's quarry, although in the northeastern part of the quarry a contact similar to that in Everett's quarry could be seen. Internal deformation in the schist is more apparent than in the limestone, as perhaps would naturally be expected, whether in place or not. The calcareous rocks beneath are all highly crystalline, but apparently not deformed like the marbles that have been noted as occurring farther north. The contrast which the calcareous rocks underlying Mt. Anthony, as well as others which occur north of it and have much the same dip, have to the sheared and brecciated rocks of the general vicinity is very marked and goes with other field relations to show that most of the strata of the region have been greatly disturbed.

It should be noted that the drift covering is heavy over the western part of the valley south of Bennington and that on that account much uncertainty must exist as to the extent to which Lower Cambrian rocks form the hard rock substratum over this area. Moreover, there are outcrops of limestone over this region which cannot be assigned with certainty to the Lower Cambrian or to any other terrane. In the Bennington region what is immediately subjacent to the Lower Cambrian of the valley cannot be stated in any measure, so far as the writer's knowledge goes. Farther north in Vermont there is good reason to think that the marble formation, whatever its age, is overlain by Lower Cambrian rocks, as has been shown.

East, northeast and north of Bennington. It has not appeared necessary to modify in any essential particulars the relations as described in the author's previous paper for the areas east, northeast and north of Bennington. They may be very briefly reviewed.

A broad band of Lower Cambrian rocks extends along the eastern side of the valley under the scarp of the plateau. In its southern part, except for a small area of dolomitic limestone and overlying interbedded rocks near Bennington, quartzite forms the only surface rock over a distance of about 4 miles. In the southern portion of the band there is apparent a low southerly pitch and the arrangement of quartzite, limestone and interbedded rocks shows a conformable series, (figure 20).

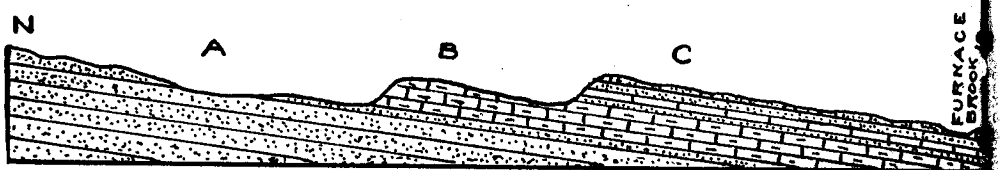


FIGURE 20. A generalized north-south section of the southern portion of the Lower Cambrian series north of Bennington, as displayed just east of the Bennington Poor Farm. Southward pitch exaggerated. A, quartzite; B, dolomitic limestone; C, interbedded dolomites, calcareous quartzites, and quartzites. All apparently conformable.

The quartzite at its northern end forms an anticlinal buckle which presents great ledges of white, granular quartzite on its eastern slopes. These have complete similarity with similar quartzite in the plateau just east of the valley quartzite and the latter is looked upon as a dismembered portion of that now flanking the plateau. Southward towards Bennington the coarser quartzite passes upward into somewhat thinner and more schistose beds and thus gives the same transition that may be observed on the western quartzite slope of "The Dome" in Pownal. On the west the surface slope of this valley quartzite descends across the edges of the beds.

At the north the valley quartzite just described, in the town of Shaftsbury, is apparently cut off by a tranverse fault. The quartzite is succeeded abruptly at the surface by limestone which form a series of arches elongated along the strike. Farther north these are replaced by similar arches of the interbedded rocks. The succession going north is thus seen to be from quartzite through limestone to the interbedded members of the series; but the members have been more disturbed with reference to each other than is the case over the southern portion of the strip. Moreover, there is apparent a series of displacements along the strike as well as folding and faulting across it.

The arches described consist of compressed folds of limestone or of the interbedded rocks and the beds frequently show overturning to the west. The arches, including the one in the quartzite and those south of Bennington, are all of similar genetic type. Northward these arches give a characteristic topographic form to the surface of much of the Vermont valley as has been mentioned.

The members of the Lower Cambrian series north of Bennington, just described, were not positively identified in any part west of the westernmost exposures of its basal quartzite member as this outcrops along the South Shaftsbury road. Much surface material covers the rock northwest of Bennington in the central and western parts of the valley. The probable correlation of certain outcrops southeast of South Shaftsbury village and in the cuts of the Rutland R. R. north of the village is not now apparent. In the writer's map of the Bennington region a probable fault was shown as bounding the whole Lower Cambrian series on the west from Bennington north to the limit of the map. For the most part the line to mark this fault was drawn some distance to the east of South Shaftsbury road. Near Bennington, however, it crosses that road at the junction with the "Stony Hill road." The boundary as thus shown was drawn partly to emphasize the close age relations of the rocks forming this broad band along the east side of the valley and partly to record the surface features indicative of displacement along their apparent western margin at the northern end of the strip.

It might be noted here that some fragmentary outcrops of siliceous and dolomitic rocks somewhat resembling the members of the interbedded series were observed one and a half miles north of North Bennington village; but it did not seem possible to determine whether they are in place.

West and northwest of Bennington. The general southerly dip that marks the limestone and marble beds on the northern slope of Mt. Anthony was traced northward to and across the Bennington-Hoosic road and was noted distinctly three-fourths of a mile northwest of the monument at Bennington Center. While the rock in North Bennington, which will be mentioned presently, shows some difference in strike and dip from that south of it, the two bear resemblances with respect to absence of pronounced internal deformation such as other rocks of the region show.

Along the banks and in the bed of Paran Creek, south of North Bennington village, the limestone beds have a strike, according to one reading selected as fairly representative, of about N. 80° E. and a dip of about 11° south-southeasterly. On the west side of the road west of the creek, opposite the office of the Cushman Furniture Company, are beds of dark gray limestone ranging in thickness from about two feet at the base of the exposure to about 10 inches or a foot near the top. Similar beds outcrop just below the dam of the Stark Paper Mill and above it farther up stream. No fossils were found and no correlation seemed justified on any basis.

In Shaftsbury a mile and a half north of North Bennington village, in the woods on an east hill slope, southwest of Twitchell's corner, were found a few ledges of the same sheared, patchy, dove-colored rock and its gray associate seen southwest of Bennington, west of the road over Carpenter Hill. The dip is westerly into the hill about 25° and the strike N. 40° to 50° E. The exposures are limited with drift all about. The dove-colored rock is plainly fossiliferous, but the markings are obscure. Spiral lines and patches representing coiled shells of some kind were noted at several places. These were hard to remove. Figure 3, plate XXXVII, gives an indication of the markings, but some of those found at the locality now being described were much more plainly shown to be sections of coiled shells. At this locality occurs a thin bed with abundant sections of small encrinal stems (fig. 1). This same bed at one place yielded two orthoceras-like specimens (figs. 2 and 4) which, however, it is hardly possible to identify. Some of the rock seen on surfaces cutting across the bedding is distinctly striped in appearance. It was at this locality that some fragmentary dolomitic and siliceous rocks, very limited in exposure, were noted. They bear some resemblance to the interbedded members of the Cambrian farther east; but from observations made about a mile farther west where more extensive siliceous beds seem to belong with a series which includes also the striped and dove-colored rocks, their Cambrian age was regarded as improbable. The fossiliferous rock and its associates are regarded as probably Chazy. It seemed likely that *Maclurea magna* might be found but a careful search did not reveal it.

Northwest of the limited exposures just described, over the hill, across a road and down a northwestern slope to a brook, for a distance of about a mile is nothing but drift. Just west of this brook and north of the road to Cold Spring Corner are low-lying ledges of black, pyritiferous phyllite. This rock passes northward beneath greatly jammed and distorted limestone in which the patchy, dove-colored rock appears again in association with gray dolomite beds, which are infolded and otherwise involved with the other rock. These beds of limestone clearly rest on the phyllite. The deformation of the limestone beds is very severe; they are folded and overturned, profoundly sheared, jointed and mashed. Fossils have not escaped. In one exposure only, a small slab about 6 feet square, and perhaps not in place, although lithologically resembling some of the ledges and quite like some rock seen a mile east, showed some coils, most of which were thick patches but clearly fossils. A piece of this slab is shown in figure 3, plate XXXVII. The ledges at this place were similar to those described above as carrying fossils.

Westward across a narrow swamp, in some woods and in the field north, are many ledges of similar rocks, although interbedded quartzite is frequent here. These rocks have resemblance to some that were noted west of Brandon just east of the Rutland R. R. track on both sides of the road through Morgan's Stock Farm and also to some others on the strike of the latter on the west side of Otter Creek along the eastern margin of Long Swamp; also with others found west of Orwell village. These latter rocks in Shaftsbury were hard to correlate with others of the vicinity.

The suggestion is strong from the field relations that the phyllite mentioned above lies beneath all these various calcareous rocks north of the road to Cold Spring Corner.

It seems probable that the various outcrops of dove-colored rocks carrying gray patches and fossils, and the associated gray beds, and perhaps also those with the interbedded quartzite, belong to the Chazy, on the basis of similarity with the outcrops south of Bennington and at places northward in the State.

An especially interesting feature of the exposures in Shaftsbury described above is the subjacent position of the black phyllite, in view of relations which have been described for areas farther north. At places west and southwest of North Bennington the relations between limestone and schist afford reasons for thinking that the limestone rests upon the schist formation.

On the lower portion of the southern slope of West Mountain are calcareous rocks similar to those just described. They are greatly sheared and "splintered." Up the southeastern slope of the mountain the limestone gives place at the surface to phyllite. At the top of the mountain is a light-colored, siliceous phyllite very similar to rock found associated with quartzite and black phyllite in the Sudbury hills except that the former is more micaceous and schistose.

Summary of the Bennington region. Both the rocks and the relations which they have to each other in this region show many resemblances to those which have been described for the region around Brandon. There are also differences. In general the Lower Cambrian series along the east side of the valley, in its lithological characters and its structural features, much resembles the other in each case. At Brandon black, and often pyritiferous, schist is associated with the quartzite along the plateau margin. At Bennington, except for a small patch lying on members of the interbedded series against the edge of the plateau, southeast of Barber's Pond, and the schist of Mason Hill, phyllite was not noted as involved with quartzite in proximity to the plateau. But it should be noted that much of the rock making up the Mt. Anthony ridge, south of the latitude of Carpenter Hill at least, is not to be distinguished from that found along the plateau east of Brandon. It is apparently the same schist which is found in both places and which also underlies the calcareous rocks described above north of the Cold Spring road in Shaftsbury. This schist has a marked similarity throughout a wide distribution, as has been brought out fully above.

A section south of Bennington, in Pownal, from the plateau on the east across the valley and the Mt. Anthony schist ridge, gives gneiss with overlying quartzite, faulted with quartzite and overlying calcareous rocks, which are faulted with each other. These latter rocks apparently extend to the base of the schist ridge on the west of the valley and here now apparently are faulted again against quartzite and phyllite which form the scarp and the surface rock along the eastern portion of the ridge. Farther west lies the limestone of North Pownal which is much involved with schist, sometimes intermingling with it in surface outcrops, sometimes underlying it, and here and there jammed in with it.

Another section north of the latter, passing through Mt. Anthony proper, shows sheared and brecciated limestones, some of which are of probable Chazy age, lying just west of the apparent western edge of the Lower Cambrian series and containing a long and strongly-marked zone of crushing, as well as the shearing characteristic of the whole mass, and west of this deformed strip gives the thick-bedded, crystalline marbles of Mt. Anthony apparently not greatly deformed internally, or as a mass, and overlain by schist in apparent conformity.

An east-west section north of Bennington, passing just south of North Bennington village, gives the Lower Cambrian as before, then an interval of unknown (drift-covered), then the flattish, dark gray limestones of Paran Creek. Farther west the indications are that limestone rests on schist.

A section passing about two miles north of North Bennington gives Lower Cambrian as before, an interval of unknown, then the rocks which were described above as probable Chazy and others associated with them. These at places lie on black, pyritiferous phyllite and probably are over much of the area now resting on the phyllite.

Farther north still, along a section passing through Shaftsbury Center or Shaftsbury Depot and West Mountain, the Lower Cambrian series lies on the east side of the valley, then certain limestones near the foot of West Mountain, then the schist of West Mountain. Except for one small patch just west of Shaftsbury Depot along the lower eastern slope, the schist of West Mountain was not found to have any limestone resting on it, although the writer's search was not exhaustive.

The Lower Cambrian series of the valley is clearly a dismembered part of a mass to which the quartzite of the plateau also belonged; whether the result of reverse or normal faulting has already been discussed for its northern extension. The evidence in this Lower Cambrian series shows that it has been under strong compressive stress, and that some of its deformational features are due to such stress. The conditions exhibited south of Bennington and in North Pownal show the action of powerful compressive forces in the region. Some rocks seem to be crushed more than others, as though caught and confined and made to deform internally because they could not get away. Other rocks seem to have escaped great internal crushing although metamorphosed by other processes, such as recrystallization.

The apparent minor displacements in the Lower Cambrian series, involving overturned folds and probable reverse faults, are evidence of former compression. The overturned folding in some cases, however, may have been due to friction instead of having preceded and initiated the rupture. In the Bennington region the evidence of upthrust of older into younger rocks is strong; but the evidence for lateral thrust, or better, lateral movement, is not so apparent. Farther north, marble that is almost certainly younger in age outcrops from beneath overthrust Lower Cambrian rocks. These relations were not established for the Bennington area. While the limestones west of North Bennington seem to be thrust on schist in some cases, and have undoubtedly been under compression, the field relations do not show that the limestone may not have rested on the terrigenous rocks prior to the deformation of the former.

In the writer's first description of the geology of Bennington, the character of the Vermont valley as primarily a structural valley was recognized; but the break between the plateau and the valley was regarded as primarily a reverse fault and the normal displacement producing the present relations was thought to have utilized the earlier reverse fault plane. This does not seem likely from the relations shown in other areas.

The present lateral distribution of the calcareous members of the Lower Cambrian series in the valley has no necessary relation to their original extension eastward or westward. Such extension must be decided by other considerations. The probability of primary upthrust of Lower Cambrian and of later normal faulting of a part of the series, together with the fact of erosion, calls for an original extension of the Lower Cambrian series as a whole to the eastward. Whether they extend westward at depth is perhaps another question. Whether they ever had a great westward extension by thrust is certainly an independent consideration.

Certain other matters may be postponed until the general summary for western Vermont is offered. Enough has been said to show that the relations are complex and that one is practically driven to inspect other areas to obtain light on this one.

ADDISON COUNTY.

Whiting and Shoreham Townships.

(Brandon and Ticonderoga topographic sheets.)

Topography. These townships lie just north of the Taconic hills of Sudbury and Orwell, in the southern part of the Champlain lowland. The surface is low for the most part in Whiting; the eastern boundary of the township in fact for a distance of four miles is Otter Creek. In Shoreham there are a few low hills.

General observations in Whiting and Shoreham. There has been a much more extensive preservation of the limestone strata, which have been noted in fragmentary areas in Orwell, Benson, Sudbury and elsewhere, northward in the portion of the Champlain lowland extending through Whiting, Shoreham and neighboring townships. On this account, some of the relations and the ages of the various rocks were early worked out in these areas, first through the work of Wing and later that of Brainerd and Seely. In the town of Shoreham was established the type section of the Beekmantown of western Vermont.

In the course of his studies the writer reviewed some of the field relations in Whiting and Shoreham.

The phyllites north of Sudbury village at and around Webster corner, which have already been described, were followed northward along the road to Whiting village by frequent outcrops nearly to the village. Along the road running west two miles north of the village the same phyllites were traced from the school house on the Middlebury road past Hitchcock's residence to school house corner. In the valley of the brook one-fourth of a mile west of Hitchcock's place, the phyllite formation showed patches of quartzite with vein quartz like that on Government Hill in Sudbury and at other places in the Sudbury hills. In general no essential difference could be discerned between the rocks composing the low ridge which extends northward from Sudbury into Whiting and those which make up the hills of Sudbury, Orwell and Benson.

West of the phyllite formation in Whiting just described, the section described by Brainerd and Seely for eastern Shoreham can be fairly easily followed if side excursions are made frequently enough to get exposures of beds which are soil-covered at other places along the strike. The apparent monoclinal character with easterly dip and the apparent thickness as described, can be made out and duly appreciated.

One-third of a mile west of school house corner, mentioned above, the road which goes westerly past Hitchcock's place turns sharply to the south to join the main road from Whiting village to Shoreham village. Along and east of this road leading south are exposures of the blue Trenton limestone dipping easterly at an angle of about 40° and extending along the strike practically north and south. West of the road are ledges of the Chazy and others which have many similarities to the Chazy, but which Brainerd and Seely called division E of their Beekmantown. Along another road just west appears division D with many fossils at numerous places. Then follow divisions C, B and A westward over Cutting Hill towards Richville. Just east of Richville is exposed with easterly dip along the main road the whitish, quartzitic sandstone which was called the "Potsdam," and which is described as forming the base of the section.

At the bridge at Richville, east of the road and in the river bank, and northward the rocks show great confusion, and north of Richville at places beds belonging to division D show westerly dip just west of this zone of disturbance. As recognized and shown by Brainerd and Seely a fault or thrust has elevated the "Potsdam" against younger beds.

West of Richville the "Potsdam" outcrops again along the road to Shoreham, apparently along the axis of a ruptured anticlinal buckle for the sandstone apparently rests at the west against division C, and possibly D. This broken anticline, however, seems to belong to a larger mass of beds which has ridden westward along a deeper and more extensive thrust plane, cutting through the Beekmantown and still higher beds. Just east of Shoreham village, near and east of the Catholic Church, are Trenton rocks succeeded eastward by Chazy beds dipping westerly, which in turn are succeeded eastward by Upper Beekmantown, dipping at a high angle easterly, according to the writer's observations. It would seem that beds which stood at a high angle of westerly dip at the time of rupture would have had this increased and even reversed by the drag along a thrust plane.

In the center of the village the "Potsdam" appears again on the eastern margin of an extensive swamp which westward is succeeded by hills of "Utica" slates.

South of Shoreham in the town of Orwell, field relations which have been described above, indicate that a limestone series like that which occurs in Shoreham has been broken by reverse faulting and minor thrusting which have brought the lower members of the series against and over higher ones, and that as now affected by erosion at some places the younger rocks are shown beneath and the older on top. Moreover, other more extensive thrust planes have carried the previously faulted series over still younger rocks on which it may now be seen resting at several places.

From the description of the relations as inspected in Whiting and Shoreham the similarity to the condition in Orwell appears. The same phyllites occur at the east succeeded westward by an unusually regular series of calcareous rocks from the Trenton down through the gray sandstone called the "Potsdam," while still farther west near the lake are hills of "Utica" slate. Except as affected by erosion the arrangement and sequence are apparently the same and it would seem that the structural relations of both areas must have been due to similar causes.

The conditions in western Shoreham and western Orwell townships raise two questions:

1. How is the preservation of the hills of rather frail "Utica" shales and included limestone bands along the edge of the lake to be explained unless by assuming their protection perhaps until relatively recent times by a more durable covering?

2. What explanation is to be given of the absence at the west of the phyllite formation found at the east beneath the limestones?

ADDISON COUNTY.

Townships of Leicester, Salisbury, Middlebury, Cornwall, Bridport, Weybridge, Addison, New Haven, Waltham and Vergennes.

(Brandon, Ticonderoga, Port Henry and Middlebury topographic sheets.)

Topography. The topography of the areas examined in these townships is for the most part typical of the Champlain lowland. Snake and Buck mountains are somewhat conspicuous elevations whose structural significance will be discussed beyond.

Observations between Lake Dunmore and Snake Mountain. In the summer of 1918 two days were spent in as careful an examination as a walking trip would permit of the country between Brandon village and Vergennes. The first part of the trip was along an irregular traverse from Brandon by way of Lake Dunmore to Snake Mountain through the townships of Leicester, Salisbury, Middlebury, Cornwall and Weybridge.

North of Forestdale the western boundary of the quartzite formation swings from the plateau to the Champlain lowland and marks the beginning of a westward extension of this formation that in the lowland becomes even more pronounced at the north in Monkton.

The structural breaks between the plateau and lowland north of Brandon exhibit their own peculiar pattern, but in it can be discerned a similarity to that at the south, in the overlapping along the strike of normal fault displacements of varying throw. Northward the western margin of the plateau is farther west than it is east of Brandon. The dismembered portions of the quartzite, or rather the Lower Cambrian series, along the eastern margin of the lowland take the form of hills and ridges which begin west of Lake Dunmore and gain in prominence northward. In general the relations are similar to those shown along the eastern margin of the Vermont valley from Bennington, through Shaftsbury, Arlington and farther north. Observations were not made with sufficient thoroughness to show conclusively whether or not outcrops of marble, or the rocks associated with it, occur within the area chiefly occupied by the Lower Cambrian series, and therefore whether actual overlap occurs as it does around Brandon, although probable overlap by thrust is suggested.

Dolomite like that associated with the marble around Brandon and farther south in Dorset was noted at Leicester Junction and at other places and the interbedded series was found a mile west of East Middlebury village along the road from that village to Middlebury. The valley quartzite, however, northwest of Lake Dunmore extends westward to a meridian a mile west of East Middlebury village, at least.

East of Lake Dunmore is a prominent scarp in the quartzite and the lake appears to lie in a structural basin. North of Lake Dunmore the place of this scarp is taken by another lower one which breaks the quartzite a mile west of Bryant Mountain. The basin in which the lake lies appears to be the counterpart of those at the south near Arlington and Manchester which are filled with drift.

Three miles northwest of East Middlebury village, and two miles from outcrops of the interbedded rocks of the Lower Cambrian series west of the village, along the road to Middlebury, are exposures of sheared, blue limestone, carrying gray, woolly patches which after a short distance are succeeded by outcrops of marble that lie about a mile southeast of Middlebury village. The relations thus far noted present a strong similarity to those found around Brandon.

In the fields a mile west of Middlebury are abundant exposures of the bluish or dove-colored rock showing the same shearing and the same gray patches that have so frequently been mentioned and which are associated with other limestones resembling the Trenton. Many ledges were examined for fossils, but nothing definite was noted. The prominent structural feature is strong shearing with easterly dip.

Two miles west of Middlebury were observed outcrops of phyllite. Some of this rock is like the light-colored phyllites seen in the Whiting and Sudbury exposures, in texture, but darker in color. It was found along the valley of Ledge Creek. No attempt was made to trace the boundaries of this formation with adjacent rocks and no contacts were found.

West of the phyllite is a ridge known as "The Ledge." The dove-colored rock was noted here. West of "The Ledge" the surface sinks to the level of the Lemon Fair River in Weybridge. West of the Fair the surface rises very gradually to the eastern slope of Snake Mountain.

Observations near Snake and Buck mountains. In the northeastern part of Bridport the eastern slope of Snake Mountain is formed of cherry-red or brick-red quartzite which dips easterly. On the west the mountain presents a good scarp of varying altitude fronting the lowland, but at places the drift is piled rather high against it.

Along and near the east road to Addison, west of the mountain, are good exposures of the grayish-blue limestone carrying *Maclureas, Ophiletas* and other fossils.

Two miles east of Addison village, along the road to New Haven Junction, north of the mountain, were noted black shales, weathering gray, and these one-half mile farther east in an excavation beside the road one-half mile west of Otter Creek gave many graptolites, identified as *G. pristis.* Above the shales in this pit is limestone apparently lying on the shales and which in lithology resembles some of the higher Beekmantown. At the bridge across Otter Creek is dove-colored limestone which appears again northward along the road to Vergennes apparently dipping easterly. Farther north, three and a half miles south of Vergennes, the limestone dips easterly about 20° and is full of fossils, including *Maclurea magna.* The rock does not appear to be so badly sheared as is its apparent counterpart east of Snake Mountain and southeast of Middlebury.

Buck Mountain shows a conspicuous scarp on the west which is not so sharp as that of Snake Mountain.

East of the limestone at the bridge over Otter Creek, along the road from Addison village to New Haven Junction, limestone gives place to quartzite, "Red Sandrock," which forms the eastern slope of Buck Mountain and dips easterly. This gives place eastward to limestone.

Near the northern end of Buck Mountain a road crosses it. North of this road, quartzite forms the base of the eastern slope, but a short distance west up the slope it gives place to large exposures of the bluish or dove-colored rock with its gray associate and the former carries indistinct fossils. Field notes indicate that the limestone is sheared and that it continues westerly and apparently forms an anticline, for easterly dip occurs on the east and one-fourth of a mile west the dip is westerly. Northward along the strike of the westerly dip the limestone presents an abrupt, abraded edge 500 yards south of the house at the end of the private road. About three-fourths of a mile farther north and one mile south of Vergennes, in a pit east of the road, shale appears. Here the rock has a larger exposure and is more limy than that noted farther south, north of Snake Mountain, but in general resembles that in which graptolites were found two and a half miles east of Addison village. The shales appear on a meridian intermediate between limestone outcrops farther south which suggests that they were once covered by limestone or quartzite which has been eroded. In the south wall of the pit the rocks show that the formation has been greatly crumpled.

Summary. The faulted and scarped western edge of the Green Mountain plateau continues northward from Brandon and fronts a wide Champlain lowland lying to the west. Along the eastern margin of the lowland lies a series of rocks whose basal quartzite member is like the quartzite forming the escarpments of the plateau. In the lowland and on the edge of the plateau the quartzite is overlain by a dolomite and in the lowland there is present also a series of interbedded dolomitic and quartzitic rocks like those that have been described for Brandon and areas farther south. The lowland rocks are dismembered portions of those forming the plateau. The relations in the main are like those at the south throughout the long extent through which they have been traced in the descriptions of this paper.

Although conclusive evidence from field relations examined by the writer may not be offered to show that the Lower Cambrian series at the east overlaps other rocks along a thrust plane, such as was described for Brandon, a dolomite was seen during a subsequent season at Leicester Junction, lying on the marble, and the resemblance of the former to the dolomites so frequently noted around Brandon in association with the marble was noted. It does not resemble the rocks which seem to be Chazy and its counterpart was not found west of the meridian of Middlebury village. During a subsequent season also were inspected some outcrops along the road from Leicester Junction to Whiting village which bear strong resemblance to the interbedded rocks seen northwest of Brandon village. They occur south of the road about a mile west of the Junction and the exposure is limited. In fact, drift very thoroughly hides the hard rock between Otter Creek and the brook farther west, and the exposures are not at all satisfactory for study. Two and a half miles west of the Junction, just east of the railroad track, limestone shows a puddled appearance and carries salmon-pink or buff-yellow patches of calcite like those northwest of Brandon. In Huntley's quarry at the Junction a dolomite is involved with pinkish marble and west of the quarry, at some old quarry holes, beds of ochre-yellow dolomite are involved with pinkish marble.

South of the Leicester Junction-Whiting road some of the few exposures along the road to Foster corner show the sheared blue limestone of the Sudbury exposures farther south.

If the various outcrops indicated above belong to the Lower Cambrian series they carry the margin of it west of the meridians along which the marble and its associated rocks outcrop at Leicester Junction, and southeast and northeast of Middlebury village.

At Swinington's quarry near Leicester Junction the dolomite shows a structure like that at the old Norcross quarry at South Dorset. They both offer structure to be considered in connection with the characteristic deformations of the rocks of the region. See plate XXXV.

The bluish-gray or dove-colored limestone and associated gray dolomite southeast and west of Middlebury village are regarded as the equivalents of similar rocks around Brandon and west of it. West of Middlebury they have apparently the same relations to sheared blue limestone as in eastern Sudbury and the whole series bears the same relation to the phyllite in eastern Cornwall that the calcareous rocks at the south do to the phyllite formation of the Sudbury and Orwell hills. In eastern Cornwall, in fact, the phyllite band simply interrupts at the present surface the continuity of entirely similar calcareous rocks that now lie each side of it. These calcareous rocks lie on the phyllite and are not interbedded with it. Westward in the valley of the Lemon Fair the hard rocks largely or wholly disappear from surface view and the next outcrops westward are the quartzitic rocks of the "Red Sandrock" formation on the eastern slopes of Snake Mountain. Farther north, however, on the meridians of the phyllite and the limestones west of Middlebury the "Red Sandrock" of Buck Mountain appears at the surface with every indication at its northern end that limestones similar to those lying on the phyllite west of Middlebury village also lie on it, while the quartzite on the eastern slope of Buck Mountain passes eastward beneath similar limestones. Whatever it may mean, there is a substratum to these similar limestones which shows a lateral variation within not very long distances from phyllite to quartzite.

The published descriptions show that with minor surface interruptions the quartzite of Buck Mountain connects northeasterly with similar rock in Monkton, which in turn is described as "merging" with the quartzite of the plateau. Account should be taken, of course, of the normal and other probable displacements at the east.

Snake and Buck mountains are the topographic counterparts of the interbedded quartzite and phyllites composing the Orwell hills. They also lie along practically the same meridian.

West of Snake Mountain are calcareous rocks apparently similar in important respects to those at the east, but less altered, and fossiliferous; the dove-colored rocks yield Chazy fossils.

North of Snake Mountain are black shales giving "Utica" graptolites and this rock is overlain by limestone, which is probably of Beekmantown or Chazy age. Along a meridian lying a mile to the east are dove-colored rocks which northward west of Buck Mountain give *Maclurea magna* and other Chazy fossils. And still farther north and on a meridian lying east of the Chazy outcrops are shales like those at the south carrying *Graptolithus pristis*.

There is apparently a fault in the quartzite on the north of Snake Mountain, but it is not apparent that there is any structural lateral offset. The physiographic offset between Snake and Buck mountains appears to be due to the irregular course of the displacement that bounds those eminences on the west and which north of Snake Mountain swings eastward and then again northward. There are minor scarps and surface interruptions between Snake and Buck mountains. Around Snake and Buck mountains there were not noted by the writer any places at which the quartzite and shales are in contact and only one place, as described, was seen where the shales had limestone above them. The probable relations of the quartzite, and the limestone which probably lies on it, to the "Utica" rest upon probable conditions shown elsewhere which will be described beyond.

The displacements marked by the scarps on the west of Snake and Buck mountains have been described or pictured as reverse faults by which the quartzite was elevated to its present position with respect to the surrounding rocks. They will be discussed beyond so as to show that they are probably in character, and relations to earlier thrusts, similar to those which broke the rocks along the western edge of the plateau at the east and the Orwell and Benson hills at the south.

CHITTENDEN COUNTY.

Burlington.

(Burlington topographic sheet.)

Observations near Burlington. Vergennes was the most northern point reached by the writer in the course of a trip on foot through western Vermont in the summer of 1918. There has been no opportunity since to make close field observations between the parallels of Vergennes and Burlington. Some mention may be made in the final summary of certain published accounts of the relations shown in the territory intervening. At Burlington trips were made to points along the lake shore and to the valley of the Winooski, which may be mentioned here for sake of completeness.

The celebrated Rock Point locality at Burlington should be visited by anyone who is interested in the problems of rock deformation in western Vermont. Here is exposed a relation that is often concealed along the lake shore. The phenomenon of overthrust falls within the range of easy understanding as one surveys the sharp contact of the Cambrian sandstone on the Ordovician shale formation, and the inspection is helpful in visualizing the relations at other places where the aid of the imagination is needed more.

The massive quartzite-dolomite, "Red Sandrock," often without any marked visible internal deformation, rests on greatly crushed and crumpled, black slates and shales, with stringers and nests of quartz and calcite. The color of the quartzite varies in this vicinity; while often red it is frequently gray and brown. The shore section at Rock Point is a detached one; north and south of it the shore is in Champlain clays.

East of the lake shore the best exposures near Burlington are along the Winooski River. At the Lower Falls, red and gray quartzite in massive ledges in the stream and along the banks lie in a flattish position, dipping gently in a general easterly or northeasterly direction. East of Winooski village the gray quartzite is succeeded by limestone of uncertain age.

FRANKLIN COUNTY.

St. Albans Bay.

(St. Albans and Milton topographic sheets.)

Some observations along the lake shore south of St. Albans Bay. Some apology seems necessary for the very brief original notes offered for the country north of Burlington. A part of one rainy day was spent along the lake shore near St. Albans Bay south of Melville Landing. Heavy weather prevented much being done on the trip and illness from influenza practically closed field work for the season.

From Melville Landing southward the shore as followed for three miles towards Camp Rich in Milton is formed of "Utica" slates and shales which form low cliffs and minor headlands. The road hugs the shore for the distance mentioned and advantage has evidently been taken of the level topography in laying the road out. Back from the shore at varying distances are exposures of limestone which were not examined except as mentioned beyond. The slates were inspected casually for fossils but none was found.

About two miles north of Camp Rich, above a shore cliff of the shale and only a few rods from the shore, were noted light-colored, siliceous phyllites or slates which at once recalled the similar rocks in Whiting and Sudbury. This exposure seemed somewhat isolated and surrounded landward by limestone. Ledges of the latter occur only a few feet away from the slate, but the contact was not seen. The relations were not absolutely conclusive as to whether the limestone or the slate was superior

in position. The shore road is here a fourth of a mile from the bank. Limestone apparently continues eastward to the road and across it. East of the road a low ridge of gray, "marbly" limestone is succeeded by a fairly high escarpment of gray dolomite. From the general relations as noted here and northward, east of the shore road, it was concluded that the phyllite is beneath the limestone and that the former rests on the "Utica." The phyllite is correlated in the writer's mind with similar ones farther south in Addison County and is thought of as, in general, equivalent to the quartzite or "Red Sandrock" which farther south in Milton and Colchester comes to the shore, either resting on the "Utica" or dipping into the lake. The phyllite north of Camp Rich as just described is apparently very limited as a surface formation in the immediate vicinity of the outcrops noted. Northward towards St. Albans Bay, limestone apparently rests on the "Utica," to judge by general field relations; but both phyllite and limestone are regarded as resting by thrust on the "Utica" formation.

GRAND ISLE COUNTY.

South Hero and Grand Isle.

(Plattsburg topographic sheet.)

During the season of 1920 some examination was made of the formations on the island of Grand Isle, often in the company of the State Geologist. The geology of this interesting island has been most recently studied by Professor Perkins, whose excellent and careful descriptions will be found in his Second and Third Reports. In this paper the writer wishes to record only a few observations which bear more particularly upon the deformation of the rocks.

The surface mantle on the rocks of Grand Isle is largely composed of the deposits of an old "lake" bottom. The exposures of the hard rocks, however, are sufficiently numerous inland, even over the lowest portions, to permit an apparently fairly accurate delineation of the boundaries of the different formations; but the covering is heavy enough to conceal in most places such critical features as contacts over considerable distances.

In a general way the formations may be divided into the shale formation, which occupies the northern, eastern and southeastern portions of the island, and the limestone strata which stretch as a wide strip along the western side from its southwestern end northward two-thirds the distance across the island from south to north, and which at the north extend towards the east into the central portions. The present apparent surface distribution, in a large way, of the rocks just mentioned, in itself appears to have some structural meaning which apparently could hardly be grasped in its true signification from the study of this island alone. Especially confusing would probably be a close age relation of some of the members of the shale-slate formation with some members of the limestone strata and an apparent transition between the two at many places, not only in lithological characters, but in the fossils as well. In addition to these features of general distribution there are some details which will be mentioned presently.

The limestone strata include the Beekmantown, as a small patch at the southern end, which is better exposed on Providence Island a mile and a half away, the Chazy, Black River and Trenton. In general as seen along the shore and also inland a short way from it the beds of these different terranes have not been greatly deformed internally. An almost continuous section in limestone extends from Phelps' Point at the southwest to Wilcox Cove along shore, and more or less widely interrupted exposures occur to the eastward a short way from the shore along an old "lake" bottom and along the old beach and some ridges that bound it on the east.

The Chazy rocks are usually impressive in their massiveness. Some of the beds are several feet thick; in one case a bed is as much as 20 feet through. These strata are prevailingly quite flat in position along shore, and so far as examined are free of pronounced internal deformation, although they show more evidence of it inland so far as the more limited exposures permit observation.

The Black River beds are limited. They too are somewhat massive, but less so than the Chazy rocks. They might be considered as somewhat intermediate in this respect between the Chazy and the Trenton. Along shore these beds are also prevailingly almost flat in position. They are very smoothly and symmetrically jointed as a rule. An occasional outcrop of rock with some characters of the Black River, but much crushed and filled with veins of calcite, occurs near the west shore; but a consideration of general relations makes it seem doubtful if such rock is in place.

By far the larger part of the limestone as mapped for the present surface belongs to what is called Trenton, and which probably is Trenton, but perhaps not all there is on the island that should be included in this terrane. Professor Perkins has been impressed with the Trenton or transitional character of some members of the shale-slate formation and has been at work on the problem of a clearer separation of the Trenton from the so-called "Utica" of the island. From what will be indicated beyond it may appear that structural features among some of these rocks will have to be considered in working out their age and other relations.

The Trenton rocks that are readily recognized and have been mapped as such have, like the Black River and Chazy, where they occur along shore a nearly horizontal position. A fine section is exposed from Rockwell Bay northward, in which there appears to be only gentle but variable inclination of the beds. The exposed portion of the stratum is composed of limestone beds of varying thickness, ranging from 2 through 4 or 6 to 8 or 10 inches with intercalated shaly layers. The rocks in their dark gray and somewhat monotonous appearance throughout are in contrast with the dense and more heavily-bedded Black River and the massive and often more distinctly marked Chazy.

Deformation of the Trenton beds, including visible shearing within them, is found in the shore section and now and then a small fold or buckle appears which sometimes appears to be associated with a fault displacement. In one case the latter appeared to be a tension fault; at another place, near Wilcox Cove, there was suggestion of thrusting and therefore of compression. On the whole, however, along shore there is less evidence within the various limestones of the action of compressing forces upon them than farther east. There is some evidence of normal faulting across the general strike of the rocks, both within formations and between them, and some of these are apparently marked by shore indentations at the present time, as well as by juxtaposition of rocks of different ages. How far most of these displacements may run inland it is difficult to find out.

It has been assumed and would probably by many observers be assumed that these various limestone beds and formations have at the present time their original stratigraphic interrelations and primary geological sequence, and that they are probably near the place of their deposition; that, in other words, they have not been greatly disturbed from the place where they were laid down, though bearing some evidence of deformation.

The careful systematic examination which would be necessary to show it was not made to find out to what extent, if any, the primary interrelations of the rocks of different ages which these limestones represent, may have been changed by the action of thrusts; but in addition to the insignificant disturbances which have been mentioned, effects distinctly to be attributed to the action of compression were observed in the limestones at other places on the island.

Along a ridge about one-half mile east of the west shore and east of Sawyer's Bay, and eastward from this ridge in more scattered exposures, beds of Trenton limestone give satisfactory evidence of internal deformation, not only in their sheared structure, but in the compression, distortion, fragmentation, or obliteration of their fossils. Minor buckling may be seen and an easterly dip due to shearing can be readily distinguished from that of stratification. Some of the fragmentation of fossils may have occurred during or prior to deposition; but in the field it is possible within short distances across the strike, and sometimes apparently along the strike, to pass from one ledge with excellently preserved fossils, such as *Bellerophon,* to other ledges in which, at the distance of only a few hundred yards at the most, alteration will vary from compression, as shown by a flattened Bellerophon, nearly to obliteration. Account is taken in this statement of differences in fossil contents due to natural variation in passing from bed to bed across the strike.

Observations seemed to indicate that in the Trenton beds, because of their more thinly-bedded character, deformation due to buckling and crushing, and probably shearing, found expression more readily than in the more massive Black River and Chazy. It hardly needs more than a casual inspection of the limestone rocks as one goes east from the lake towards their eastern edge to discern the evidence of the greater disturbance and deformation which they show over those along the lake at the west. Along their eastern margin some of them are clearly crushed and carry many calcite veins.

The limestone formations whose deformational features have just been discussed are those which may in the field be separated clearly from those which have some similar lithologic and structural characters, but which are in more intimate major structural association with the shale-slate formation. Along the lake shore at places between Rockwell Bay and Wilcox Cove beds of not appreciably deformed rocks of probable Trenton age pass into other apparent Trenton rocks which are rather strongly sheared, and between these and other rocks which have been called "Utica" there is sometimes difficulty in drawing any decided lithological distinction.

The so-called "Utica" slates and included limestones, perhaps together with some Trenton rocks, may apparently as a formation be differentiated somewhat sharply from the limestone strata which border the lake, as just described, on the basis of the deformation which it has suffered. In general, these rocks present much the same aspect with respect to deformation wherever observed. Under severe compression the beds of the shale-slate formation have not only been folded and tilted, but apparently because of pronounced difference in behavior of beds of different thickness and strength under stress of pressure and probably also load, there has been frequent rupture with much crushing and frequent movement of one part of the mass over another part, producing great confusion. An exposure of great interest as showing this behavior of the slate formation is to be seen in the cliffs south of the Grand Isle end of Sand Bar Bridge, and which is pictured in the Third Report. In lithological and deformational aspects the members of this formation are like those along the shore of the mainland south of St. Albans Bay and at Burlington and in essentials like those farther south in Addison County. The lithological differences and resemblances among the different slates and shales through the distances separating the localities just mentioned are of the same order and character as those which appear in comparing the slates of western Vermont with those of some parts of the Hudson valley.

Interpretation. In the course of the writer's examination of Grand Isle the question arose very early in his mind as to what is the present structural relation which the limestones have to the slates. Search did not show any of the limestones resting on the slates. So far as the writer's observations have gone, and also the descriptions of others, it appears that the structure of the island as a whole is best explained by the relations shown at the east on the mainland and at other places in western Vermont which have been described in this paper.

In the first place, one notes the relatively great deformation of the shale-slate formation already referred to and the contrast which it bears to the limestone strata viewed as a mass. The contrast recalls the relations on the mainland where a dolomite-quartzite showing little visible internal deformation rests on greatly crumpled slates and shales in all essential respects like those of Grand Isle only a few miles to the west. The slates of the mainland having the inferior position to older rocks that has been noted at so many places, but in this connection, especially along the lake shore from St. Albans Bay to Burlington, undoubtedly once had connection across what is now the lake surface between the mainland and Grand Isle with the slates of the latter. Did the Cambrian quartzite ride over the slates, or rather did the thrust plane along which it was driven cut through the slate formation above the limestones now exposed at the surface on Grand Isle, or did it cut through it along what is the plane of contact of these limestones on the slates? In other words, do the limestones of Grand Isle structurally lie below the "Utica" of the island or above it? If above it, they lie unconformably along a thrust plane and are not in their original position. The considerations offered all suppose the slates to be younger than the limestones. On such a supposition as overthrust there probably will not be in most cases, of course, actual transition from undeformed Trenton limestone into deformed "Utica" slate or limestone. There might, however, be transition from sheared Trenton limestone into continuous, unsheared limestone, but all within the mass that had been moved. The idea of overthrust does not preclude the inclusion of Trenton rocks in the "Utica," but such rocks would presumably have to be thought of as having once been separated from the undeformed Trenton rocks by a greater or less interval.

In connection with the idea of overthrust the question of the relations of the limestone strata of Grand Isle to the quartzite on the mainland calls for consideration. A better knowledge than the writer has of what lies on the quartzite east of the lake might help in answering this question. Published accounts are not conclusive. Conditions farther south that have been examined may give some suggestions.

Did the quartzite which now lies on the slate formation along the mainland at Malletts Bay and Burlington once extend over both the slates and the limestones of Grand Isle? Or did its extension westward by thrust stop short of Grand Isle? Its absence west of the mainland is not conclusive, but is suggestive. It would seem that if this durable formation once extended any distance west of the eastern shore of the lake some remnant of it would be preserved. In this connection may be recalled the apparent contact of limestone on the slates around St. Albans Bay with apparently no quartzite or phyllite intervening, and other places southward where either some phyllite, or slate, or quartzite, lies between limestone and the "Utica." Again may be noticed the eastward extension of the lake surface to form St. Albans Bay where apparently only limestone rests on the slate formation. It would appear, even from the few observations made by the writer in northern Vermont, that either limestone, or quartzite, or phyllite may rest on the "Utica," presumably by thrust, along the mainland. In view of this probability it is not difficult to imagine the limestones of Grand Isle as lying on the slate-shale formation by thrust.

In the areas farther south that have been described, it will be recalled that along the lake region it is some member of the limestone that lies on the "Utica" and that at only one or two places of obscure relations is there suggestion of visible contact of any member of the quartzite-phyllite formation on terrigenous rocks of younger age.

The correlation and unification of the phenomena of these various localities will have to be undertaken in the closing summary.

At places on Grand Isle the Chazy and apparently the Black River are shown to have such relations to the slates, when mapped and when inspected in the field, that it is difficult to draw any other conclusion than that the two are in contact. At other places it is the Trenton that is or appears to be in contact with the slates. Judging again by conditions as shown farther south, some of the relations of limestone to slate on Grand Isle may be the results of displacements due to normal faulting; but all of them apparently may hardly be explained on such a basis. There is nothing to suggest that the limestones have been completely inverted; they retain at least their depositional attitude. When one finds a mass of Chazy limestone surrounded on three sides by the slate formation and remembers that the latter is unquestionably the younger rock, two possible explanations suggest themselves; either younger rock has simply been dropped by normal faulting so as to surround the older rock, partly by slates perhaps and partly by younger limestone, as is the apparent case north of Keeler Bay; or the older rock has been thrust on the younger strata. The first hypothesis is entirely adequate to explain the present relations, if perhaps we recognize the possibility of differential faulting, for there is apparently nothing in the interrelations of the different limestone strata which opposes such a view. On either view the limestones are presumably present at depth, but in one case the limestones are different at depth from those at the surface with respect to their original relations to the slates of the island and in the other case the rocks at the present surface and at depth have presumably simply slipped by one another along planes of normal faulting. The latter view would of course have to assume some disturbance as the result of compression in order to account for the features shown by the various rocks, but might in the minds of some, not appear inconsistent with the contrasts exhibited by the two principal formations of the island with respect to their deformation. Such a view, however, does not seem to take sufficiently into account the obvious thrust deformations of the region of which the island is a part. Whether we assume or not that the big mass of Trenton rocks in the western part of the island is underlain by Chazy beds, the explanation of relations seems to be possible on the basis of thrusting. Probably we should have to take into account that the map to show the distribution of the formations is not absolutely accurate, although as much so as conditions at the present time allow in view of the surface covering and the non-committal or doubtful character of isolated and small outcrops. Where the present conditions suggest Trenton in contact with slates may not be really the case; but even if it should be normal faulting subsequent to other deformation might readily account for such conditions, although normal faulting is perhaps not necessary to explain them.

If on the mainland it is quartzite-dolomite that rests by thrust on the slate formation there appear at least two possible ways to account for the relations on Grand Isle and of Grand Isle to the mainland by thrusting:

1. Prior to the major thrust, as it may perhaps be called, that carried the quartzite over on the "Utica," as now shown along the mainland, there was reverse faulting and minor thrusting by which the limestones lying east of what is now Grand Isle were broken, perhaps because of the massive character of the Beekmantown-Chazy strata, and thrust up and over the "Utica." In this deformation the slates were tilted and overturned. As the heavy limestone strata rode over them they were further jammed beneath the load and by the drag and often broken and mashed. The limestones themselves were broken and moved more or less against each other. At this time were formed the deformational features which they show. Subsequently there

occurred some normal faulting, perhaps differential in the same episode, and as a deformation perhaps repeated. Before the normal fault displacements presumably thrusting had ceased. Before it had ceased perhaps the stresses which had been only partially eased by the reverse faulting and minor thrusting just referred to produced a great thrust that carried the basal Cambrian up through the "Utica" and drove the former westward over the younger rocks, and over those which now form Grand Isle. But it has already been remarked that if the quartzite once extended very much farther west of its present edge along the shore of the mainland it seems somewhat remarkable that some remnant of its westward extension has not been preserved, unless the mainland is a downfaulted block with reference to the lake region which does not seem probable. According to this postulate, however, it is not necessary to assume that the quartzite once covered what is now Grand Isle.

2. The limestone strata of Grand Isle once belonged to a region that lay eastward from Grand Isle and the "Utica" slate formation on it, one may not say how far. They may have had a relation to the quartzite-phyllite formation entirely similar to that now shown by the limestones which have been described as lying on the phyllite formation at the south in Benson, Orwell, Sudbury and other parts of Addison County. At the time this region was undergoing the compression that produced the various thrusts which may now be seen, there was at first ease of stress by shearing and minor faulting and thrusting. Then came a great thrust, widely extended, deep and powerful, and strongly resisted by the combined masses of the quartzite-phyllite formation and the heavy strata of limestone which lay on the former. The great thrust cut through the various rocks along an irregular plane that often intersected the quartzite, but often also passed from that formation into the overlying limestone strata and cut irregularly through them. As this rupture developed, the mass above rode over the mass below. Sometimes the quartzite and sometimes the limestone was brought to rest upon the slate. When the thrust left the quartzite-phyllite formation and cut into the limestone the former was left at depth west of the presumable line of emergence of the thrust at its surface. Not only would such a thrust plane as has been postulated be very irregular as a plane, but the line at which it cut the surface originally and its trace after erosion would probably be very irregular and sinuous. It is even conceivable that such a plane would have cut through a great thickness of Beekmantown, Chazy and Trenton beds in such a way as to carry Beekmantown here, Chazy there and Trenton at still other places on the "Utica." After, and perhaps a long time after, such thrusting as has just been supposed had ceased, there would have occurred normal faulting. The laterally disturbed masses were now chopped more or less

vertically and displaced. Some of the relations on the island now existing or apparent, might thus be explained. By such an hypothesis of thrusting as just developed, the quartzite probably never lay over what is now Grand Isle, although it may once have overlain a part of what is now lake between the islands

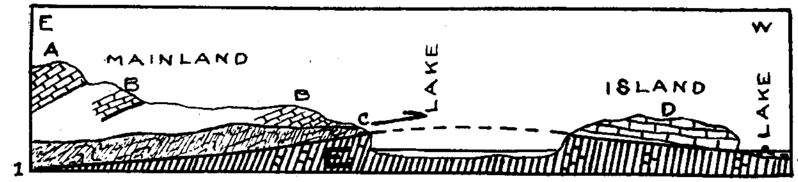


FIGURE 21. A generalized section to show the writer's interpretation of the present relations of formations along the eastern shore of Lake Champlain north of Burlington. The relations shown on the mainland are drawn from studies near St. Albans Bay. A, gray dolomite; B, gray, "marbly" limestone; C, light-colored, slaty phyllite (Lower Cambrian); D, limestone capping an island and resting by thrust on folded "Utica" slate, E. 1-2 thrust plane.

and the mainland. At St. Albans Bay apparently we have the thrust plane cutting through the limestone except at certain places where a bit of the phyllite was caught beneath it; but farther south at Malletts Bay and Burlington, the plane passed well down in quartzite and opposite here the quartzite conceivably once extended farther westward. The region now represented by the lake has been excavated in "Utica" shale and slate after the removal of overthrust rock that was partly quartzite and partly limestone. The writer has not had opportunity to inspect the mainland on the New York side in a critical way; but certain relations seen farther south, near Benson Landing, suggest that part of an overthrust mass of Ordovician limestone now rests against the Adirondack mass north of Putnam Station, and one wonders how far overthrust may have affected the New York side. According to this view of the relations at Grand Isle the limestones there could hardly have been exposed to view by erosion of overlying slate; but presumably limestones similar to those at the surface exist at depth below Grand Isle.

That the various considerations just offered are more than speculations is proved by overthrust farther south. Practically on the meridian of Grand Isle and 60 miles south of it along the east shore of Lake Champlain in Orwell, as has been described, we find the "Utica" formation and in some cases, apparently, Black River and Trenton, rocks, overridden by members of the Beekmantown formation and perhaps older beds which also have been cut through in such a way as now to carry one horizon and now another over on the slates. The erosion of the overthrust limestones at places in western Orwell has exposed the "Utica" slates which are sometimes inundated and sometimes not. Here again the quartzite-phyllite formation lies to the east and over it the limestones of western Orwell seem to pass eastward, as has been described. Similar relations are shown in Shoreham, but in this township, and in Whiting on the east, the limestones have been better preserved. The quartzite-phyllite formation emerges at the present surface only as a low ridge through Whiting. At the west the "Potsdam" of Shoreham village fronts a wide lowland partly swamp and partly hills of slate. Here we have in process of formation the kind of hard rock surface and topography which the unglaciated bottom of the lake would present, and it becomes apparent that the lowest portion of the Champlain lowland is the surface of the rock bottom of the greatest depth of the lake.

The various detached masses of limestone found now at various places in the region of the lake seem to be not simple erosion inliers of rock substantially resting where it was formed, but rather thrust-erosion inliers of rocks now more or less removed from the places of their deposition. Whether it is likely that these displaced rocks have been moved more than once for any distance from their original sites may be discussed in the final summary.

Mention has been made of probable normal faults cutting across the strike of the rocks of Grand Isle. These undoubtedly pass down into the slate formation. Numerous dikes of igneous rocks cut through the slates and limestones along the shore and inland. These dikes usually show no evidence of great disturbance after their formation. They were formed after the limestones came to have their present relations to the slates and probably after or during the subsequent period of normal faulting. In the cliff south of the Grand Isle end of Sand Bar Bridge there is a dike that gives some suggestion that it has been disturbed, but not greatly. Perhaps it would be possible to explain its features as due to the character of the original fissure; in the limestones, while there is some offsetting here and there, it is evidently due to the dike rocks following a previous small lateral displacement. Igneous intrusion in the form of dikes is widespread on the island, and on the mainland even southward to and in the Taconic region.

GENERAL SUMMARY.

The studies offered in the preceding pages were begun with the definite idea of trying to get some light on the plan of structure of the rocks of western Vermont. As details accumulated it became apparent that many different areas presented similar phenomena involving similar rocks and the search began for some principle that would unify the various features of the field relations and explain the apparent anomalies.

Suggestions have been offered in the preceding discussion at several places as to interpretations that might be put upon field relations; but it has been the writer's experience that hardly a single area sufficed to explain completely its own structural features. At several places also certain questions which the field relations raised have been formulated and the statement made that answers to them might later be attempted.

The preceding descriptions have shown the confusion that prevails in the field, but at the same time have tried to make it plain that when the surfaces of different areas are carefully compared there is at many places over a wide region much apparent uniformity in the relation which certain rocks bear to each other when such differences as metamorphism and present condition of erosion are taken into account. Careful examination also brings out the existence of certain kinds of deformation in the rocks of the region which having once been seen are readily recognized at many places and soon impress one as being characteristic. The resemblances that appear from place to place grow upon one and the differences stand out less prominently until the time comes when it seems possible to discern some order in the midst of the confusion.

The first working hypothesis which suggests itself is that the key to the present relations is that of secondary deformation of the rocks. They have been profoundly disturbed. Underneath their present static relations and immobility it seems possible in imagination to see them once more in action. While the changes which have been wrought throughout the long time that has doubtless elapsed since the rocks underwent their major deformations have greatly dimmed the complete picture, and the light from scattered localities gives only an uncertain illumination of some features, encouragement is experienced in the fact that the main outlines come out with increasing sharpness as new areas are examined.

In presenting this summary and in inventing hypotheses by which to try and explain the various structural features and the history of the region as a whole, there are several apparently important field relations that should be kept in mind more particularly to bring out unity of structure. With these it would seem the minor differences must be reconciled.

1. The great north and south extent along the western edge of the Green Mountain plateau and eastern portion of the Vermont valley in Vermont, from Pownal to Middlebury and beyond, of a similar series of rocks comprising conformable, thick-bedded and thin-bedded quartzites and interbedded schists at the base, followed by dolomites and interbedded dolomites and quartzites.

2. The conformability, as shown at Bennington, of the different rocks named in 1 in the order of (a) quartzite-schist formation; (b) dolomite or dolomitic limestone; (c) interbedded dolomites and quartzites.

3. The occurrence of this series at the present time chiefly in the areas mentioned in (1) and the predominance of the upper members in the valley and lowland, where they appear sometimes in conformable relation with the quartzite member of the series and where sometimes the interbedded rocks rest directly on marble, or directly on quartzite, and apparently at some places on an interbedded quartzite-schist formation. The frequent occurrence of a dolomite resting on the marble or involved with it, which dolomite differs from other dolomite with which it is in frequent proximate field association and seems to belong to the same general formation to which the quartzite and interbedded dolomites and quartzites belong.

4. The present absence of this series just described, in its completeness, west of the Vermont valley.

5. The wide distribution west of the Vermont valley, including parts at least of the main Taconic range, of a terrigenous formation made up of black phyllites or schists, lighter-colored, fissile or slaty phyllites, and more or less massive quartzite which are rather plainly interstratified, as shown in surface sections at numerous places from the latitude of Pownal to that of Sudbury and which can be discerned in fault scarps at places west of the range in the Taconic hills.

6. The striking similarity among black phyllites and other members of this terrigenous formation at most places over the region of its present distribution, with certain variations appearing on account of greater metamorphism in some areas. The close geographical and geological association which this formation has with the quartzite-dolomite series described above and the similar north and south extension of the two in this association at the east along the region of the Vermont valley.

7. The practical restriction of the outcrops of the marble formation to the region of the Vermont valley, or to the incisions along the eastern border of the Taconic range, or to the eastern part of the Champlain lowland; and the exposure by erosion of patches, belts, or other outcrops of the marble from beneath the calcareous members of the quartzite-dolomite series described above (3), and apparently also from beneath masses of terrigenous rocks having the interbedded structure and composition mentioned above (5).

8. The probable Lower Cambrian age of the quartzite-dolomite series on the bases of fossils found in the quartzite and at some places in the calcareous members, in connection with the conformability shown by the members of the series.

9. The clearly disturbed condition through compression of the Lower Cambrian series along the western margin of the plateau, involving displacements of one part in relation to another part of the series and the displacement of the whole series or parts of it by overlap on other rocks; the former to be observed all along the western edge of the plateau and the latter to be noted at many places, at some more clearly than at others.

10. The practical impossibility of separating on any basis, except somewhat different mineralogical composition clearly due to metamorphic changes, rocks found on the edge of the plateau and others found in the Taconic range and its physiographic outliers and also in the hills of southwestern Brandon, and of Sudbury, Orwell, Benson, Hubbardton, Pownal, Bennington, Shaftsbury, Pawlet, Rupert, and other townships, some of which have been mapped as "Berkshire Schist" and some as "Cambrian." The wide distribution at the present erosion surface of all the characteristic members of this terrigenous formation from Pownal to Sudbury and possibly also to the northern part of the State, although the writer's examination of the region along the lake north of Burlington gave only the quartzite and the lighter-colored phyllites, and between Whiting and Burlington only the quartzite ("Red Sandrock").

11. The apparent wide distribution, with interruptions over large areas clearly due in part to erosion and probably in part to previous disturbances which affected the ways in which erosion could work, of Ordovician limestones and their metamorphosed derivatives on the terrigenous formation which has been described, found in Whiting, Sudbury, Brandon, Orwell, Benson, West Haven, Hubbardton, Danby, Tinmouth, Rupert, Shaftsbury, and also at the north near St. Albans. The occurrence of similar limestones on the quartzite, or "Red Sandrock," of Snake and Buck mountains, and in their vicinity. The greater continuity at the present surface of the Ordovician calcareous rocks in Shoreham, Whiting, northern Sudbury and Orwell, and the much more fragmentary condition of the same rocks at the south in the Taconic hills.

13. The impossibility of assigning age to the terrigenous rock on the basis of the limestone associated with it in all the places examined.

14. The overlap in some places of quartzite of Lower Cambrian age (at and north of Burlington) and at other places of Ordovician limestones, like those which rest on the terrigenous rocks, including the quartzite, on the slates and shales of the so-called "Utica" formation, to be seen at various places along or near the eastern shore of Lake Champlain.

15. Evidence of repeated normal and reverse faulting in the quartzite-dolomite series, the latter sometimes causing the quartzite, sometimes phyllite to rest against the dolomite or against the interbedded members, various aspects of which faulting may be seen at different places from Bennington to Salisbury, along the eastern portion of the Vermont valley.

16. Evidence of repeated reverse faulting and of normal faulting in the overlapping Ordovician strata near the lake, to be seen in Shoreham and Orwell townships and at other places.

17. Evidence of disturbance by normal faulting, and probably also by reverse faulting, of the quartzite-phyllite formation among the Taconic hills.

18. Evidence of internal deformation by strong shearing of the calcareous rocks lying on the the terrigenous rocks which increases somewhat gradually as one goes eastward from the lake region.

19. The highly-metamorphosed character of the marble at the east.

20. The more schistose condition of the rocks of the main Taconic range.

21. The relatively unaltered character in most cases of the rocks near the lake.

22. Absence of recognizable Beekmantown east of the immediate vicinity of the lake.

One of the first difficulties that was encountered in applying any hypothesis to explain present structure as a result of deformation was that of arriving at a feeling of certainty as to the age of the terrigenous formation with which the fossiliferous Chazy-Trenton limestones are so frequently associated and in such apparent relations as to leave no doubt of the superjacent position of the limestones with respect to the terrigenous rocks. Some of these terrigenous rocks have been called Ordovician and and others Cambrian in areas in which the writer was unable to see a valid distinction. The writer has satisfied himself on the point that the age of the terrigenous rock cannot always be told from the limestone associated with it—it may be in some cases apparently (Cambrian); but if this is the fact it leaves the age of quartzite-phyllite formation as a whole still a question. Especially should it be noted that the presence of Ordovician limestone with phyllite is not indicative of a similar age for the latter in any cases which the writer has examined. The limestone has the character of an overlapping formation on the terrigenous mass. The next difficulty in applying an hypothesis is to get the limestone on the terrigenous formation. How did it come there? In trying to answer this question another difficulty appears. The writer was unable to find any visible contacts of limestone on the quartzite or phyllite. In southern Shaftsbury the two are very near at the present surface and the limestone here is greatly mashed and broken, affording a suggestion that it was thrust on the phyllite; but the field relation is not conclusive. In other words, there is nothing to show that the limestone might not have been deposited on the phyllite, or at least on contiguous phyllite, and have been slightly disturbed later, or that it must have come to its present position from some more or less remote place. In other places the two rocks are near together, but the question of whether the apparent overlap is one of deposition or one of thrust apparently may not be positively settled by the contact relations, although it has not proved possible to find any rock that might be thought of as representing the shore accumulation along the transgressing strand line of a sea advancing upon terrigenous rock. If the overlap is one of depositon it would seem that the limestone was probably laid down upon the terrigenous formation without definite and continuous basal overlapping member.

It would probably be argued that the fact of a subjacent position for the terrigenous formation with respect to Ordovician limestones is not conclusive evidence of its greater age, in a region in which thrust deformation is regarded as the key to the structure. This probably must be admitted. What is the probability as one views the region as a whole?

The Brandon-Sudbury-Orwell region is one of great interest in connection with the question of the relation of quartzite-phyllite formation to the Ordovician limestones. As has been described, the terrigenous rocks pass beneath the limestones northward in Orwell, and also in Sudbury, except for a narrow ridge that passes northward through Whiting to Weybridge. Little doubt remains that the extensive areas of limestone north of Orwell and Sudbury rest on the northward continuation beneath them of the terrigenous rocks of the hills at the south. The latter rocks also, except for normal faulting, pass beneath the marbles and their associated rocks in Brandon and appear again east of Brandon village. At this place the intimate association which they have with Lower Cambrian rocks, makes the presumption of a similar age very strong.

The quartzite of Snake and Buck mountains apparently has the same relation to the Ordovician limestones that the phyllites of Whiting have and the quartzite joins northeastward with unimportant interruptions at the surface through Monkton with the rocks of the plateau, and southward after a more extensive surface interruption under the limestones with the quartzite-phyllite hills of Orwell. Through the quartzite of Charlotte and Shelburne and northward, the southern quartzite joins with that north of Burlington which carries Lower Cambrian fossils. Southward the hills of Orwell join with similar rocks that carry Lower Cambrian fossils. It would certainly seem that from surface continuity, or what amounts practically to it, since the fact of similar limestone resting on the different terrigenous rocks is apparent, the probability of the Lower Cambrian age of the quartzite-phyllite formation underlying the limestones of Benson, Orwell, Sudbury, Brandon, Whiting, and probably even Bennington and Shaftsbury, is strongly indicated, as well as the equivalence of the quartzite ("Red Sandrock") farther north to the rocks of the Taconic hills. The case would be stronger if depositional overlap of the limestones could be proved or shown to be very probable. It is hard to prove the point. In Orwell and Benson the limestones have unquestionably been greatly disturbed and perhaps moved some distance from the east, if the contrast which they exhibit with the rocks of the lake region that have been overridden means anything in this connection; but they do not give an impression that is at all conclusive of having been transported from a distance and superposed on the terrigenous rocks on which they lie. If the point of the former widespread covering of the terrigenous rocks by the limestones be accepted as probable, then there is involved a long distance from east to west for these limestones to have been moved bodily across it over the rocks on which they now lie, although it is quite conceivable that they could have been disturbed from their original positions and probably were. It would appear more probable from the appearance which they now present that if they had a movement of translation from the east it was one in which the mass beneath participated; that, in other words, they really "rode" along the thrust plane on a mass of terrigenous rock that transported them. From all the viewpoints that the writer could utilize after a careful field study, it appears to him quite as if not more probable that the limestones were deposited on the terrigenous rocks. All the field relations suggest such a history rather than that they have come to be distributed on the quartzite-phyllite formation by thrust. On this view then the latter formation is older than the limestones and if it may be made to appear extremely probable that there is unity in the terrigenous formation over all the areas where it shows essentially the same characters, except perhaps for difference in metamorphism, then the principle of thrust as the key to structure in the presence of what may be actually seen of overlap in the region seems to apply. Some applications of it have already been made without, however, stating much about the probable relative age of the terrigenous rocks, except that they had suggestive association with the Lower Cambrian rocks at the east and that they seemed unquestionably to be normally beneath the limestones, including the marble.

In connection with the discussion or argument just given it should be remembered that on previous pages it has been contended that there is nothing which the writer has been able to see in the terrigenous rocks of the Orwell-Sudbury hills that supports the idea that two terranes are there represented. The rocks seem to compose a formational unit. The question is, What is the age of the unit? Whether one regards it as Cambrian or as Ordovician, the problem remains of accounting for the superior position of the limestones. Accordingly, the field relations were considered from the point of view of any of the terrigenous rocks being of Ordovician age to see if the principle of thrust which has to be recognized could be applied on that basis.

At this point it seems advisable to call attention again to one other relation which, in the writer's opinion, argues against the terrigenous rocks under discussion being younger than the limestones, including the marbles. Over the extensive limestone areas north of Brandon, Sudbury and Orwell we do not find any schist above the limestone. The strongest argument for the younger age of the schist appears to be its superior position at places farther south. This relation has already been discussed.

The idea that any of the terrigenous rocks under discussion are of Ordovician age assumes that the limestones are in general older than such terrigenous rocks and that the latter represent changed conditions of deposition in a sea which first laid down the limestones on an older base, conformably or unconformably. How could the conditions have permitted change from limestone to sand and mud rocks so that now in what is the Taconic range the limestones could have a covering of younger schist and so that conditions elsewhere in the vicinity, such as north of the range, could be as they now are? It is still conceivable, if Ordovician limestones were succeeded and covered by terrigenous deposits, that during a period of compression and thrust, Cambrian rocks could have been brought to lie on the Ordovician schists, while the Cambrian rocks passed under the limestone at depth.

If the schist capping Mt. Anthony in Bennington and Dorset Mountain and the ridge in between be regarded as of Ordovician age, passing by resemblances which much of this schist shows, except for metamorphism to rocks that have been shown as Cambrian on maps which represent the schist as Ordovician, many of the field relations are apparently not impossible of explanation while allowing the presence of deformation of the region by thrusts.

One may first imagine an eastward transgression of an Ordovician sea probably over an eroded Cambrian floor with deposition of limestone. If after the deposition of a certain amount of limestone an elevation should have occurred landward, it is possible to imagine that terrigenous deposits would have been carried westward out over the limestone which had been overlapping the older land. Deposition of limestone would have been halted landward but might have continued at the west and at other places, so to speak, while the muds and sands under the new conditions were making at places at the east. It is of course possible to imagine that these terrigenous rocks were restricted in their distribution and were not laid down everywhere along the changing strand. While some effort is required to imagine different conditions of deposition in such close proximity as to give originally the same abrupt passage from schist to limestone that is now to be seen at the northern end of the Taconic range, it is not inconceivable. In some way, according to the terms so far given of this hypothesis, the absence of the schists over the marbles and limestones at the north must be explained, it being assumed that the limestones at the north and those underlying the schist at the south are essentially the same and that both rest on a similar base. We may further imagine that the westward distribution by seaward overlap of muds and sands was restricted, perhaps in some places more than others, in its extent and that at the west these deposits graded laterally into more limy muds which graded downward into Trenton and upward into the so-called "Utica." We may imagine that at certain places the deposition of limestone continued practically during the whole time that the schists were making at other places, or that at places the limestones were succeeded by other deposits which were of such character that they could be easily eroded and therefore do not now appear above the limestone, as north of the Taconic range for instance.

The hypothesis just considered is in reality the theoretical extension of another involving other field relations and considerations, more especially the occurrence of essentially equivalent limestone strata lying on a terrigenous mass, composed everywhere of parts indistinguishable in one place from those of another, and which seems to be a formational unit, and which occurrence, as discussed above, seems to be due to the deposition during the Ordovician period, and perhaps the latter part of the Cambrian period, of the limestones of those periods on the mass of terrigenous material which now underlies the limestones. The field relations indicate unconformity of contact although actual contact was not found.

If now we take such evidence as we have of the age of the terrigenous substratum, some of which was given above, and regard it as of probable Cambrian age and probably largely Lower Cambrian, from what we know of the geology of surrounding regions as well as that of western Vermont itself, we may formulate more definitely another hypothesis to explain certain primary relations which preceded the disturbance of the region by great thrusts.

We may imagine the Paleozoic history of the region to have begun with the deposition of extensive masses of terrigenous materials marked by a thick sandstone at the base overlapping from the west on an older land north and south all along through what is now western Vermont and certainly also beyond its confines. As the sea deepened offshore, muds mingled with the sands until a great thickness was accumulated. Oscillations of level or other conditions, perhaps a combination, finally produced a mass of interstratified mud and sand. We may further imagine that there was lateral variation in these terrigenous deposits. Possibly where rivers flowed into the sea the sands were carried farther offshore and formed deltas between deposits of finer materials extending in either direction, north and south. On these deltas the ebb tides and periodic diminution of river floods exposed the sands to the weather and the oxidizing agencies produced the red color now marked by certain members of these

rocks on which the limestones now seem to lie. Finally, conditions would have permitted the deposition of the dolomitic limestones and interbedded dolomites and quartzites so widely present north and south in association with the quartzite-schist series. The hypothesis as thus far developed does not assume that the present geographical relations between the rocks of the Taconic region that are being regarded as Lower Cambrian and the Lower Cambrian rocks along the western edge of the plateau and in the Vermont valley was the one which obtained when these respective rocks were forming; but on the contrary recognizes that they are now separated by thrusts. Nevertheless, the calcareous rocks of the Lower Cambrian series were probably once present over the Lower Cambrian terrigenous rocks of the Taconic hills.

After deposition of Cambrian sediments had continued for a time, perhaps for Middle and part or all of Upper Cambrian time as well as during the Lower Cambrian period, a disturbance may be thought of as having folded or otherwise deformed the Cambrian beds and raised them above the sea. Erosion would have followed and a considerable but unknown mass of rocks presumably would have been removed, exposing the Lower Cambrian rocks. The changes which the Cambrian rocks underwent during this disturbance could be thought of as having produced some of the differences now apparent between them and the limestones which rest on them at many places. It is noticeable, from east to west, that the terrigenous rocks on which the limestones lie are more uniformly altered than are the limestones; they present less variation in metamorphism over the same areas.

Finally came a submergence of this denuded Cambrian surface and the deposition of a series of calcareous rocks, one can hardly say at just what time because the bottom of series is not now present in western Vermont, as the oldest Ordovician limestone or sandstone usually rests by thrust on much younger strata. One cannot say what may be present at depth underneath a probably great thickness of Ordovician rocks in the lake region which have been overridden by great masses of other rocks, including some Ordovician. The hypothesis of Ordovician deposition that is being developed is in fact erected on the basis of the overriding mass, in largest part.

Near the lake the great thrust plane along which were carried the rocks from the east over on those at the west, sheared away from the terrigenous rock into and through various Ordovician horizons, but apparently through nothing older than the so-called "Potsdam" which has been described.

The deposition of the limestones apparently proceeded by overlap eastward, laying down first, at the west, the Beekmantown and by progressive advance farther east some Chazy and Trenton. What may have come above the limestones at the east has already been discussed. At the west we have evidence that the Trenton was followed by the "Utica," but this rock apparently does not now appear east of the erosion margin of the great thrust except from beneath by exposure from erosion, as south of Mt. Philo in Ferrisburg and Charlotte.

Such an hypothesis seems to offer a ready and simple explanation of the occurrence of Chazy-Trenton beds apparently resting directly on the terrigenous formation in Orwell, Sudbury and Benson, if the latter formation is the Cambrian. It also permits the interpretation that the fragmentary areas of Ordovician limestone in the Taconic hills are erosion outliers resting unconformably upon the rocks beneath. The hypothesis does not necessarily call for the interpretation of schist now resting on the limestone, or marble, as younger, in view of the possibilities of modifications by thrust deformation. One thing that seems to support the idea of depositional overlap is the geographical extension of the limestone over the terrigenous formation, if erosion is taken into account.

To some it would seem almost incredible that the Beekmantown which has such a tremendous apparent thickness near the lake was not deposited over what are now the Taconic region and the Vermont valley. Seely, in fact, could not believe it. The fact remains that the Beekmantown has not been positively recognized away from the lake in what is to be regarded as the mass that has been in some degree transported from the eastward. Is it possible that it could have been deposited? Is it possible, for example, that the marble is the Beekmantown? Allowing again the necessity for recognizing thrusts, is it possible to explain the present relative position of Chazy-Trenton limestones and the terrigenous rocks of the Taconic hills in Orwell and Sudbury and still have the Beekmantown in the marbles at the east? It would seem that in this connection it is necessary to consider the probability of downfaulting of the marble and that some restoration of the rocks along the eastern border of the Vermont valley would have to be made, as has been done above, in order to weigh the question properly. When such restoration is made the probable Ordovician calcareous rocks of the valley are apparently raised to the level of those which lie on the rocks of the Taconic hills and the presumption grows that the marbles are younger.

To some the explanation of the occurrence of the limestones on the quartzite-phyllite formation by deposition might not appeal. It would then be necessary to account for the relation in some other way, say by thrust. Could a thrust plane have cut through a mass of rocks that lay to the eastward of the present Taconic hills in such way as to carry everything that lay above the calcareous rocks that now occur in the Taconic hills on the toe of the thrust and further in such way as to superpose these Chazy-Trenton limestones on Lower Cambrian, at the same time pushing what lay on the Lower Cambrian still farther west, the mass pushed now having disappeared by erosion? It might be possible, since there seems to be no necessary rule to govern the way in which a thrust plane would cut having once been initiated. Such explanation might leave Beekmantown at depth somewhere at the east. It magnifies more than ever the principle of thrust and the distance of movement. That we must suppose that such thrust, if it occurred, carried Ordovician limestones on Cambrian seems best shown north of the Taconic hills, where the evidence is strongest for the terrigenous rock ("Red Sandrock") being Cambrian. If it carried the limestones on Cambrian there is it probable that it would have elevated them to Ordovician schists only a few miles to the south in the Taconic hills?

The idea of depositional overlap fits the conditions at Snake and Buck mountains if we recognize the possibility of lateral variation of the Lower Cambrian sands and muds.

The proximity of the phyllite in the Whiting-Weybridge belt to the quartzite of Snake and Buck mountains offers no particular difficulty. The hypotheses mentioned have not been knowingly stretched to meet the facts. They take careful account of studied field relations. Any discrepancies may be put down for the most part as due to differences of assignment of age to certain rocks and to other differences of interpretation.

In the descriptions of the various areas given in the preceding pages, application has been made of some of the ideas that have just been developed. In the lake region there is acceptable evidence which has long been recognized of westward thrust. Perhaps some of the details offered in this paper are new, and perhaps some of the explanations are original. It is plain that we must recognize the present juxtaposition of masses that were once more or less separated. When we find the "Utica" exposed from beneath the mass, which we look upon as having moved from the east, at some distance east of the present lake shore, the probability of extensive movement appeals strongly. We are bound to consider the possibility that much of the calcareous rock now exposed in the lake region is transported rock. If such could be established with much certainty, our ideas of sedimentary provinces might require modification in some measure. We do not now view the rock where it was originally deposited.

In Benson and Orwell it may appear that we should recognize the probability that a phyllite of Cambrian age now rests on a slate of Ordovician age by thrust. It may be that we shall have to do the same or something similar at the east, but there the conditions are more obscure.

The possibility of extensive thrust or of any geographically extended thrust between the plateau and the Taconic range does not seem to have received much attention or credence. The evidence for thrust overlap has been cited and the question discussed above. It remains to consider a few localities more specifically than has been done.

Apparently, without doing violence to the hypothesis of Cambrian or post-Cambrian folding and erosion and subsequent Ordovician overlap, or even to the idea that the latter in some way brought terrigenous rocks to rest on the limestone that rests on supposed Cambrian, it is possible to imagine that at some time after the overlap occurred, possibly after a period of erosion, but not necessarily, during a period of compression a part of the Cambrian quartzite-schist formation was broken and thrust through and over the limestone. In this way a schist could have come to overlie a limestone or a marble and might appear in a greatly disturbed region to be conformable. But the possibilities seemingly do not end here. If the Ordovician limestone were succeeded upward by terrigenous rock, in some such way as described above, or otherwise, these might even be overthrust by older terrigenous rocks so that Cambrian quartzite or schist might come to lie on Ordovician schist, while the former underlay the limestone at depth.

It appears that the metamorphism shown by the schist of the Taconic range, which it should be noted in many cases, does not exceed that shown by the rocks of some of its foothills, could readily have been produced in muds of Cambrian age and if these should have by thrust been elevated and shoved westward on Ordovician calcareous rocks, they might readily have come into such relation with less altered or originally somewhat different terrigenous rocks as to give an appearance of being wholly different in age, which aspect would be heightened by the fact of their position relative to the limestone. In a region of thrust lithological transitions as indications of increasing metamorphism in relatively undisturbed rocks and therefore as indications of similar age, may have unsuspected significance.

The relations around Bennington are very complicated and those are apparently most so which at first appear simple. It would appear on the basis of general unity of structure of the rocks over a wide region that the conditions at Bennington should be capable of any explanation which should essentially satisfy the conditions farther north in the Vermont valley. On the basis of downfaulting, evidence for which is as strong at Bennington as at any place in the valley, one may attempt a restoration like that which was imagined for the valley around Dorset. The elements of uncertainty are many. The conditions south of the latitude of North Bennington are somewhat different from those north of it, which lends some support to the idea of transverse or east-west faulting between Mt. Anthony and West Mountain.

The elevation of the surface of the valley quartzite south of Bennington to that of the plateau would carry a certain amount of the calcareous rocks of the Cambrian upward, but it is not clear that it would carry all as the interbedded rocks along the western side of the valley south of Bennington may not rest on

quartzite. The proximity of the sheared and otherwise greatly deformed dove-colored limestone and its associated rock just east of Mt. Anthony, south of Bennington town, to interbedded rocks practically contiguous with them on the east, certainly suggests overlap such as is found and more plainly seen at the north. In the imaginary elevation of the interbedded rocks of the valley along the western portion south of Bennington, apparently beneath them would be carried upward some younger rock which had been overlapped by them. The conditions so far imagined give us apparently old rock resting against younger rock along a reverse fault and a thrust plane. Perhaps on the principle of differential normal faulting in the region, the Mt. Anthony ridge would have to be elevated somewhat in this process of restoration. The crystalline limestones and marbles underlying Mt. Anthony are relatively undeformed internally, presenting in their clearly-bedded condition a contrast to the marbles farther north; they are highly crystalline, but to a large extent not mashed and crushed. Directly east of them the bluish-gray limestone and its gray associate are greatly deformed internally, largely through shearing and brecciation. It would appear that this evidence of compression with the general field relations could be taken to mean that there had been a movement of one rock mass on another and the two masses which seemingly would have been involved are the marbles of Mt. Anthony and the sheared rocks just east of them. The marbles are presumably younger than the other rocks. Walcott found certain fossils (Trenton) which would seem to indicate such a probability; the writer found certain fossils which indicate Chazy age for the sheared rocks (see above). The Chazy has apparently broken and ridden upward on the Trenton along a reverse fault plane now marked by the rather extended zone of strong brecciation south of Bennington.

The marbles of Mt. Anthony are capped by schist or phyllite. Along the ridge southward near Carpenter Hill the rocks along the summit and eastern slope are interbedded black phyllite, sericite schist and quartzite. Along a scarp which extends from Carpenter Hill nearly to Pownal Center these terrigenous rocks, for some of the distance at least, rest against the interbedded series of the Lower Cambrian. South of Pownal Center the surface rocks of the ridge are largely crushed black phyllites, often pyritiferous, or chlorite-sericite schist. The schist mass bends southeasterly and cuts across the strike of the interbedded and other rocks northward, finally abutting against the massive, granular quartzite of the plateau.

West of Carpenter Hill is the crushed limestone of North Pownal with some sheared, bluish or dove-colored rock along the eastern part of the mass. On this limestone and jammed in with it is the black, pyritiferous phyllite, the same rock that surrounds it. Between Carpenter Hill and the limestone hill at North Pownal are areas in which patches of phyllite and limestone are intermingled at the present surface. In North Pownal the limestone rests on the schist; it does also west of the Hoosic River, north of Pownal station. The field relations all about speak with emphasis of former strong compression of the region.

Reckoning with the idea of an overlap of Ordovician calcareous rocks on an old Cambrian surface, as developed in connection with apparent relations at the north, and with the evidence of severe compression which is everywhere manifest, the present relations seem to be capable of at least partial explanation. It would seem that except for normal faulting their relations must recognize deformation by powerful compression and that the structural characters of the rocks show that deformation took place largely in the "zone of fracture." The evidence is good that many of the rock masses have come to be where they are now as the result of disturbance by rupture and displacement.

The interbedded terrigenous rocks on Carpenter Hill are counterparts of similar rocks on which the Ordovician limestones rest in the northern part of the Taconic hill region. The schist of Mann and Mason hills, except for its more abundant chlorite, is like that of West Mountain. The dove-colored rock and its gray dolomite are like those in Benson and Orwell, except for greater metamorphism; they are much like those in Brandon.

Proceeding with the strong feeling that has come from actual and extensive examination of the whole region it seems that the Bennington area does not differ essentially from other areas of the Taconic hills near the Vermont valley that have been discussed. It appears that under compression the rocks of the region were broken by reverse faults. It would seem that the members of the Lower Cambrian series were displaced with reference to each other and that the members of the overlying Ordovician rocks were also displaced with reference to each other. It seems possible to imagine that the quartzite-schist mass was either ruptured without much folding or that it was folded and overturned and then ruptured. The marbles of Mt. Anthony were protected from pronounced deformation by a great fracture, probably a reverse fault, that cut up through them. At Carpenter Hill and southward the crush zone apparently dies away. The quartzite-schist mass was apparently either folded and overturned or ruptured and pushed up, perhaps both. The calcareous rocks of North Pownal were caught and mashed and the schist jammed in with them and carried over them; it was also apparently carried over Mt. Anthony. On the basis of restoration, the Lower Cambrian calcareous rocks may once have overlapped the rocks that formerly lay on the Mt. Anthony ridge. In testing the validity of the interpretation, one must recall contrasts in the different rocks with reference to metamorphism. The schist and

for the most part the Ordovician calcareous rocks were subjected to conditions different from those within the mass that overrode them. The probability of overlap by lateral thrust is strong, on the basis of what is known farther north, but its extent is wholly uncertain. All thrust relations have been thoroughly disguised by normal faulting. Whether any of the Ordovician calcareous rock has been much displaced by lateral thrust it is not possible to tell.

North of North Bennington we find the counterpart of the dove-colored rock which occurs south of Bennington, and which seems to be Chazy, resting on the phyllite, although greatly deformed. Whether this rock is substantially in place it is not possible to decide. On the basis of a restoration it would be lifted to some extent and might come to the level of similar rock now found on the southern slopes of West Mountain. Erosion, as well as faulting, have operated to obscure relations here.

It is still maintained that by a combination of reverse faulting and lateral thrusting, a portion of the floor on which the Ordovician rocks apparently lie, whether by deposition or otherwise, could be carried over the limestone and perhaps give the appearance of being something very different from what it really is.

Regarding apparent conformability; this might be simulated. Logan has distinctly called attention to the superposition of certain rocks on others which seem to be conformable, but which give the strongest possible impression of being very different in age and speaks of the probable greater age of those which are superior in position.

There is apparently nothing which requires that a thrust plane should cut in any particular way through the rocks that are interposed, so to speak, in its path except a variable resistance. It might have undulated in the most irregular fashion at some places and have been fairly regular at others. At times it might have passed from a horizontal direction to one nearly vertical, and might have cut downward as well as upward. In cases where patches of limestone rest on a schist, which in turn rests on a marble presumably by minor thrust and where all are overlapped by thrust, it is possible to imagine that these patches either represent rock that is where it was before overlap by a thrust which cut above them, or that it has been carried there by the thrust cutting down into limestones farther east and moving some of that rock with the overriding mass. They would belong in a different category in one case from what they would in the other, being simple or displaced erosion outliers in the former case and thrust erosion outliers in the latter. The question of the extent to which thrusts may have moved masses of Ordovician limestone or marble, small or large, it is of course impossible to decide. The possibility apparently needs to be recognized.

North of Brandon the thrust apparently did not raise Cambrian schist and push it on marble, but only the interbedded series was thrust on the marble.

Northward it may be that the thrust along the western edge of the plateau disappears and that there is only one thrust plane. The eastern thrust at the south may be a minor one compared with that which drove the Lower Cambrian rocks and their load over the "Utica," and possibly may have been of widely different date.

It is interesting to note that apparently nowhere west of the plateau and east of the margin of the thrust as now developed by erosion along Lake Champlain or in the Taconic hills has the base or basement of the presumably Lower Cambrian been exposed.

In the early stages of the deformation which was to culminate in lateral overlapping thrusts of the Cambrian rocks, the whole floor of these rocks and their overlying load under the tremendous compression were probably folded and crumpled. There were probably developed many reverse faults of varying throw, some of which were probably very small. At this time the rocks undoubtedly also were strongly sheared. Schistose structure was developed in the impure muds, cleavage in the slates, and folds and ruptures in the quartzites. Similar deformations were produced in the overlying limestones.

The dates of these displacements may only be conjectured. In view of the apparent nature and magnitude of the regional deformation one cannot be sure that some later Paleozoic strata may not have once been present in the region.

At some post-Ordovician period the strata were cut by dikes of igneous rock, which in many places cut through the displaced rocks from the substratum beneath. So far as the writer knows, there is no evidence that sets the date of the intrusion and it may have been post-Carboniferous.

It is not easy to discern how much deformation of the thrust planes by folding occurred subsequent to their formation. East of Brandon the apparent plane of overlap of the interbedded series of the Cambrian does not seem to have been much deformed. Irregularities in thrust planes, which are more probably irregular than regular at the outset, by subsequent compression of the region seemingly would not be easy to see. If the thrusts were of pre-Devonian date it seems as though there would be more evidence than is apparent of subsequent deformation in the Appalachian folding of post-Carboniferous time. The probability of a late date for the big thrusts on this basis grows stronger.

The presence of thrusts in the region on the scale that has been described in part and postulated in part greatly complicates the question of the character and extent of any folding that has

been assumed to have occurred at the close of Ordovician time in this region. The assignment of date to the structural features of the rocks of a region like that of western Vermont depends upon one's viewpoint.

It seems reasonably clear that at some time subsequent to the production of the major features of the region that are due to compression, there came a period of extensive deformation by normal faulting. It would seem that it was at this time that the structural outlines of what are now the Vermont valley and Champlain lowland were formed. Between what is now the western edge of the Green Mountain plateau and the region now represented by the Taconic range, the rocks were dropped, producing a great structural trough. Northward was formed the outlines of the Champlain lowland between the plateau on the east and the Adirondacks on the west. Considering the downfaulted region as a whole the movement was differential and involved flexures as well as actual ruptures. The date at which this deformation occurred again can only be conjectured. Possibly it occurred at the time when similar deformations outlined the great Triassic troughs of our Atlantic border.

It seems not unlikely that during the time of post-Triassic faulting in the eastern part of the country there might have been renewed disturbance of this general region and that some of the fault lines now marked by scarps in the Taconic hills and elsewhere may belong to this period of disturbance. Such displacements are not to be confused, however, with reverse faults. It is, however, often not possible to decide whether certain obvious displacements between interbedded quartzites and phyllites of the Taconic hills are reverse or normal faults.

Some of the displacements along Lake Champlain which have been regarded as reverse faults or thrusts and are marked by scarps are apparently really normal faults within thrusted masses. The margin of the thrust is really at a distance from the scarps in question. For example, the displacements on the west of Snake and Buck mountains and west of the Orwell and Benson hills are probably normal faults cutting through a great lateral thrust. These masses were covered at one time and have been exposed by erosion. They stand higher now than the rocks at the west of them because the latter were dropped and the quartzite was carried downward beneath them. The thrusts extended west of these scarps an indeterminate distance, and apparently often, if not usually, across the lake, at least.

There is apparently nothing definite in the region to tell whether any of the thrusts were the results of previous erosion. It is true that east of Brandon and at other places the interbedded series lies on the marble and it is probable that other Cambrian rocks lie on marble; but it seems conceivable that these conditions could have been produced even though there were a mass of rocks above the limestones now represented by the marbles by reason of the way the thrust plane could have cut through the mass.

It is not necessary that we should assume that the marbles were not covered by other rocks when these thrusts occurred. Such has not intentionally been the argument; the explanation of the particular kind of terrigenous rock that now covers the marble at places is apparently one problem to be solved. A great shear seemingly might have been as effective as erosion in truncating a folded series. This statement would seem to apply generally and to fit the conditions along the lake as well as those near the plateau.

The present physiography. It has been a widely-accepted theory that during middle and late Mesozoic time a large portion of the Atlantic border of our country was reduced by the forces of subaerial erosion to a great peneplaned region, and that in succeeding Tertiary time the region was elevated by an extensive warping movement. According to this theory the present physiography is to be explained as the result of the renewed action of the base-levelling agencies as the region was gradually elevated. For certain regions it does not appear that any better theory has been advanced to explain the present conditions within them.

Accepting this view, the present physiographic outlines of western Vermont apparently must have been shaped along lines that had been determined by the great deformations which the region had suffered. The rocks in the different parts of western Vermont, whether the region was one of early folding and much later thrusts or one of folds and thrusts independent of pronounced earlier deformation, had been brought into such relative positions that during late Mesozoic time, allowing for some erosion, there was produced much the same relation that we see today from west to east across the State: a great truncation of perhaps lofty masses and exposure of rocks of one age here and another there. We note the oldest rocks at the east and the youngest at the west, as far as exposure has gone. The structural outlines of the Vermont valley and Champlain lowland had presumably already been laid down by the downfaulting of great blocks of soft rocks between masses of more resistant crystallines. Although all were alike presumably reduced to a peneplain in late Cretaceous time, upon later elevation the forces of erosion discovered the downfaulted masses of softer rocks and wore them rapidly away.

The present physiography of the region gives some hints of the deformations which it has undergone, and a gross surface section across the State adds something more; but it must be apparent that the physiography by itself is wholly insufficient to explain the complicated structure of the rocks of western Vermont.

SUPPLEMENTARY NOTE.

Some of the names in this paper designating fossils from exposures studied by the writer are used chiefly as general descriptive terms for forms whose identities the nature of the material would often make it difficult to establish. As indices to the horizons of the containing rocks their values have been recognized in many instances by reason of concomitant features, such as reasonably apparent stratigraphic associations with other rock whose identity could seemingly be more conclusively fixed, and from occurrence in similar rocks at other places in the same region with other and different fossils whose identities were more obvious. Particularly among terms used for such general descriptive purposes the names *Pleurotomaria* and *Murchisonia* were applied to markings which strongly resemble either some of the species of *Pleurotomaria* or some of those of *Murchisonia* as described in the older literature to which the general reader probably would most likely first refer, such as the Paleontology of New York by James Hall, or early publications of the Geological Survey of Canada by Billings, as well as the early descriptions of the formations of Vermont. Most of the forms assigned to *Murchisonia* by earlier writers are now referred to other genera (*Lophospira, Hormotoma*, etc.), and the same is true for *Pleurotomaria.*

Other names which have been used in reference to fossils are obviously citations from the literature and in such connection are employed without presuming to pass upon their validity or synonymy.

Certain other names have been employed also because of their use by others with reference to Vermont formations in describing certain characteristic fossils and in making comparison thereby with rocks of other regions. In such cases attempt has not usually been made to establish with absolute positiveness just what names in the latest synonymy of Ordovician fossils should apply to the forms referred to. In the list given beyond certain probabilities are indicated.

The general structure of the region suggests that, so far as preservation of fossils in certain disturbed and somewhat metamorphosed strata permits, it may prove desirable to undertake studies designed to draw comparisons among fossils of different localities and rocks in the general Champlain region in order to obtain further light on the probable extent of the thrust deformations which the region has obviously suffered, and to ascertain if any peculiar or anomalous faunal features exist in the region which could be ascribed to such disturbances as the foregoing paper has discussed.

It may perhaps be said that the older names have an historical value in tracing the progress of knowledge of the rocks of western Vermont; but better knowledge of the exact affinities of the fossils is doubtless required before the ancient geographic relations of those rocks may be fully understood.

NAME USED.	POSSIBLE OR PROBABLE EMENDATION.
Bellerophon sp.	Probably *Sinuites cancellatus*, Hall.
Ophileta complanata, Vanuxem.	Possibly equivalent to some one of the forms described as *O. compacta*, Salter.
Maclurea magna, Emmons.	*Maclurites magnus*, Lesueur.
Strephochaetus sp.	*Girvanella*, probably *ocellata*, Seely.
Trinucleus concentricus, (*Trinucleus concentrica* of various authors).	*Cryptolithus tesselatus*, Green.
Graptolithus pristis.	*Graptolithus pristis*, Hall. (Possibly *Diplograptus* sp. or *Glossograptus* sp.)
Prasopora sp.	*P. simulatrix*, var. *orientalis*, Ulrich. (Some specimens collected by the writer at South Hero were examined by Dr. Ruedemann of Albany in connection with studies of Trenton fossils from Grand Isle and identified as *P. simulatrix*, var. *orientalis*, Ulr.[1] In view of the recognition of this form in the Champlain valley the writer prepared radial and tangential sections of specimens collected by him at the grist mill, one mile west of Orwell village, and on the lake shore in Orwell just north of the Benson line, and compared with the descriptions and figures given by Ulrich in the Geology of Minnesota, vol. 3, part 1, 1895, pp. 245-248, plate 16, and found his specimens also to be *P. simulatrix*, var. *orientalis*, Ulr.)

[1] Personal communication.

BIBLIOGRAPHY.

1845—ADAMS, C. B. First, Second, Third and Fourth Annual Reports on the Geology of Vermont.

1846—EMMONS, E. Agriculture of New York.

1861—HITCHCOCK, E., and Others. Geology of Vermont, 2 vols.

1861—BARRANDE, J., LOGAN, SIR W., HALL, JAMES. Correspondence on the Taconic System and the age of the Fossils found in the Rocks of Northern New England and the Quebec Group of Rocks. Amer. Jour. Sci. Vol. 31.

1861—BARRANDE, J. Documens Anciens et Nouveaux sur la Primordiale et le Systéme Taconique en Amerique. Bull. Soc. Géol. de France. Vol. 2.

1863—LOGAN, SIR W. E. Geology of Canada, Text and Atlas.

1877—DANA, J. D. An Account of the Discoveries in Vermont Geology of the Rev. Augustus Wing. Amer. Jour. Sci. Vols. 13 and 14.

1877—DANA, J. D. On the Relations of the Geology of Vermont to that of Berkshire. Amer. Jour. Sci. Vol. 14.

1879—DANA, J. D. On the Hudson River Age of the Taconic Schists. Amer. Jour. Sci. Vol. 17.

1880—DANA, J. D. Note on the Age of the Green Mountains. Amer. Jour. Sci. Vol. 19.

1882—DANA, J. D. The Geological Age of the Taconic System. Quart. Jour. of the Geol. Soc. Aug., 1882.

1884—GEIKIE, A., PEACH, B. N., and HORNE, J. The Crystalline Rocks of the Scottish Highlands. Nature. Vol. 31.

1884—DANA, J. D. On the Southward Ending of a Great Synclinal in the Taconic Range. Amer. Jour. Sci. Vol. 28.

1885—FORD, S. W. Great Fault, Schodack Landing, N. Y. Amer. Jour. Sci. Vol. 29.

1885—DANA, J. D. On Taconic Rocks and Stratigraphy, with a Geological Map of the Taconic Region. Amer. Jour. Sci. Vol. 29. See also Vol. 33, 1887.

1886—MCCONNELL, R. G. Report on the Geological Features of a Portion of the Rocky Mountains. Ann. Rept. Geol. Surv. Can. Vol. 2.

1886—DANA, J. D. Berkshire Geology. A paper read before the Berkshire Historical and Scientific Society, Pittsfield, Mass., Feb. 5, 1885.

1886—BRAINERD, E. and SEELY, H. M. Notice of Geological Investigations along the Eastern Shore of Lake Champlain. Bull. Amer. Mus. Nat. Hist. Vol. 1.

1888—PEACH, B. N., HORNE, J., GUNN, W., CLOUGH, C. T., HINXMAN, L., CADELL, H. M. Communicated by GEIKIE, A. Report on the Recent Work of the Geological Survey in the North-West Highlands of Scotland. Quart. Jour. of the Geol. Soc. Vol. 44.

1888—WALCOTT, C. D. The Taconic System of Emmons and the Use of the Name Taconic in Geologic Nomenclature. Amer. Jour. Sci. Vol. 35.

1888—DANA, J. D. A Brief History of Taconic Ideas. Amer. Jour. Sci. Vol. 36.

1888—MARGERIE et HEIM. Dislocations de l'écorce terrestre. Zurich, 1888.

1888—ELLS, R. W. Second Report on the Geology of a portion of the Province of Quebec. Ann. Rept. Geol. and Nat. Hist. Survey of Canada. Vol. 3, Part 2.

1890—WALCOTT, C. D. The Fauna of the Lower Cambrian or Olenellus Zone. Tenth Annual Report of the Director, U. S. G. S.

1890—BRAINERD, E. and SEELY, H. M. The Calciferous Formation in the Champlain Valley. Bull. Amer. Mus. Nat. Hist. Vol. 3.

1891—HAYES, C. W. The Overthrust Faults of the Southern Appalachians. Bull. Geol. Soc. Amer. Vol. 2.

1891—BRAINERD, E. The Chazy Formation in the Champlain Valley. Bull. Geol. Soc. Amer. Vol. 2.

1891—WOLFF, J. E. On the Lower Cambrian Age of the Stockbridge Limestone. Bull. Geol. Soc. Amer. Vol. 2.

1891—WALCOTT, C. D. Correlation Papers, Cambrian. Bull. U. S. G. S. No. 81.

1892—WILLIS, BAILEY. The Mechanics of Appalachian Structure. Thirteenth Annual Rept. of the Director, U. S. G. S. Part 2.

1892—VAN HISE, C. R. Correlation Papers, Pre-Cambrian. Bull. U. S. G. S. No. 86.

1893—DARTON, N. H. On two Overthrusts in Eastern New York. Bull. Geol. Soc. Amer. Vol. 4.

1893—WILLIS, B. and HAYES, C. W. Conditions of Appalachian Faulting. Amer. Jour. Sci. Vol. 46.

1893—FOERSTE, A. F. New Fossil Localities in the Early Paleozoic. Amer. Jour. Sci. Vol. 46.

1893—DALE, T. NELSON. On the Structure of the Ridge between the Taconic and Green Mountain Ranges in Vermont. Fourteenth Ann. Rept. of the Director, U. S. G. S. Part 2.

1894—PUMPELLY, R., WOLFF, J. E., and DALE, T. N. Geology of the Green Mountains in Massachusetts. Monograph U. S. G. S. No. 23.

1894—WHITTLE, C. S. Algonkian Rocks in Vermont. Jour. Geol. Vol. 3.

1895—DALE, T. N. Structural Details in the Green Mountain Region and in Eastern New York. Sixteenth Ann. Rept. of the Director U. S. G. S. Vol. 4, Part 1.

1895—VAN HISE, C. R. Principles of North American Pre-Cambrian Geology. Sixteenth Ann. Rept. of the Director U. S. G. S. Vol. 4, Part 1.

1896—BRAINERD, E. and SEELY, H. M. The Chazy of Lake Champlain. Bull. Amer. Mus. Nat. Hist. Vol. 8.

1898—DALE, T. NELSON. The Slate Belt of Eastern New York and Western Vermont. Nineteenth Ann. Rept. of the Director U. S. G. S. Part 3.

1899—EMERSON, B. K. The Geology of Eastern Berkshire County, Mass. Bull. U. S. G. S. No. 159.

1899—WHITE, THEODORE G. Upper Ordovician Faunas in Lake Champlain Valley. Bull. Geol. Soc. Amer. Vol. 10.

1901—RUEDEMANN, R. Hudson River Beds near Albany and their Taxonomic Equivalents. N. Y. State Mus. Bull. No. 42.

1902—WILLIS, BAILEY. Stratigraphy and Structure, Lewis and Livingston Ranges, Montana. Bull. Geol. Soc. Amer. Vol. 13.

1902—PERKINS, GEORGE H. The Geology of Grand Isle. Third Report of the State Geologist.

1904—DALE, T. NELSON. The Geology of the North End of the Taconic Range. Amer. Jour. Sci. Vol. 17.

1905—RAYMOND, P. E. The Fauna of the Chazy Limestone. Amer. Jour. Sci. Vol. 19.

1906—MERRILL, G. P. Contributions to the History of American Geology. U. S. Nat. Mus. Report for 1904, No. 135.

1906—EDSON, G. E. Geology of St. Albans and Vicinity. Fifth Report of the State Geologist.

1906—SEELY, H. M. Beekmantown and Chazy Formations in the Champlain Valley. Fifth Report of the State Geologist.

1907—KEITH, ARTHUR. Roan Mountain Folio. Geological Atlas of the U. S. No. 151.

1908—PERKINS, GEORGE H. Preliminary Report on the Geology of Chittenden County. Sixth Report of the State Geologist.

1908—EDSON, G. E. Geology of the Town of Swanton. Sixth Report of the State Geologist.

1908—PERKINS, GEORGE H. Preliminary Report on the Geology of Franklin County, Vt. Sixth Report of the State Geologist.

1909—RUEDEMANN, R. Types of Inliers Observed in New York. Bull. N. Y. State Mus. No. 133.

1909—VAN HISE, C. R. and LEITH, C. K. Pre-Cambrian Geology of North America. Bull. U. S. G. S. No. 360.

1909—SCHUCHERT, C. Paleogeography of North America. Bull. Geol. Soc. Amer. Vol. 20.

1910—DALE, T. N. The Cambrian Conglomerate of Ripton in Vermont. Amer. Jour. Sci. Vol. 30.

1910—SEELY, H. M. Preliminary Report on the Geology of Addison County. Seventh Report of the State Geologist.

1910—PERKINS, GEORGE H. Geology of the Burlington Quadrangle. Seventh Report of the State Geologist.

1910—KEMP, J. F. and RUEDEMANN, R. Geology of the Elizabethtown and Port Henry Quadrangles. Bull. N. Y. State Mus. No. 138.

1911—ULRICH, E. O. Revision of the Paleozoic Systems. Bull. Geol. Soc. Amer. Vol. 22.

1911—GORDON, C. E. The Geology of the Poughkeepsie Quadrangle. N. Y. State Mus. Bull. No. 148.

1912—WILLIS, BAILEY. Report on an Investigation of the Geological Structure of the Alps. Smithsonian Miscellaneous Collections. Vol. 56.

1912—RICHARDS, R. W. and MANSFIELD, G. R. The Bannock Overthrust. Jour. Geol. Vol. 20.

1912—DALE, T. NELSON. The Ordovician Outlier at Hyde Manor in Sudbury. Amer. Jour. Sci. Vol. 33.

1912—DALE, T. N. The Commercial Marbles of Vermont. Bull. U. S. G. S. No. 521. See also Ninth Report of the State Geologist, 1914.

1913—KEITH, A. Further Discoveries in the Taconic Mountains. Abstract. Bull. Geol. Soc. Amer. Vol. 24.

1913—DALE, T. N. The Ordovician Outlier at Hyde Manor in Sudbury. Second paper. Amer. Jour. Sci. Vol. 36.

1914—GORDON, C. E. Notes on the Geology in the Vicinity of Bennington. Ninth Report of the State Geologist.

1916—PERKINS, GEORGE H. The Geology of Western Vermont. Tenth Report of the State Geologist.

1917—EMERSON, B. K. Geology of Massachusetts and Rhode Island. Bull. U. S. G. S. No. 597.

ERRATA

The title of plate XXXVIII should be, "Willoughby trough from the south."

The title of plate XL should be, "General view of Willoughby Lake."

On page 285, line 7, the word "new" should read "now."

The title of plate XLII should be, "Mount Pisgah from the lake."

The title of plate XLIII should be, "Mount Hor from the lake."

On page 284 plate XL should read plate XXXVIII.

Lake Willoughby lies in the western part of the town of Westmore, near the eastern boundary of Orleans County, and some twenty-three miles north of St. Johnsbury. It is one of the most beautiful sheets of water in the United States and would not suffer by comparison with the Alpine lakes of Switzerland. To quote from Mr. Walter Crockett's "Lakes of Eastern Vermont," we have here "a rare combination of lake and mountain scenery, a lake (five miles long and from one-half to one and one-fifth miles wide) of exquisite loveliness set amid bold and rugged mountains, the dark tints of the evergreen forests and the delicate silvery whiteness of the birches being reflected as in a mirror in Willoughby's deep waters. * * * * *" "On either side, at the southern extremity of the lake, like giant guardians, stand Mount Pisgah and Mount Hor, with their Scriptural names, keeping watch over this vision of scenic loveliness." The slopes of these mountains are densely wooded save where erosion reveals nearly vertical cliffs of dark, bronze-colored rocks, slashed with bands and patches of a lighter material. Below the cliffs are enormous talus heaps of granite and other material. Rock falls are frequent, a fall in July of this year blocking the road for several days.

The lake may be likened to the section of a giant calabash gourd, with its broad end lying in the relatively open country and its curving neck penetrating and forming a gap in the mountain range at its southern extremity. The lake shores were formerly impassible to vehicles, communication between the eastern and western valleys being either by boat or else by a mountain road running east of Mount Pisgah. But some sixty years ago a road was built along the eastern (Mount Pisgah) shore and now forms part of the main highway between St. Johnsbury and Newport. Numerous summer cottages and the Westmore Hotel are located along this road towards the northern end of the lake. "Westmore," a girls' camp, was built in 1919 on a commanding hill on the northwestern shore. The camp is closed this season owing to financial difficulties, but will probably be reopened. This

PLATE XXXVIII.

General view of Willoughby Lake.

is surely to be desired, for a more beautiful site for such a place would be difficult to imagine.

Around the northern end of the lake are numerous objects of interest, among which may be mentioned a mineral spring and the so-called "Balanced Rock," an enormous glacial boulder of granite, thirty-three feet high, which towers above the trees, a silent reminder of the great ice age of the long ago. At the foot of Mount Hor, on the western side of the lake, there is a fern grotto.

Near the southern end of the lake an excellently conducted tea house, The Boulders, and a casino, both run by the Lyndon Improvement Society, offer their hospitality to motorists and others. Good beaches at either extremity of the lake afford opportunities for bathers and campers, and are thronged on Sundays and holidays.

Lake Willoughby lies about ~~1,160~~ 1170 feet above sea-level. Details regarding this determination will be presented later. From its southern end a trail of easy grade leads to the summit of Pisgah, whose elevation is given as 1,654 feet above the lake-level. Here several unwooded areas afford a superb view of the surrounding country. From the opposite shore Mount Hor, heavily wooded even on its summit, rises 1,000 feet above the lake and presents the form of a rough crescent with the "bow" facing the observer. The contour of Hor, seen from the north, suggests a whale's head and behind this there is a sharp peak, appropriately known as the "Fin." Farther west lies Mount Wheeler, whose eastern face presents steep, rugged cliffs of granite. Beyond this, Barton Mountain is seen and the range of mountains continues as far as the eye can reach.

Southward, down the cross-valley, in the town of East Burke, lie Burke, Kirby and Umpire mountains, while in the distance is the Presidential Range of the White Mountains, with Mount Washington raising its huge bulk against the sky. From the northern exposure, on a clear day, Lake Memphremagog and Mount Orford, one of the highest of the Canadian peaks, are visible. To the northwest are to be seen the next westward range of the Green Mountains, the Lowell Mountains, and Jay Peak. Farther south lie Mount Mansfield and "The Lion" (otherwise called Camel's Hump, a sad misnomer).

Numerous ponds dot the surface of the country: Seymour Lake, Island Pond, Long Pond, Bald Hill Pond, Newark Pond, east and southeast; and several marl ponds to the westward. In the next valley to the westward, through which the Passumpsic Division of the Boston and Maine Railroad passes, in the town of Barton, lies Crystal Lake, a lovely sheet of water, two and one-half miles long and three-fourths of a mile wide.

Taken altogether, a more charming region for summer cottagers and campers and tourists, or a more fascinating place for botanists and geologists, would be hard to imagine. The State roads, made of glacial gravel, than which no better road "metal" can be found, are well kept and the ever increasing travel is a tribute to the charm of this delightful land.

TOPOGRAPHY AND PHYSIOGRAPHY.

In connection with his valuable article on The Post-Glacial Marine Waters in Vermont,[1] Professor Herman L. Fairchild of the University of Rochester, has constructed a map showing the drainage basins and glacial lake outlets in Vermont as the great Labrador Ice Sheet retreated northward at the close of the last glacial period. Professor Fairchild's map is here reproduced (Plate XXXIX) and is of great value in connection with the present article.

From the map the topography of the region can be easily grasped. Willoughby lies in the Lake Memphremagog drainage basin, which is demarcated on the west by the Lowell Mountains and on the east by the mountain chain (unnamed as far as the writer is aware) which includes Mount Pisgah and Mount Hor. As already noted, Lake Willoughby may be compared to the section of an enormous gourd, five and two-tenth miles long, with its broad end, one and one-fifth miles in maximum width, lying in the relatively open country, and its "neck," curving somewhat to the eastward and penetrating the mountain chain, between Pisgah and Hor, for a distance of a mile and a half, where it is from one-half to three-fourths of a mile wide. The lake is very deep, varying according to popular report from 600 feet to "bottomless." More accurately, Dean H. E. Hawkes of Columbia University, who is a summer resident, has made careful soundings and brought out some intensely interesting facts. The sketch (figure 22) which shows the contour of the lake on an east-west

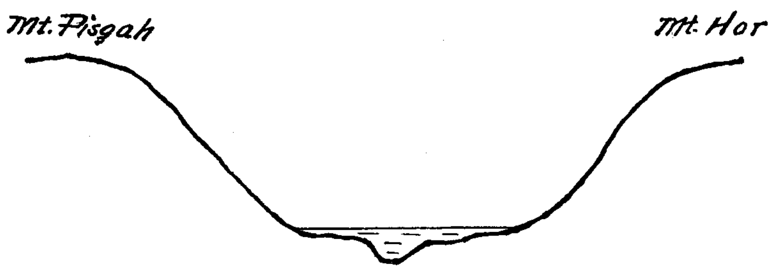
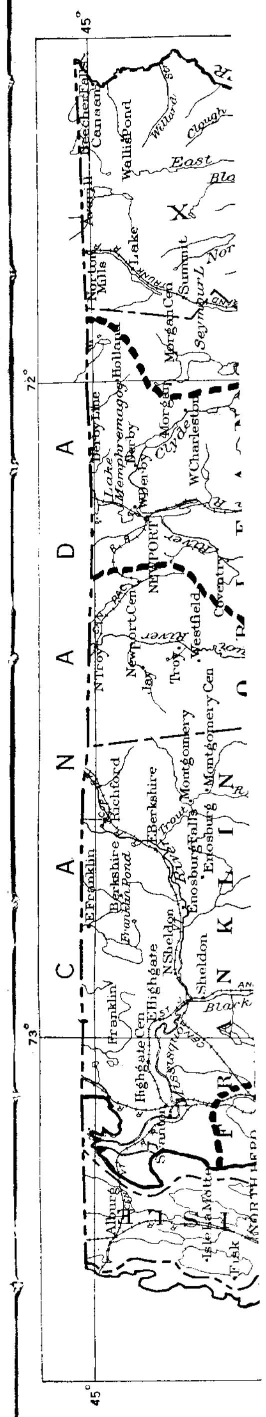


FIGURE 22. Contour of Willoughby trough.

line, opposite Devil's Rock, has been made from his data. It shows that the water deepens rapidly to about 200 feet and that, about one-third the distance across, there is a gorge in the bottom, ninety-six feet deep and fifteen to twenty rods wide, which has

[1] Report of the Vermont State Geologist, 1915-16.



Map of Vermont showing drainage basins and glacial lake outlets.

been traced for about three miles northwards. The maximum depth of the lake is therefore 296 feet. The significance of this gorge will be discussed later. The lake is fed by Mill Brook, which flows down from Long Pond, and several other mountain streams as well as by springs in its bed. The surplus waters flow out at the northwest end of the lake into Willoughby River, a tributary of Barton River, which empties into Lake Memphremagog.

Willoughby is a glacial lake and lies directly in the watershed between the Memphremagog and the Connecticut drainage basins (see plate XXXIX). It is dammed at either end by glacial material. The surface of the lake is given as from 1,080 to 1,100 feet above sea-level. The Boston and Maine Railroad survey has determined the elevation of the waiting-room door-sill, at the West Burke station, as 932 feet above sea-level. Taking this as a datum, the writer made several aneroid measurements of the lake-level, the average of which showed the lake to be 223 feet above the datum, or 1,155 feet above the sea-level. The determinations were made, using an automobile, within half an hour of each other, on clear days, so that local barometric fluctuations were eliminated. Experiments with the barometer between known elevations, in Burlington, showed that it had a minus error of four per cent. This would make the possible error in the determination of the lake-level as nine feet and the probable true elevation as 1,164 feet above sea-level.

Lake Memphremagog is 685 feet above sea-level so that, if the glacial damming were removed, Willoughby would drain completely, through Barton River into Memphremagog and thence into the St. Lawrence.

South of the watershed a cross-valley extends southeasterly to East Burke, where it joins the valley of the Passumpsic River. This cross-valley is littered with morainal material. Beginning at the water-level at the head of the lake, the moraine rises in a steep hill to a height of 110 feet, on the Cheney estate, while the road over the hill, built at an easier grade, is twenty feet lower. The distance from the lake to the top of the hill is two-tenths of a mile. The road still rises and reaches its maximum elevation of 120 feet above the lake, at a distance of six-tenths of a mile from it. Two-tenths of a mile farther on bed rock is reached, at an elevation of ninety-five feet above the lake. This, as far as has been determined, is the true height of the divide between the Memphremagog and the Connecticut drainage basins, as it existed in pre-glacial times. It shows that the Willoughby basin is rock-rimmed on its southern end and that it has always drained to the north—in other words, that this is not an example of a pre-glacial southerly drainage being reversed by glacial damming, such as the writer has found to be the case in the Roxbury and Warren valleys. Further discussion of the significance of these facts, as they affect the question as to the origin of the lake will be presented later.

THE MOUNTAINS AND VALLEYS.

We have here to distinguish between the mountain chains and ridges which are structural, that is, which were folded up at the close of Ordovician time by diastrophic forces exerted from the eastward, and the granite mountains of the region, which were irrupted through the earlier formations at a later date, perhaps in the Devonian. The structural mountains and ridges trend roughly northeast and southwest, and through the main valley, in East Burke, the Passumpsic River flows southerly to its confluence with the Connecticut. The granite chain of mountains trends more nearly east and west and therefore cut across the structural ridges at an acute angle. Between the two systems of mountains and ridges are several cross-valleys and through these several tributaries of the Passumpsic pass, one flowing from the divide in the Barton valley and another rising in the ponds south of the Willoughby divide. The west wall of the Willoughby-Burke valley is formed by a series of ridges, the most northerly of which dies out at the base of Mount Hor, just south of the lake. The ridges forming the east wall of the valley die out in Mount Pisgah. The Willoughby-Burke valley is far too large for the stream which at present occupies it. The explanation is evidently to be found in the tremendous volume of water formed by the melting ice at the close of the Glacial Period.

The granite intrusives occupy a great area in Barton and Westmore and form a chain of peaks which includes Wheeler, the Fin, Hor, Pisgah, Owl's Head, Bald Mountain, etc.

THE WILLOUGHBY TROUGH.

The most striking feature of this whole region is the great trough in which Lake Willoughby partly lies (plate XL). As the traveler passes over the divides on the way from Lowell to Newport, or from Orleans to Westmore, or as he approaches the lake from West Burke, he sees in the distance a great notch in the mountain barrier, a huge U-shaped trough such as is unique in Vermont topography but which is often observed in the Rocky Mountains. The fantastic form of Mount Pisgah, rising 1,654 feet above the lake, forms the northern half of the trough, while the great whale's head of Mount Hor, 600 feet lower, makes up the southern half. The two summits are perhaps three-quarters of a mile apart and are nearly in an east-west line.

The writer believes that the gouging out of this great trough could have been done only by glacial action. A river flowing between the mountains would have carved out a V-shaped valley.

PLATE XL.

Willoughby trough from the south.

Furthermore, the study of the topography and elevations of the lake and the surrounding region has shown that a river here would have been an impossibility—as well try to imagine water flowing across the ridge-pole of a house! On the other hand, such great troughs are of common occurrence in the northern Rockies, where geologists have studied them and have agreed upon their glacial origin. New evidences of profound glacial action in this region are everywhere abundant. Vermont is littered from border to border with glacial débris: sand and clay, gravel and boulders. Our highest mountains (as well as those of New Hampshire and New York) are strewn with glacial erratics, while the rounding and grooving and striating of the bed rock not only testifies to the advances of the great ice sheet but also point out their directions. Our valleys are often dammed with morainal material, which marks the resting places of the ice sheet between its advances. Sometimes the rivers have been reversed in their flow, as in the Roxbury and Warren valleys. A very large proportion, perhaps all, of our lakes (and indeed of those of the northern part of North America) have been formed by glacial damming, and it has been seen that Lake Willoughby is no exception. Readvances of the ice sheet over its own moraine often fashioned this material into low, elliptical ridges of unsorted material which are known as drumlins; while streams flowing under the ice produced sinuous ridges and mounds of water-sorted material called eskers and kames.

The great ice cap, which held North America in its grip as far south as Long Island and, roughly speaking, along the courses of the Ohio and Missouri rivers, originated in several great centers of accumulation in Canada. The part which covered New England is known as the Labrador Ice Sheet and it has been estimated that it was 10,000 feet thick in northern Vermont. That such an ice sheet, laden with material which it plucked and gathered up as it advanced, shod with rocks firmly frozen in its sides and bottom, and exerting a pressure of hundreds of tons to the square foot, would be entirely capable of gouging out troughs in the valleys it traversed, snubbing off mountain spurs, and smoothing and grooving and striating rock surfaces, is entirely believable. That its melting would have left the mantle of transported material—erratics, even on the highest mountain tops, moraines and other phenomena—goes without saying.

The glacial theory was Agassiz's and is now universally accepted. But it is interesting to Vermonters to read Hitchcock's Report on the Geology of Vermont and find that he attributed all this observed glacial phenomena to the action of icebergs floating in an ocean which covered the continent, grounding on and striating the mountain tops and depositing their loads where they melted. Just where they obtained these loads, why the winds blew so constantly that so many parallel striations were cut, why valleys were particularly favored as repositories for the transported material—these and many other vexed questions were left to the imagination.

Now at Willoughby and in its vicinity, we find many proofs of glacial action. The glacial damming which holds the lake in its basin has already been mentioned and it has been seen that from the south end the land rises 120 feet above the lake-level, in six-tenths of a mile, and discloses bed rock, two-tenths of a mile farther south, at an elevation of ninety-five feet. From here southward the ground is covered with a thin mantle of glacial till. The photograph (plate XLI) shows this material as seen in a gravel pit, nine-tenths of a mile from the lake. It is to be noted that the till is unsorted, the largest boulders occurring at the top of the bank, and that it is composed of granite, limestone and schist boulders (perhaps ninety per cent. are granite) together with coarse sand. In the valley are also to be noted mounds of till and several low eskers. At West Burke, bed rock is exposed in the river channel. Several large eskers are seen along the road from West Burke to Lyndonville. The highway cuts across one of these and the roughly-sorted nature of the till may be observed. Glacial boulders, or erratics, are myriad and often enormous. They are found on the summit and slopes of Pisgah (two over ten feet high) and probably on Hor, though the latter mountain was not visited, since the foliage is so dense and unbroken that the ascent would be of doubtful value. Down the valley towards Burke, eight-tenths of a mile from the lake, there is one of the largest; on the south shore of the lake there are others, which could not possibly have dropped from the cliffs; and in the open country to the north of the granite range are many more. The largest erratic, the so-called "Balanced Rock," has already been mentioned. Most of these boulders are granite, those in the open country probably having been brought from the intrusives in Derby; but here and there one encounters a mass of diabase which must have been transported many miles, since this rock is not native in the lake region. On the road from Westmore to Brownington Center there is a fine kame.

No groovings or striations have been found by the writer on the cliffs of Pisgah or Hor, nor is this to be wondered at, since erosion would have long since obliterated them. But on the northwest shore of the lake, in front of Camp Westmore, the granite surfaces have been smoothed and rounded by glacial action. There may be faint striations here and also on the summit of Pisgah but the markings are too faint to afford positive proof.

OTHER EVIDENCES OF GLACIATION.

From the north end of the lake, the granite range of mountains presents a series of crests and troughs, with gently curving western slopes and much steeper eastern slopes. The steep cliff

PLATE XLI.

Bank of glacial till on the road to West Burke.

forming the eastern face of Mount Wheeler suggests glacial snubbing, though of course, this effect has been accentuated by erosion. East of Mount Hor, the Willoughby trough breaks the rude symmetry of the mountain chain. If the trough were not there the long western slope would culminate in the summit of Pisgah. This will be referred to later.

Crystal Lake, in the town of Barton, which lies in a valley a few miles to the westward, is also a glacial lake, held in its basin by glacial damming. From its eastern shore a granite mountain rises sheer from the water. The granite here is very compact and it has been smoothed and fashioned into long, rounded surfaces, extending north and south, by glacial action. On it are to be seen parallel striations which bear north, 15 degrees west. It is not to be doubted that, were the surfaces of Pisgah and Hor as compact and resistant to erosion as are those of Crystal Lake, we should have found similar evidences of glaciation. That they are much more susceptible to weathering, from the nature of their composition, will be shown presently.

The proof is convincing, to the writer at any rate, that Willoughby is a glacial lake and that it lies in a glacial trough.

But what was the origin of this trough and what caused the deep gorge in the lake bottom? Ice sheets have overridden and to some extent modified mountain crests, but they are hardly competent to attack a mountain barrier and gouge out a trough such as Willoughby's. They require a foot-hold, so to speak, and there must accordingly have been a valley between Hor and Pisgah in pre-glacial times. But it has already been noted that a stream-cut valley under any such conditions of topography as obtain at present would be an impossibility, since the lake lies directly in the divide between the two drainage basins.

Professor Fairchild has brought out some most interesting facts regarding this general region in his study of the ancient shore lines and sea beaches between the Hudson and the Connecticut Rivey valleys.[1] He shows that in glacial times the New England region stood at a much lesser elevation above tide than at present, owing perhaps to the incalculable weight of the overlying ice cap. As the glacial cold gave way to a more genial climate and the ice cap retreated northward, the marine waters followed the retreating ice cap and, in Vermont, occupied one after another of the drainage basins shown on his map (plate XXXIX). The sea encroached up the Hudson and Lake Champlain valleys, up the Connecticut valley, and up the St. Lawrence valley, till what is now New England was an island. As the ice retreated the land, released from its burden, rose and now stands 400 feet higher, at the southern border of the State, and 800 feet higher, at the northern border, than it did at the time of greatest subsidence. From what is now Lake Memphremagog

[1] *Ibid.*

an arm of the sea reached up the Barton River to Barton, while from the Connecticut valley another arm extended to Lyndonville, leaving the high land between Lyndonville, Sutton and Barton as a narrow isthmus which separated the Connecticut inlet from the St. Lawrence inlet. Now Lyndonville's elevation is 715 feet above sea-level; Sutton, 1,061; Barton's, 950; and Willoughby's, about 1,160. Hence, after the ice retreated up the Willoughby-Burke valley, dropping its débris and forming the lake basin, the lake stood over 400 feet above the glacial seas and did not form a connecting strait. Hence, the post-glacial waters played no part in forming the basin. Professor Fairchild states that the uplift of the marine plain was not uniform but that the grade increased more rapidly towards the north. Now this suggestion of changing elevations and warped surfaces during geologic time leads to the speculation as to whether, under radically different conditions of the topography, the valley between Pisgah and Hor was cut by a stream flowing north or south, with the gorge in the present lake bottom representing a torrential period in the stream's history. This is mere speculation and has nothing tangible to recommend it. We have, therefore, to look for more convincing evidence.

GEOLOGY OF THE REGION.

In working out the geology of the State it is highly important that the different areas mapped should be correlated as far as maybe, in order to prevent the multiplication of names for formations that may be lithologically or structurally identical, as well as to give unity to the work. In the northern part of the State, east of the Cambrian schists and gneisses which form the backbone of the Green Mountain range, Professor C. H. Richardson of Syracuse University, has been at work for many years, mapping the terranes and describing in great detail the formations. The writer takes pleasure in acknowledging his indebtedness to Professor Richardson and he has made an extended reconnaissance, in order to connect the geology of the Lake Willoughby region with that already worked out by his colleague farther to the west.

Richardson has shown[1] that east of the Green Mountain axis, in East Newport, Coventry, West Brownington, Irasburg, Albany, Craftsbury and Greensboro (as well as Calais, East Montpelier, Berlin and Northfield) there lies a great area of magnesian limestone. He has established the name, Waits River Limstone for this formation and on stratigraphic and palaontologic evidence has determined that it is of Ordovician age, as late as Lower Trenton. He has furthermore divided the formation, on mineralogical grounds, into three phases: 1. The Waits River Phase, the type locality of which lies far to the south, along

[1] Reports of the Vermont State Geologist, 1907-08 to 1917-18, inclusive.

the Waits River in Topsham. This is described as "a beautifully banded variety, closely resembling the Columbian marble of Rutland, Vermont." Richardson notes that this phase appears east of Lake Willoughby, in Westmore. It is the most easterly of the three. 2. The dark, steel gray Washington Phase, which he reports in Derby, Brownington, Newport and Coventry. 3. The Coventry Phase, which lies west of the Washington and "is darker than the other two, more carbonaceous, sometimes shaley, and never susceptible of a polish." "It traverses Irasburg, Coventry and Newport, and dips uniformly in a westerly direction." Northeasterly and southwesterly across this formation, Richardson locates three long, narrow, parallel belts of slate, to which he has given the name, Memphremagog Slate. He gives the strike of these belts as north, 30 to 40 degrees east, and the dip as 75 to 80 degrees westerly. The most easterly of the belts is described as "lying west of the Barton River and best seen along the height of land between Barton Landing (now Orleans) and Coventry, where it is black, shaley, occasionally pyritiferous, and unsuitable for roofing." "It is flanked upon both the east and west by the Waits River Limestone. The second, or middle member, Richardson states, is a black clay slate, occasionally pyritiferous, yet with perfect cleavage. Like the first, this belt is flanked on either side by limestone. The third, or most westerly belt, is separated from the second by the Coventry Phase of the limestone and is black, carbonaceous and highly fissile."

In the geology of the Willoughby region we are concerned principally with three lithologic members: a phyllite, a limestone, and the intrusive granite. The phyllite is found most fully exposed in the quarry of the Pike Manufacturing Company in Brownington, a mile north of the foot of Lake Willoughby. Here it is a dark gray, fine-grained, non-fissile rock, with the bedding planes covered with minute scales of black mica (biotite) and considerable pyrite, whose weathering has produced rusty surfaces. The rock is divided into huge masses by jointing planes but no slaty cleavage is visible. In places the phyllite becomes more fissile, while in others, where it is in contact with intruded granite, it becomes practically a hornfels. It is non-fossiliferous. In the north wall of the quarry a sheet of granite, several inches in thickness, has been thrust in between the bedding planes. The coarse crystallization of the intrusive is particularly noticable and has of course been caused by the slow chilling of the magma between the cold walls of the sedimentary rock. . The phyllite has been quarried for some forty years for use as whetstones. The cutting mill is located at Evansville, three miles west of the quarry. This phyllite forms the country rock in the region northwest of the lake traversed by the writer this summer in his reconnaissance. It strikes northeast and southwest and dips from 18 to 47 degrees westerly, forming the ridges and valleys of Westmore (that is, west of the granite range of mountains), Brownington, northern Barton and part of Orleans. The writer has followed it continuously westward to Brownington village and thence southwesterly to Orleans. In Westmore and Brownington, and to a smaller extent in Orleans, the phyllite has been cut and intruded by granite, and it is evident that the tilting of the strata to an invariable northwest dip has been caused by the great batholithic intrusion. In this region the phyllite is interlaminated with one or two strata of limestone. The cross-section (figure 23) shows the relationships.

Now at Orleans, eleven miles west of the lake, the writer has found this phyllite cut by the most easterly member of the Memphremagog slates. The contact may be seen a few rods north of the railroad station, in a ridge west of the track and just beyond the E. E. Chandler Company's factory. Here the slate appears as a black, moderately fissile rock, showing good slaty cleavage and shot through, on the bedding planes, by minute parallel scales of pyrite. It strikes north, seven degrees east, and dips forty degrees westerly. The slate cuts diagonally across the phyllite, which appears as a dark gray, compact, non-fissile rock, showing no slaty cleavage and no pyrite inclusions. It strikes north, twenty degrees east, and dips seventy degrees to the westward. Strikes and dips of both members vary widely in different localities. The presence of the slate and phyllite in contact with each other—the slate away from the heat and compression of

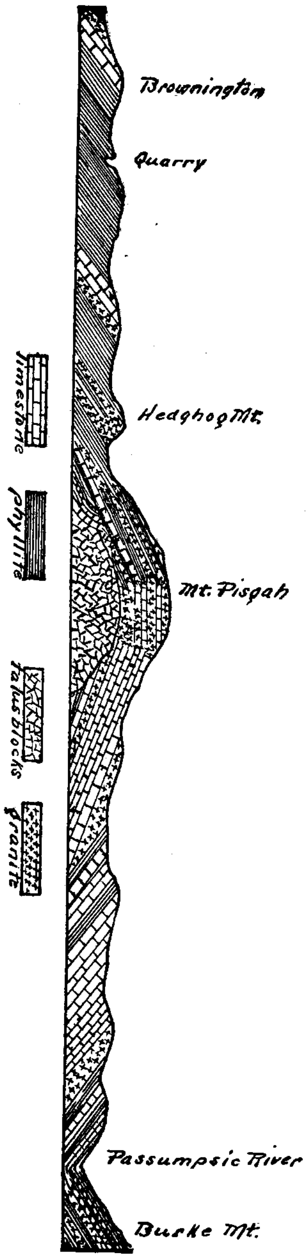


FIGURE 23. Cross-section between Brownington and Burke Mountain.

the strata caused by the granite upthrust, and the phyllite often in contact with the intrusive and often very closely folded—raises an interesting question regarding the reason for the existence of each member: whether the composition of each is practically the same and dynamic action has alone been responsible for the difference in structure; or whether the slate has been formed from more homogeneous clays and the phyllite from less. The problem is reserved for further investigation.

Regarding the age of the phyllite, if the slate is Lower Trenton, it is evident that the phyllite is older and belongs farther down in the Ordovician scale, but no fossils have yet been found to locate the exact place.

It has thus been seen that the region northwest of Lake Willoughby is one predominatingly of phyllite, with a few interbedded strata of limestone, both tilted up, to some extent intruded by, and evidently underlain by, a great granite batholith. West of this phyllite, in Orleans, is slate; in northwestern Brownington, according to Richardson, is limestone. To continue the reconnaissance south and east of the lake, we find here, extending from the granite range to West Burke, a region predominatingly of limestone, interbedded to some extent with phyllite—a condition exactly opposite to that which prevails north of the range. The limestone is the variegated Waits River Phase and, with some interbedded strata of phyllite, or its decomposition product, shale, it makes up the northeast-southwest-trending ridges of the region. But as we examine the country from West Burke through Burke Hollow and across the Passumpsic River to East Burke, we find the limestone partly giving way to ridges of sericite, amphibolite and phyllite, with the phyllite predominating. The dip of these strata varies from thirty-two to forty-five degrees southeasterly. But east of the river the land rises and culminates in Burke, Kirby and Umpire mountains, which lie about twelve miles southeast of Pisgah and Hor. The strata in this region are made up of phyllite and limestone and dip northwesterly, thus forming with the other strata a synclinal trough, in which the Passumpsic River flows. Burke Mountain (3,500 feet above sea-level) is made up of phyllite, uplifted and injected by granite. On the slopes of the mountain, as well as on the crest, are to be noted many small "horses" of phyllite included in the granite mass. There has been much assimilation of the phyllite by the granite, which has resulted in mongrel-looking rock. This remains to be studied.

The cross-section of the whole region (figure 23) from Brownington to Burke Mountain (northwest to southeast), at right angles to the trend of the ridges, indicates how the strata have been tilted up and intruded by a rising granitic magma, forming, west of the Passumpsic, the anticline of the so-called "granite range" and creating east of the river, Burke Mountain.

With these facts in mind, we may now proceed to study the structure of Pisgah and Hor with greater understanding.

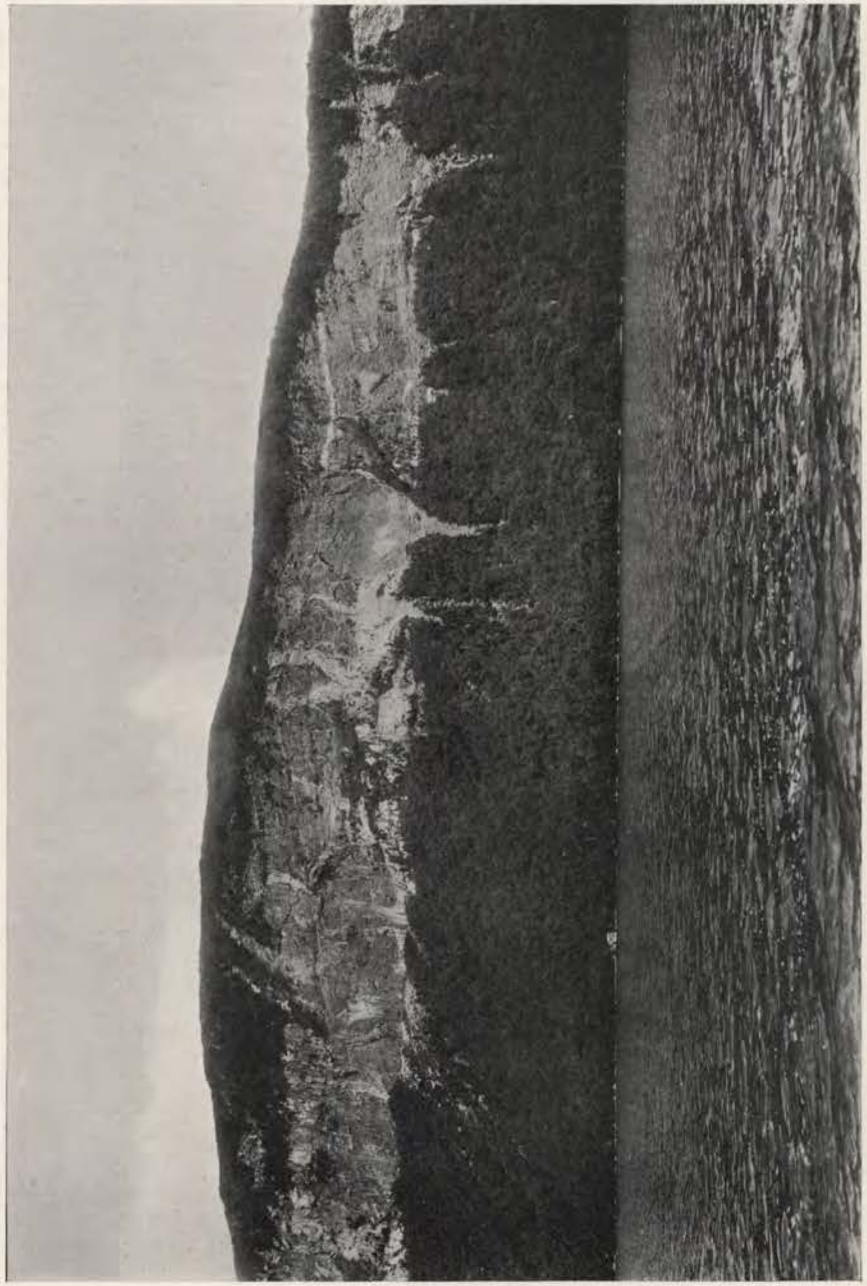
It is noted at once that these are not mountains of pure granite but are made up of strata of limestone and phyllite, uplifted and intruded along their bedding and joint planes by the igneous member. The rocks can be studied at close range only along the lakeshore road under Mount Pisgah and from the tops of the talus piles, since the dense vegetation and glacial mantle are the despair of him who attempts to geologize in the woods. But from the precarious vantage point of the talus tops much of interest is to be seen. The greater part of the bare Pisgah cliffs (plate XLII) is made up of limestone, weathered to a dark bronze color on the surface, but showing steel blue on the fresh fracture. It is compact and answers the description of the Washington Phase of the Waits River Limestone, already described. Along its bedding and jointing planes the limestone has been intruded by the granitic magma. Seen from the lake this granite appears in some places as great splashes of white rock; in others, as narrow strata outlining the limestone bedding planes and furnishing a means of measuring the dip of the strata. Sighted from the lake-level, the strata at the northern end of the exposure dip northerly 26 to 29 degrees, while at the southern end they are more nearly horizontal. But using the clinometer on the bedding planes themselves, at the top of the talus piles, one finds that the strata also dip quite uniformly six or seven degrees to the eastward, thus forming warped surfaces. Measurements were made on as many strata as could be reached on the cliff face and also on the top of the cliffs, at the summit of the mountain, and the readings obtained were quite consistent.

Some interesting contact phenomena were observed. Where the granite and limestone are in contact the blue rock has been whitened and rendered crystalline by the metamorphic action. There is also some interbedded phyllite, as one would expect, and this has been changed by the heat of the intrusive to a flint-like rock, called hornfels.

Just above the talus pile the photograph shows a great arched mass of granite which is possibly the great core of the mountain. In places great slabs of granite lie against the mountain, like a huge shell, and are in the process of peeling off and dropping. Great blocks of this material, nicely poised far above the head of the observer, force extra-geologic considerations upon his meditations.

Walking along the road from the "Boulders" northward, we find the blue limestone in place by the roadside but tipped up here and there to a high angle and intruded by the granite. Of course great fallen masses of granite and limestone and glacial material are everywhere in evidence. As we proceed northward,

PLATE XLII.



Mount Pisgah from the south.

phyllite gradually replaces the limestone in the outcrops till, just beyond the watering trough, where a fine mountain torrent gushes forth (one and seven-tenths miles from the head of the lake), we come to a great vertical face of rock, thirty feet high and seventy-five feet long, which has been cut by the road builders and which affords an excellent opportunity for rock study. This rock-face is made up of nearly vertical strata of phyllite, interbedded with one or two strata of limestone and intruded along the bedding planes by the granite. The phyllite here has been changed by the heat of the intrusive and the enormous pressure to hornfels. The granite is very fine grained.

The next interesting rock exposure is found in the bed of a brook, at the foot of a hill, fourth-tenths of a mile north of the Westmore Hotel. This is at the north base of Mount Pisgah. Here there is a large outcrop of phyllite, dipping twenty-seven degrees northwesterly, interbedded with a single stratum of limestone and intruded by granite. The flow structure in the limestone bears evidence to the enormous pressure to which it has been subjected. The strike of the strata is north, 75 degrees east.

Taking the road leading northeastward to Charleston, the next town to Westmore, we find phyllite outcrops on the ridges on either side, with granite outcrops here and there. A short walk across the fields southeasterly, on the land of John Hinton, brings us to a commanding position on a high ridge, which offers a superb view of the surrounding country. Island Pond lies in a hollow due east, while Charleston village lies north, with Seymour Lake in the town of Morgan, beyond. Bald Mountain, the most northerly peak of the granite range, bears southeast and slopes sharply down and merges into the valley floor. The granite here on the ridge contains small inclusions of phyllite. It is seen clearly that the granite range, trending nearly east and west, cuts the phyllite ridges at a sharp angle.

Returning to the main road, along the lake shore, we find by the yellow boat-house, six-tenths of a mile from Westmore Hotel, an interesting outcrop of limestone and phyllite strata, cut and intruded by granite. There are two strata of blue limestone and several of phyllite. The outcrop presents a warped surface, dipping fifteen degrees northerly and thirty-five degrees westerly, thus dipping under the lake. The granite has been forced up along the bedding planes and has also cut across the strata. In structure the outcrop is an epitome of Mount Pisgah. Mention has already been made of the fact that granite is found in smoothed and rounded masses on the west shore of the lake, in front of Camp Westmore; hence there can be no doubt that the lake bed would show all three of the rock members present.

The north slopes of Mount Hor and the Fin are heavily wooded and show no outcrops; but beyond them, as already stated, Mount Wheeler presents a steep cliff face to the east. Judged by this face, the mountain is pure granite, the talus piles being made up of huge blocks and the cliff above these piles showing no limestone or phyllite. The granite is very fine grained, with dikes of coarser granite cutting across and showing where rifts in the first mass have been healed by later injections. Near the top of the cliffs the granite becomes very coarse and feldspar crystals three or four inches in width are noted.

The road around Barton Mountain to Barton village reveals granite on every hand, with no phyllite or limestone visible to the casual glance.

South of the lake, down the valley towards West Burke, the country is predominatingly limestone, overlain of course by the mantle of glacial drift. The valley is a true syncline, the limestone dipping westerly on the east slope and easterly on the west. The west ridges are cut by the granite range and die out at the foot of Mount Hor.

Near the south end of the bare face of Mount Pisgah, as has already been stated, the limestone strata become nearly horizontal and then dip to the south, where the mountain cuts the east wall of the Willoughby-Burke valley. In the fields immediately south of Pisgah small limestone hills are seen, with the strata dipping about twenty degrees southerly. As already noted, the blue limestone of the mountain mass here gives way to the light, variegated phase.

On the valley road, eight-tenths of a mile from the head of the lake, limestone is found in place lying in the phyllite member, which is here a shale. The limestone is warped, dipping four degrees southerly and ten degrees easterly, and evidently belongs to the Mount Pisgah side of the valley. As before noted, this outcrop marks the true bedrock divide in the valley and is ninety-five feet above the lake-level, thus showing that in preglacial times the gorge in the lake bottom could not have been the bed of a northward-flowing stream. A few rods farther on, a wood road branches off to the eastward and here granite and a stratum of phyllite are found in place. In the brook bed near at hand the variegated limestone is exposed by a small cascade and is seen to dip twenty degrees southeasterly.

The limestone in this region south of Pisgah is underlain and cut by granite, which appears in outcrops here and there among the limestone exposures. A few yards of trenching, at one place, exposed a fine contact of the two rocks and very interesting contact phenomena were observed. This will be referred to later under the caption of Petrography and Mineralogy.

To return to the lake, the northwest shore has been discussed. At the south end, Mount Hor (plate XLIII) rises abruptly from the water, with great talus piles lying against its face. Since the mountain is practically inaccessible for geological

PLATE XLIII.

Mount Hor from the south.

work, one must depend on the bare cliffs for evidence. The northern exposures of the cliffs (at the right of the photograph) are made up of smoothed surfaces of fine grained granite and show no limestone. But from the top of the talus piles, at the southern exposure, we find conditions similar to those on the cliffs of Pisgah. Broad strata of blue limestone are injected and cut by granite and whitened in places by the heat of the intrusive. The strata form a great arch, dipping north and south and we get a suggestion of a great granite core under this arch. They also dip from seven to twelve degrees to the westward, thus forming warped surfaces, as on Pisgah, except that on the latter mountain the dip was easterly. Figure 24 shows the relationships. Several phyllite strata are met with, as on Pisgah—in fact conditions on both mountains are practically identical and the conclusion is inevitable that at some time the strata were continuous and the two mountains one.

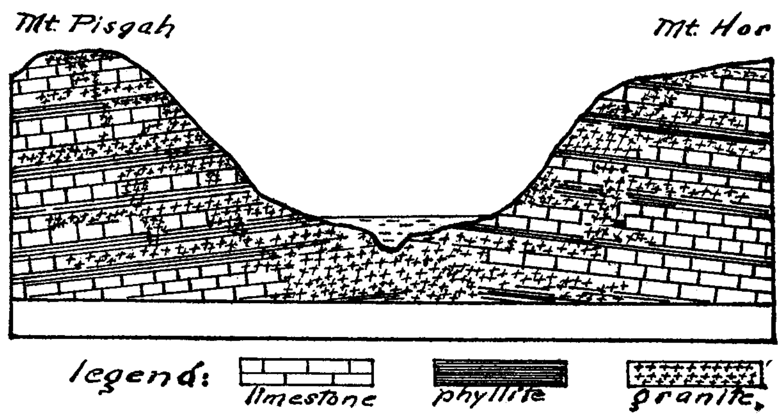


FIGURE 24. Section across Mount Pisgah, the lake and Mount Hor.

PETROGRAPHY AND MINERALOGY.

The granites of Pisgah, Hor and Wheeler mountains are practically identical and are to be classified as quartz monzonites. They are light gray in color and vary in texture from very fine to very coarse. The essential constituents, in descending order of abundance are: milk-white feldspar, mostly oligoclase, which is somewhat kaolinized and saussuritized, quartz, with fluidal cavities, microcline, microperthite, muscovite and biotite. There are also some introduced carbonate, apatite needles, and more or less pyrite. There is nothing in the study of these granites to show that they were not formed from the same magma.

The phyllite is a dark gray, non-fissile rock. Its bedding planes are studded with coarse mica grains, which give it a brilliant appearance. These bedding planes also include pyrite and its oxidation often produces a rusty appearance. A study of the thin sections reveals fine interlaced laths of muscovite and biotite, with here and there fine veins of quartz and feldspar. The sections are strewn with very fine mineral dust.

On page 294 it was noted that, in the fields south of Mount Pisgah, trenching exposed the contact between the granite and the limestone members. At this contact there was found a light gray, compact mineral substance, of undetermined extent. A thin section of this substance showed, in descending order of abundance: tremolite, vesuvianite, quartz (with many inclusions), orthoclase, titanite (which occurred in groups of typically wedge-shaped crystals), and possibly grossularite. No carbonate was seen. It is evident that the contact minerals, tremolite and vesuvianite, have been formed by the action of the acid granite magma on the basic magnesian limestone, which it intruded. Naturally, the granite predominated, thus giving an excess of quartz and feldspar and a lack of unaltered carbonate.

Such developments of contact minerals are common where acid magmas invade basic rocks but, as far as the writer is aware, this is the first instance in Vermont to be recorded.

CONCLUSIONS.

We have had indisputable proof that at one time the granite mountain range was continuous across the Willoughby trough. The study of the strata, as mapped on figure 23 shows that, before the granite intrusion, the country was made up of horizontal strata of phyllite and limestone, the phyllite predominating on the north, the limestone on the south, and the two members interfingering to some extent. The strata are Ordovician in age, as shown by Richardson's work.

At a later date, probably in the Devonian (since most of the granite of Vermont was intruded then) a rising granitic magma appears to have tilted up these strata and to have intruded and broken through them at or near the juncture of the phyllite and limestone, producing the range of mountains which now forms the divide between the Memphremagog and Connecticut drainage basins. There was no trough, or even valley, at this time and Pisgah and Hor were parts of the same mountain ridge. It has already been noted that the symmetry of the peaks and valleys of this so-called granite range suggests that the trough was a later development. The range was formerly much higher than now, for of course the granitic magma did not reach the surface and flow out, but remained a great batholith, parts of which have been revealed by the long period of erosion that has since elapsed.

There is absolutely no evidence to support Hitchcock's view that Pisgah and Hor were two separate outcrops of granite uplifted through the limestone and leaving a valley between[1]—quite the contrary!

How then can we account for the valley which glacial gouging has fashioned into the great trough, and which glacial damming has provided with the lake? It has been shown from relative elevations that no stream could have cut down the valley, and that the advancing ice sheet would not have been competent to do the work unaided. The popular idea that the mountain range has been split apart by some "convulsion of nature" will hardly do; for in that case we should expect to find Hor and Pisgah mirror-images of each other—like the halves of a divided apple—while as a matter of fact, they are quite different.

The only remaining hypothesis that will fit the facts is that of trough-faulting. By this we mean that, after the Pisgah-Hor range was uplifted, two parellel sets of faults developed and the section of the ridge between them sank, thus forming a trough-fault or "Graben." This was later glaciated and fashioned into the great trough in which Lake Willoughby partly lies. The classic example of this type of faulting is, of course, the upper Rhine valley, but many such faults exist, even in Vermont, where the writer has found them in the Roxbury valley.

Unfortunately, this fault theory cannot be supported by the finding of fault-scarps or fault-planes, which would give us the location and extent of the displacement, but this does not invalidate the theory, since the extensive erosion, talus piles and glacial filling might easily have obliterated all traces of them.

It has been shown that the Pisgah-Hor range cuts across the structural ridges at an acute angle and that the ridge forming the west wall of the Willoughby-Burke valley dies out under Mount Hor; while the ridge next north of Pisgah dies out just north of that mountain. These two ridges are about in line and were probably at one time continuous. If the fault theory be true, the missing part of this ridge must have been intruded by the granitic magma and must have sunk when the magma receded. Here again evidences of faulting should be found in these ridges but, on account of the glacial till and the deep vegetable mould, geological investigations are practically out of the question in the woods covering this region.

The theory of trough-faulting is therefore advanced to account for the presence of the valley which, the writer believes, existed between Pisgah and Hor before the coming of the ice sheet. The extent of the faulting and the size of the pre-glacial valley are matters of small importance, since all that was needed in the mountain barrier was a point of attack for the advancing ice sheet. The "plucking-action" of the ice, once begun, must have been favored by the jointed character and softness of the limestone and phyllite.

[1] Geology of Vermont, Volume II, p. 905.

The gorge in the bottom of the lake, referred to on page 282, is undoubtedly due to glacial gouging. As a tongue of the ice sheet was forced down the valley, between Pisgah and Hor, its velocity must have increased and therefore its cutting power. This cutting force would have been exerted principally in a downward direction. It is to be remembered that we are postulating an ice sheet thousands of feet thick, whose downward pressure must have been tremendous; so that the cutting of such a gorge is quite conceivable. Of course we have no means of knowing how far south the gorge originally extended, but it is to be presumed that it gradually died out south of the trough, since here the ice tongue debouched into the open valley and its velocity (and hence its cutting power) diminished.

SUMMARY.

The present study has shown (1) that Willoughby is a glacial lake, 1,164 feet above mean sea-level, by barometric measurment; (2) that it lies partly in a glacially-fashioned trough between Mount Pisgah and Mount Hor; (3) that these mountains are composed of phyllite and limestone strata, of Ordovician age, uplifted and injected by granite; (4) that this granite is a quartz-monzonite; (5) that the pre-glacial stage of the glacial trough could not have been a stream-cut valley but was probably a trough-fault, or "Graben"; and (6) that the gorge in the bottom of the lake was caused by glacial cutting. Reconnaissance work has connected the established geology of the region to the westward with that of the Willoughby vicinage and has opened up this country for further field work.

MINERAL RESOURCES

G. H. PERKINS.

The value of stone and other materials sold by Vermont companies during the years 1919 and 1920 is probably greater than ever before for the same time. This is in spite of some untoward conditions which existed, especially during 1919, because of the higher prices obtained for all that was sold. In same cases strikes, scarcity of labor and other troubles, hampered all sort of industries and the depression in building all over the country and difficulty in obtaining structural steel added to the perplexities of those having rock products to sell. Of late, however, all companies have reported increasing and very satisfactory business conditions and in many cases the year 1920 is reported as "the best ever."

Before the close of 1920 all the above obstacles to successful business operations in the quarries and mines had largely been overcome and the promise of the immediate future is very good. In various Reports of this Survey during the past twenty years, more or less has been published concerning the mines of the State and it is needless to repeat much of what has been told, but a brief statement as to this phase of our mineral industries may not be out of place.

METALS.

Mining of metals in Vermont has never been on the whole profitable. It is perhaps unfortunate that there are within the State various beds of iron ore, copper, manganese—which have attracted so much attention that most have at one time or another during the last hundred years been worked and thereby a not inconsiderable amount of good money has been spent to little or no purpose. In years past, some gold mining has also been carried on, notably at Plymouth. So far as I have been able to discover, none of the Vermont mines ever paid for the cost of working, except in the case of a few for a short time.

The final outcome of all has been loss for the very sufficient reason that the material mined has not been sold and could not be sold for what it cost to mine it. For this reason, mining in

Vermont has always in the end proved a losing game and there is no reason to suppose that, so far as metals are concerned, it can by any possibility be anything else.

The history of the Ely mine will perhaps be recalled as an exception to this, but while that mine appears to have paid for a short time, it certainly has on the whole been a losing proposition.

It should be understood that it would be very far from the purpose of the Geologist to discourage mining where there was the least probability of success, but he certainly would fail of his duty did he not utter a very earnest warning to the people of the State that they should be very slow to invest in any proposition to mine iron, copper or gold in Vermont. It may seem to some quite superfluous to make such suggestions, but so long as samples of ore are continually coming to the Geologist for examination and so long as there are those who are ready to put money into schemes for exploiting a suspicious looking ledge which they have discovered on some farm, such warning is not untimely.

During the past hundred years, mines of iron, manganese, copper and gold have been started and some worked to a considerable extent in various towns in the State, and besides these metals, lead and zinc ores occur. The latter have never been found in other than very small masses and I do not think that much money has ever been lost in the attempt to realize on their production. So far as I know, no other metals have been found in Vermont, though indications of several others have been reported, but when followed out it has been found that the supposed mineral did not occur.

IRON has been longer mined in Vermont than any other metal. Just when the first iron mine was started in our State I do not know, as I have not been able to find any record giving the date, but it was surely more than a century ago. The oldest iron mine of which I can find account was at Chittenden, where a furnace was built in 1792. This was operated for many years.

There are in Vermont several ores of iron as *chromite* in Jay, Troy and Westfield; *siderite,* or iron carbonate, in Plymouth; *limonite* and *hematite* in Brandon and a number of other towns; *magnetite* in a few places.

In the *"Annual Report on the Geology of Vermont"* by Professor C. B. Adams, then State Geologist, published in 1845, brief accounts are given of iron mining and furnaces at work in Bennington, Wallingford, Brandon and a number of other towns, and no less than thirty towns are named in which some iron ore had been found, and in his second *"Report on the Geology of Vermont,"* 1846, Professor Adams gives fuller details concerning many of these deposits. That first and last a good deal of money has been thrown away in working some of these deposits is too certainly true, but all have long since been abandoned.

It is interesting, historically, to read some of the records of these old iron mines. Thompson in *"Vermont"* says that "in Bennington the iron works consisted of three large blast furnaces which produced 2,000-3,000 tons of pig iron per annum, giving employment to 150-200 hands and 40-50 teams." Here the ore (which is limonite) was obtained from two beds in the east part of the town. The mine was worked until a shaft seventy feet deep was sunk and several galleries "several hundred yards" long excavated.

Of the mine in Chittenden we find "About 600 tons of ore are raised annually, much of it smelted in the works in Pittsford. In 1839 a forge was built which made about 500 tons of bar iron per day."

So far as I have been able to find, the greatest amount of money invested in any iron producing scheme was spent in Forestdale. Here in 1850 the Brandon Iron and Car Wheel Company carried on work for several years. An old Report states that "The amount of capital paid in is one hundred and seventy-five thousand dollars." How much of this was ever realized I suppose it would be impossible to find out, but some iron was sold. Iron was mined in Brandon in 1810 and there were iron furnaces there in 1820.

Besides the far more common ores of iron, *hematite, magnetite, limonite,* etc., there are deposits of more unusual ores as *chromite* or *chromic iron* in Jay, Troy and Westfield, which have been worked to some extent, but by no means as much as the ores mentioned above.

SIDERITE or iron carbonate has been found only in Plymouth, where a deposit has been worked to a considerable extent. Other ores of iron have also been very sparingly found, but these are of interest only to the mineralogist.

MANGANESE. Associated with hematite in Forestdale and elsewhere, two of the common ores of manganese are found and there are other places where, as in Wallingford, manganese ores, *psilomelane* and *pyrolusite,* occur. Some of these have been worked more recently than any of the iron ores. At one time, several hundred tons of manganese were annually produced and sold.

COPPER. In Professor Adams' First Report we find the statement, page 30, "Mr. Reynolds, agent of the copperas works, has discovered native copper in small quantity on Copperas Hill," but a footnote discredits the statement. I have quoted this here because even now there are those who search for native or pure copper and, of course, search in vain.

Native copper has never been found anywhere in this country in other than very small quantities except in the Lake Superior region, Arizona and Oklahoma. Hence it is useless to try to find it in Vermont. It is indeed possible that very small bits may be found in any locality where an ore of copper is found, but in commercially valuable quantity it has been, and in all probability will be, found only in the localities named. The copper Indian spear heads, celts, etc., now and then found in the State are all from Lake Superior region.

Our copper ores are mostly chalcopyrite, or copper sulphide, though a small bed of *bornite,* purple copper, was worked in Berkshire several years ago for a short time. The great deposits in Strafford, Vershire and Corinth, are chalcopyrite mixed with a much greater quantity of pyrite and pyrrhotite. No mines in the State have been so long or so recently worked as these, but as Professor Jacobs has given an account of them in Tenth Report, pages 192-199, and Eleventh Report, pages 141-147, it is unnecessary to add to the above.

LEAD in the form of *galenite,* which is the most common ore, is found in Brandon, Thetford and several other towns, but nowhere in other than very small veins. Usually, *galenite* carries a small percentage of silver and some of that found in Vermont does so, but other specimens give not a trace. Where it does occur in *galenite,* it affords the only examples of silver ever found in Vermont.

SILVER has been reported many times for many years in one locality or another in Vermont, but in none of these has the ore been found to exist. Many a fairy tale is related according to which some Indian or more commonly, Spaniard, told of finds of rich silver ore, but any such story may be at once dismissed as impossible. No real silver ore has ever been found in Vermont or anywhere near the State and after a century or more of investigation it is perfectly safe to say that none will be.

Rather less extravagant, but similar, stories are told and by intelligent people, in which lead is the mineral. These are of course not of hidden treasure from silver mined on the spot, but of Indians who were accustomed to go to some secret locality and come back with a lot of new lead bullets. I speak of these fabulous stories because, strange as some may think it, they have come to my attention and were apparently more or less accepted by those who told them, within the present year. I have in previous Reports spoken of gold in Vermont, but it seems necessary to refer to this metal again.

GOLD is found in Vermont in many localities, but like the metals mentioned, it has always cost much more to mine or collect it than the resulting gold has been worth. There is not the least probability that gold mining can ever be worth while here or that money invested in it will ever bring satisfactory returns. Not as long as iron, but for many years, gold has been sought in Vermont and found too, but, as I have said, it has cost far more to find it than it was worth when found.

I suppose more mining of this sort has been done in Plymouth and Bridgewater than anywhere else, though a considerable amount of money and labor has been wasted in numerous other towns. Gold mining in Bridgewater was begun in 1851 and continued there and in Plymouth for many years until finally, the work was abandoned and the mines closed.

In the most prosperous times of these works it is doubtful if they paid more than expenses. Probably the statement in the "Geology of Vermont," published in 1861, is quite fair. "To attempt to arrive at accuracy in the amount obtained in all the 'diggings' in town (Plymouth) were a difficult task; but from reliable sources through which information could be obtained, it is probable that between seven and eight thousand dollars were obtained during the season of 1859. As to the question whether it was profitable to a majority of those who worked we give it as our opinion that not one in ten who have engaged in gold washing in that town has realized as much from it as he would have done by working on a farm at ordinary wages * * * * * * and from the best estimates that we are able to make from the data in our possession, we are of the opinion that if the whole amount of gold washed in Plymouth during the year 1859 were put together and from it deducted the expense of erecting dams, sluices, water wheels, pumps and other incidental expenses connected with the work, the remainder, if divided would not amount to fifty cents a day to the hand," page 847.

For most of those who read this Report, much that has been written above is, I am fully aware, wholly unnecessary, but almost daily experience has proved that there are many others who may well think of the statements here made. There seems to be something about mining that fascinates many sensible persons as well as many who are not and, apparently, it will be a long time before unwise investment of money in some sort of mine has ceased.

It should be known and remembered that, while in many cases large sums have been realized from mines, it is nevertheless true that a very large majority of mines in all parts of the United States have failed to return anything, or at most have returned little, for the outlay which has been made upon them. This is especially true of mines of the metals, but it is to a great extent also true of all mines. Everywhere, only one mine out of a great number has ever paid. Anyone who doubts this can look up the mining statistics for himself.

GRAPHITE, or as commonly called, black lead, though not in any sense lead nor is it metallic, occurs in mica schist throughout the Green Mountain area. Sometimes it is not very abundant in the schist and scarcely noticeable, but many times it is sufficiently abundant to give a distinctly greasy feel to the rock and often raises the question whether a graphite mine cannot be started on some farm.

The State has been pretty thoroughly prospected for a long time by many expert investigators and nowhere has any *bed* of graphite been found. The small amount necessary to give a graphitic appearance to schist is far from being sufficient to make the rock commercially valuable.

A little graphite scattered through another rocks is of no value for any purpose. It is only when it occurs in masses of pretty pure quality that it is commercially important. Hundreds of specimens of graphitic schist of not the least value have been sent to the office of the Geologist during the past few years, hence the above.

COAL. The idea of coal in Vermont is absurd to one who knows anything of the geological history of the State, but there are a great many very intelligent people who do not know this history nor its necessary bearing upon the question. There never has been and there never can be coal found in Vermont, unless it was brought into the State from outside. The geologist must constantly be on his guard that he be not deceived by bits of this, that and other mineral that someone has dropped or thrown away to be found perhaps years afterwards. As it is very unscientific to declare that something cannot be unless some very satisfactory reason can be given, I will proceed to give such a reason for the positive statement given above.

All known coal is made from ancient vegetation in peat swamps. The evidences of a most luxuriant vegetation which continued to flourish generation after generation for thousands, perhaps millions of years, are wholly convincing. No geologist doubts them nor that coal was made from such vegetable growth. Obviously this is not the place for any but the briefest statement as to the formation of coal and only this will be made. The oldest coal of any value was made during what is called the Carboniferous Age. Before this there was no vegetation in the world capable of forming a bed of coal. After this, coal of some sort was formed in every age, though nearly all the coal mines east of the Rocky Mountains are in the Carboniferous and found in the last part of that age, the Pennsylvania Period.

Vermont is one of the oldest portions of the country and its land was all formed and transformed ages before the beginning of the Carboniferous. When Vermont was formed during Cambrian and Ordovician Ages and before, there were no plants except sea weeds, none from which any coal could have been formed. And after this, during the immeasurable interval of which I have written in former Reports, Vermont lay, apparently, open to all the disintegrating, decomposing and eroding agencies that were constantly in action, but no beds of coal or any sort of rock were laid down within its borders until ages and ages

after the great Pennsylvania coal beds were formed Not until the great Ice Age, which surely was not a coal making time, were other beds of rock formed here. For this reason we must say not only that no coal ever has been found in Vermont, but that no coal can by any possibility ever be found here.

Lest someone may wonder as to the Brandon lignite, which may seem something of an exception to what has been written, I may add that the lignite of Brandon, while it is an immature coal, is found in so very small an area and is so insignificant commercially that it is only an apparent exception. It was formed in Tertiary times, that is just before the Ice Age, but there never could have been more than a very small quantity and none has been found for some years.

I give thus fully the reasons why coal cannot be found in Vermont because within a few months several notices of the finding of coal in some Vermont locality have been sent to this office and several samples of coal which it was declared were found in Vermont have also been sent and they continue to come.

More promising than any of the mines of copper, iron or other metal are those which have been opened within a few years from which talc and asbestos are taken. As Professor Jacobs has for years been investigating the talc deposits of Vermont and has published in each of the last three Reports of this series accounts of these deposits and continues his study in the present volume, the reader is referred to his paper on Progress in Talc Production, in this volume.

ASBESTOS.

Recent operations which will be more fully described later, having been undertaken on the southern side of Belvidere Mountain in Eden, perhaps some account of this industry in past years may not be without interest. In the Report published in 1861, brief notice of asbestos may be found and a number of localities in the State in which this mineral has been found are given, but there does not appear to have been any effort to mine any of it until in 1899, Judge M. E. Tucker became interested in the frequently occurring veins of asbestos in the rock of the north, or Lowell side of Belvidere Mountain. A year or two later Mr. B. B. Blake of Eden found asbestos veins on the opposite or Eden side of the mountain.

In the Report of the Geologist for 1903-1904 there is a discussion of this region by Professor V. F. Marsters and in the U. S. Mineral Resources for 1900, pages 862-866. Professor J. F. Kemp has a notice of the same area, in which will be found much of interest to those seeking information as to the occurrence of the mineral in Vermont.

As a result of various investigations in the early nineties, five companies were formed and each accomplished some work, but only two did much more than prospecting. By far the largest amount of work that was carried on during the following few years was that of the New England Asbestos Mining and Milling Company. The map figure drawn by Professor Marsters, gives the general position of the asbestos localities.

Plate XLIIIa shows Belvidere Mountain, on the slopes of which most of the work has been done. It is to be noted that the upper part of this mountain is amphibolite, while the lower half in which all the asbestos openings are located is serpentine, from which it is believed the asbestos is formed. A discussion of this subject will be found in Professor Marsters' article in the Fourth Report, pages 86-102, and a still further study of asbestos in the Fifth Report, pages 35-61.

In the Seventh Report, pages 316-330, is a report by Professor C. H. Richardson which refers especially to the Tucker property on the Lowell side of the mountain. Without intending to indicate dissent from the opinions expressed in any of the articles cited above, the Geologist would ask the reader to hold each author responsible for his own views and not consider that they are necessarily endorsed by him because published in these volumes.

After working his property for several years, Mr. Tucker sold out to Mr. W. G. Gallagher, who worked the mine vigorously for several years and built a well equipped mill using the short cross fiber found in that part of the mountain. Through financial difficulties, Mr. Gallagher ceased to carry on the mine and it has been idle for some time.

On the other, or Eden side of the mountain, the New England Company, which was largely a Massachusetts corporation, erected several buildings, including a large and well-equipped mill, and produced a considerable amount of material, but after a time this was also abandoned and has been idle for some years. During the past year, 1920, a new chapter in the history of asbestos in this State has been commenced and it is hoped that it may come to a very satisfactory conclusion.

An entirely new company with abundant capital, and after careful examination of the locality, has bought all the property of the New England Company and considerably more adjacent. They have this season begun the work of preparation for mining and milling next season with an enterprise and enthusiasm which promises well for success. This company is the "The Asbestos Corporation of America," capitalized at $1,500,000. The following notice of this company is largely taken from an account published in the *Free Press* of October 26, 1920, which I am told by the officers of the company, is a correct statement of its activities. Up to date of this article the company had invested some

PLATE XLIIIa.

Belvidere Mountain.

$600,000 in the enterprise, that is in acquiring the property and making necessary improvements. The Geologist has visited the property twice and can testify to the fact that all work that could be carried on this season has been most energetically done.

The former buildings of the New England Company have been put into good condition and, as they are over 2,000 feet above sea-level on the side of the mountain, they are conspicuous for a long distance. The mill and other buildings are located very near the sources of the mineral to be mined and treated for market. From the mill a strip a hundred feet wide to the base of the mountain has been graded for a tramway nearly six thousand feet long, by which the prepared asbestos can be readily sent down. At the lower end of this is to be a large storehouse.

"The capacity of the mill, when in full operation, will be a hundred tons of finished asbestos a day. This will be graded and bagged in the mill, taken down the mountain by the inclined railroad and thence by truck to Hyde Park." According to Dr. Chester Gilbert, Mining Engineer, who has repeatedly examined the property, there is a practically unlimited quantity of asbestos in the rock. Aside from slip fiber, which is evident in many parts of the rock, there is a great deal of disseminated fiber, so that in many cases "all of the rock goes to the mill." Formerly the slip fiber, which is by far most common in this locality, was of little or no value, but conditions have greatly changed so that it is said that this is in good demand. "Recent inventions have enabled manufacturers to spin the slip fiber and this has entirely changed the aspect of the asbestos trade. This change in the commercial use has made possible the development of the Vermont property." "Every portion of the product is now commercially valuable, from the sand and tailings, which are used in paving blocks, and which is sold for $20 to $25 per ton, to the finer spinning grades which bring from $2,500 to $5,000 per ton." So far as the disposal of the asbestos goes there is no worry * * * for the entire output for the next ten years is disposed of.

The large mill is to be electrically operated and to this end the corporation have bought control of the Vermont and Quebec Power Corporation. This is now operating the electric plant at Stevens Mills, additions to which have been made. A pole line twenty-one miles long brings wires to the mill. From the above statements it appears that very important development in the mining industry of Vermont is assured.

All the asbestos in the Belvidere and Lowell area is what is known mineralogically as chrysotile, which is by far the most valuable kind. This is mined in the United States only in Arizona, Wyoming and California. The larger part of that produced has of late come from two mines in Arizona, but if the prospects above indicated are carried out, and there appears to be great reason to believe that they will be, Vermont may soon become the largest producer of chrysotile this side of Canada.

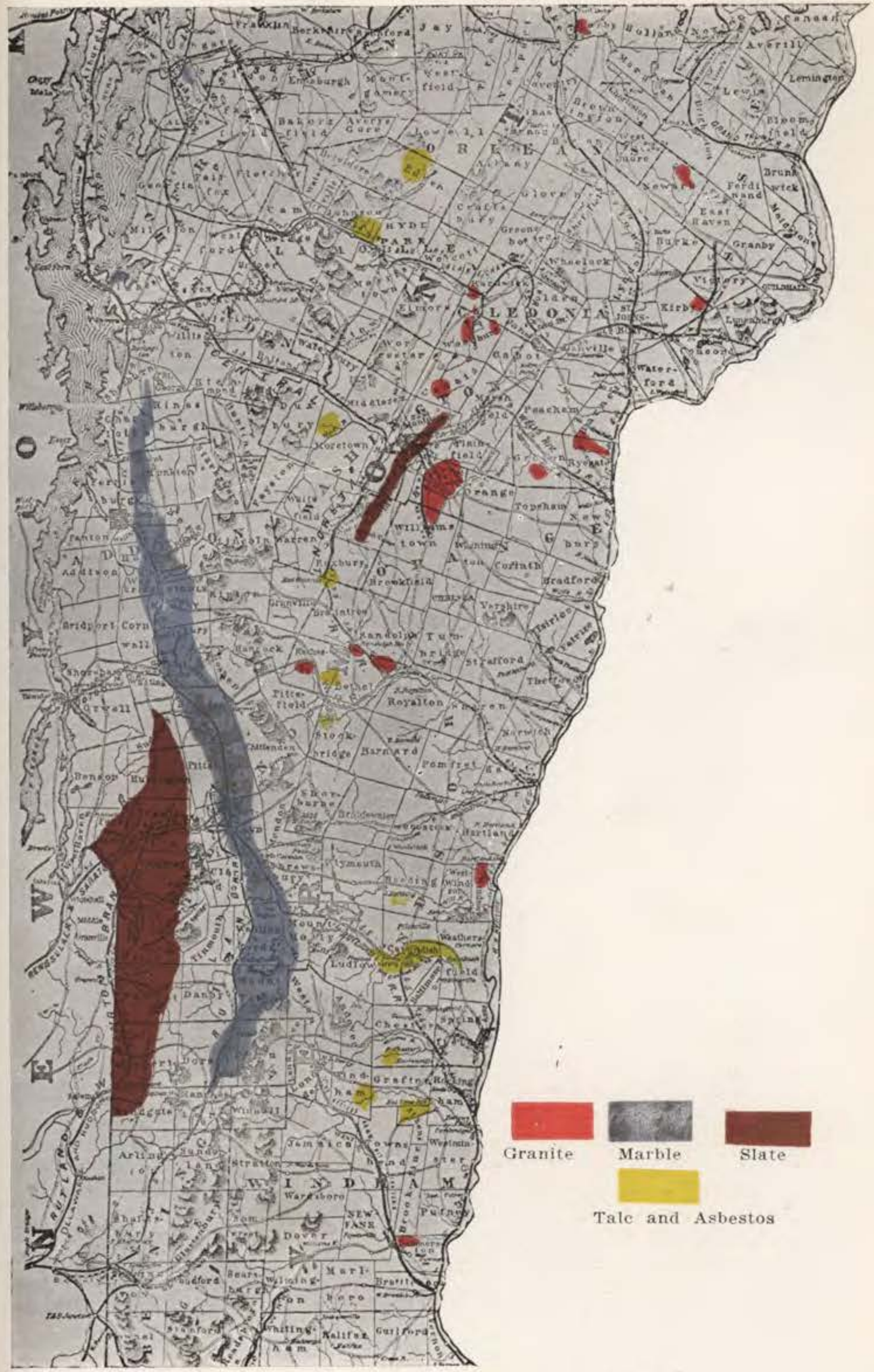
As has been stated in previous Reports, the wealth of Vermont so far as it is found in the ground is not in her metals, but in her quarries. The annual output from the granite, marble and slate quarries amounts to a very considerable sum. For more than twenty years the writer has used every method he could employ to ascertain the real value of these products, but while it has not been difficult to get what may be considered an approximate estimate and one that is probably not far from the truth, yet I am very certain that Vermont has never received full credit for what was actually sold in the markets of the world. There are several reasons for this difficulty. Some companies are very ready to give the amount of their business, but there are a number that will not report their sales for reasons that seem to them sufficient and of course this alone is enough to vitiate any total that may be obtained.

BUILDING STONE.

As is well known, Vermont sells from its quarries more granite and more marble by far than any other like area in the world, and it is second in the production of slate. In this stone, Pennsylvania leads by a long distance. The total value of the stone sold in the rough and finished is not less than $17,000,000 and probably more. It is gratifying to find that in all three of the stone industries, business is reported good and increasing. The prevailing scarcity of labor has affected them all more or less and all are employing fewer men than before the war, but there has been large demand for these materials and higher prices than heretofore are readily obtained, so that it is probable that the net income to most companies has never been larger, though there are naturally some exceptions.

It is noticeable that although Vermont is so large a producer of granite, marble and slate, yet the area occupied by these materials is not a large one. The marble and slate are found mostly in the western part of the State and, as may be seen on the accompanying map, Plate XLIV, cover only a small part of that; while the granite quarries found only east of the Green Mountains, and are much more scattered than are the quarries of the other two, yet if all the areas in which granite quarries are located were grouped in one they would not cover a large territory.

It does not follow, however, from this that the supply is likely to run out soon. The supply of granite is probably the most inexhaustible, but of the marble and slate there is enough to supply all demands for many years. The location of certain quarries may be changed somewhat now and then for one reason or another, but this does not necessarily indicate that on the whole the stone is giving out.



Map showing (in colors) distribution of granite, marble and slate.

SLATE.

The slate quarries which are at present worked are all in the extreme western part of the State near the New York line and some of the largest companies, as is seen in the accompanying list have offices in New York, though most of the material they use is quarried in Vermont.

A few companies have quarries in both states and all the red slate sold comes from the New York quarries, as there is very little in Vermont and none is quarried. There are, as most are aware, slate quarries which produce a very good black slate and several quarries have been worked, some to a considerable extent. A number have been opened in Montpelier and more in Northfield, but for several years none of these has been active. Longer ago, slate was quarried in Thetford, Waterford, Fairlee and other towns along the Connecticut River and sixty or seventy years ago several companies spent considerable money in developing slate quarries in the eastern part of the State, but all have been long abandoned. All the slate found east of the Green Mountains is black or nearly black in color and some of it appears to be of very good quality.

The Vermont Slate Belt, which for years has produced nearly all the slate sold from the State, begins in Sudbury and, with somewhat variable width, extends south to Rupert, a distance of thirty miles. In addition to the above, there is a small slate area in Benson, but this has never been worked to any extent. There are, therefore, three considerable slate belts in the State—one along the Connecticut River, of which the Thetford beds may be taken as an example, another nearer the Green Mountains, in which are old quarries in Montpelier and Northfield, and a third and by far most important, near the New York border. It is solely of this last that what follows is written.

Through Fairhaven, Poultney and Pawlet into Wells, slate quarries are very numerous and in some places, literally, small forests of poles rising about the great heaps of waste, impress one with the activity of the work carried on. Plate XLV[1] shows one of the largest of these quarries and Plate XLVI shows one of the sheds in which the slate is split and trimmed and outside is seen a dump heap, though many are far larger.

As to the character of this slate belt the following from Bulletin 586, U. S. Geological Survey, by T. N. Dale, pages 133-135, will be interesting. "The quarry maps show that the slate quarries situated within the Cambrian areas are generally very near to or not far from the edge of the Ordovician belts. In some places, as in Pawlet, Wells and West Castleton, the Cambrian slates occur within one or two hundred feet of the Ordovician grits. This proximity of the two formations occurs

[1] For the use of these plates I am indebted to the Auld and Conger Company.

in such variety that it can hardly be explained by faulting. The Cambrian roofing slates are therefore regarded as occurring not far from the top of the Lower Cambrian series as exposed in this region and very near the overlying Ordovician. * * * * * * Where the red slate occurs in close proximity to and on the west side of the Cambrian green and purple slates and the dip is easterly, as it usually is, the red slate may be found underlying the sea green, unfading green, or purple slates, and on the east side of the Cambrian areas the green and purple slates of the Cambrian may be found underlying the red of the Ordovician when both dip easterly.

"At several points (Blissville, Eureka, etc.) away from the Ordovician boundary the rock which appears to underlie immediately the Cambrian slates is the olive colored grit. * * * It is uncertain whether there may not be one or more beds of slate interbedded with this. The rock which overlies the Cambrian slate is either the black patch grit, or the Cambrian black shale, or the ferruginous quartzite and sandstone. Perhaps there is most generally a bed of limestone conglomerate or breccia, followed by black shales or slates. These vertical relations are pretty well established."

"The areal relations of the sea green and unfading green are not at all clear. Nothing has been found to show that the stratigraphic position of these two varieties of Cambrian slates is not identical. It seems probable that at a point two miles north of Poultney a change in the sediments occurred in Cambrian time sufficient to account for the diminished percentage of carbonate and the increase of chlorite and pyrite. Whether this difference in composition is alone sufficient to account for the difference in cleavage is uncertain. There may have been some difference in pressure which would account for more perfect cleavage at the south than at the north. Possibly, as has been suggested, the greater abundance of grains of quartz at the north may have restrained the cleavage structure, and so with more lime deposited at the south and more quartz sand at the north, the whole structural difference may be traced back to changes in sedimentation. Even this demarcation between the areas of fading and unfading green slate is not absolute, for fading green slates occur well within the unfading green area, as at the old quarry one and a half miles southwest of West Castleton and again one and a quarter miles south of Castleton."

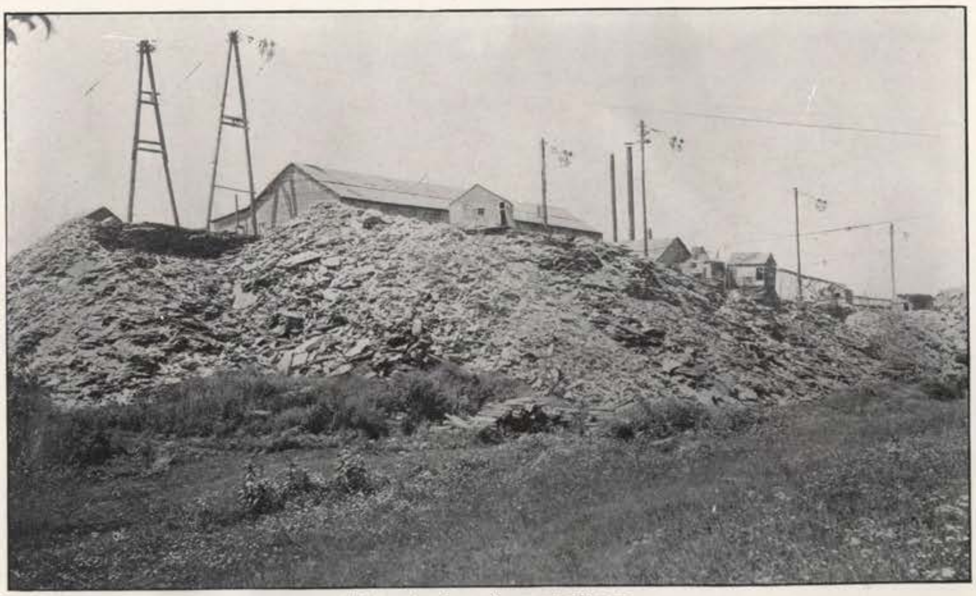
So, too, as to the structure of different colored slates Mr. Dale remarks, "The purplish slates in many places include green ribbons, calcareous, quartzitic and chloritic, an inch or two in thickness, and such ribbons run in rows or planes of green spots.

When freshly quarried, the sea green slate varies from a light gray to a slight greenish gray. In some beds it is crossed by ribbons of a dark gray or, where bedding and cleavage are

PLATE XLV.

One of the largest slate quarries—Auld & Conger.

PLATE XLVI.



Slate sheds and waste heaps.

parallel, it bears traces of organisms in dark gray. Some of the sea green slates are termed hard, others soft. The difference, judging from microscopic evidence, seems to be due to the greater percentage of carbonate in the soft ones and the larger size of the quartz grains in the hard ones.

Unfading green slate is greenish gray in color. Several years' exposure produces so little change of color that only when a fresh slate is put beside it is any change perceptible, and that is but slight. * * * *

Purple slate is not unlike the green varieties, but contains more iron oxide, Fe_2O_3.

Variegated may be of two sorts. The trade name is usually "mottled." There is mottled green and mottled purple. In the former, the general ground is green, but scattered through it are more or less numerous spots, often oval, of purple color and in the latter the ground is purple spotted with green. What is called mill stock slate is obtained from beds in which the slaty cleavage is less pronounced than elsewhere, so that the stone cannot readily be split into thin layers and it is therefore sawed into slabs or blocks and used for blackboards, billiard table tops, tiles, sinks and many such articles. The shade of color varies in different quarries in some degree, but is in all substantially as described.

Besides the bulletin referred to above, those especially interested in slate are referred to a more elaborate paper by T. N. Dale, which was published in the Nineteenth Annual Report, U. S. Geological Survey, part 3, pages 163-307, plates and figures, 1899.

From a very attractive pamphlet on slate, issued by the Auld and Conger Company, a few paragraphs have been taken in what immediately follows. Writing of the position of different beds the author of this booklet says, "The sea green veins in our quarries come first and under these lie the purple veins and still below these we find weathering green beds. So we have to go through these veins or beds, layer by layer to the bottom beds."

"The rock is quarried largely by the use of drills operated by compressed air. When the large slabs of rock are made free in the pit they are hoisted. * * * * The block cutters then reduce the large slabs to smaller ones for the splitters. All roofing slate is then split with mallet and chisel. Standard thickness of slate is all split to an average of three-sixteenths inch and is trimmed to twenty-four or more different sizes by trimming machines." "We make from any Vermont slate rock any thickness desired from three-sixteenths to an inch and a half." (The thicker slates are more expensive than the thin.) This is mainly because of the increased difficulty in trimming, handling, etc. As to appearance and durability of slate roofs there is much to be said as well as regards safety from fire. To find anything artificial that is really antique one must go to some other country and all over Europe very ancient slate roofs are found which are apparently as good today as when built.

In England there are eighth and ninth century buildings with slate roofs, put on when the house was first built, which are in perfect condition. Of course since the Vermont slate quarrying dates only from 1840, we can refer to no such examples, but slate put on fifty years ago is apparently unchanged even in a Vermont climate. We have no reason to doubt that our slate is practically everlasting.

As to this I may quote from the booklet referred to above. "Our weathering green slates from Vermont are an unusually strong material. * * * * * * These slates have an almost endless variety of shades, soft grays, several different browns, gray greens, brown greens and a few brown purples. They are generally laid with no idea of matching colors, but just as they happen to come from the quarries. A very pleasing feature of this kind of roof is its improvement with age. The colors grow mellow with time and take on some very beautiful tints, making a very artistic roof and one guaranteed to last forever."

These quotations are given not to call attenion to any particular slate company, but to bring before the reader something of the qualities and character of Vermont slate. What has been said above will apply, more or less, to all the slate from this belt in western Vermont, whether from one or another of the many quarries. The durability of our slate is largely due to the hardness and insolubility of the rock. More than half of its substance is silica, besides which there are a large number of elements, though none in large amount, so that any of the slate used if chemically analyzed contains more than twenty different elements.

As has been already noticed, Vermont produces much more slate than any other state except Pennsylvania. The slate men report that during the last year, 1920, the business has been very good, "good business in roofing slate and great demand for mill stock." I am unable to give exact figures as to the amount realized from the sale of Vermont slate, but at least we may be sure that it is between one and two millions of dollars annually. It is safe to estimate the amount at $1,500,000.

Within a few months a new use for slate has been found and the Vermont Milling and Products Corporation is actively engaged in this business. This company have large mills in Poultney and offices in Fairhaven. They grind the slate and screen the ground material, which is then called "slate granules." The screens used have 12-16 mesh. By means of an asphalt binder these granules are fixed upon the surface of some sort of fiber and, cut into proper sizes, is sold for shingles. Thus is made a flexible and comparatively light shingle which finds a ready

market. Different colored slates are used, though green is most common, the unfading green, which is quarried for the purpose of grinding.

For the information and convenience of anyone interested, a complete list of slate companies is here added. As will be seen, not only the name of each company is given, but the kind and colors of the slate produced. In the preparation of this list I have had the assistance of several prominent slate producers and it is thought to be quite accurate.

LIST OF SLATE COMPANIES IN BUSINESS IN VERMONT, 1919-1920.

CASTLETON.

P. F. Hinchey and Company, Hydeville. Quarries. Mill stock only. Colors green, mottled and purple.

Penrhyn Slate Company, Hydeville. Quarries. Mill stock only. Hydeville Plant, Lake Bomoseen Plant, Scotch Hill Plant. Mottled, green and purple.

Hydeville Slate Works, Hydeville. Mill stock only. Mottled, green, purple.

John Jones Slate Company, Castleton. Quarry. Mill stock only. Mottled, purple.

Lake Shore Slate Company, West Castleton. Quarry. Mill stock only. Mottled and purple.

FAIRHAVEN.

Clark and Flanagan Slate Company. Quarries. Mill stock and roofing. Unfading green, purple, mottled, gray.

Durick, Keenan and Company. Quarry. Mill stock only. Mottled and purple.

Eureka Slate Company. Quarries. Roofing slate. Unfading green, mottled, purple.

Fairhaven Marble and Marbleized Slate Company. Quarry. Mottled purple, green.

Locke Slate Products Corporation. Mottled, green and mottled purple.

McNamarra Brothers Slate Company. Electrical slate only.

Mahar Brothers Slate Company. Quarries. Mill stock and roofing. Mottled, green and mottled purple.

Old English Slate Company. Quarry. Roofing. Mottled and purple. Office, Boston, Mass.

W. H. Pelkey Slate Company. Quarry. Roofing. Green.

Vermont Milling and Products Corporation. Ground slate only for roofing. Mill at Poultney; Office, Fairhaven.

A. B. Young Slate Company. Mill stock only.

POULTNEY.

Auld and Conger Company. Quarries in Vermont and Pennsylvania. Roofing. Weathering green, unfading green, sea green, purple, mottled.

Donneley and Pincus Slate Company. Quarries. Roofing. Unfading green, purple, mottled.

General Slate Company. Quarries. Roofing. Sea green, mottled, purple, gray.

Owen O. Jones Slate Company. Quarries. Mill stock and roofing. Unfading green, mottled purple, gray.

New York Consolidated Slate Company. Quarries. Roofing. Green, purple, unfading green, mottled.

F. C. Sheldon Slate Company. Quarries. Roofing. Purple and sea green.

WEST PAWLET.

Rising and Nelson Slate Company. Quarries. Roofing. Sea green.

WELLS.

O'Brien Brothers Slate Company. Quarries. Roofing. Purple and sea green.

Burdette and Hyatt. Quarries in Wells; Office in Whitehall, N. Y. Roofing. Mottled purple and green.

Norton Brothers Slate Company. Quarries in Vermont and Granville, N. Y.; Office in Granville, N. Y. Roofing. Green, purple, red.

O. W. Owens and Sons Slate Company. Quarries in Vermont and New York; Office in Granville, N. Y. Roofing. Green, purple, red.

Progressive Slate Company. Quarries in Vermont and New York; Office in Granville, N. Y. Purple, green, red.

F. C. Sheldon Slate Company. Quarries in Vermont; Office in Granville, N. Y. Roofing. Sea green.

Vermont Slate Company. Quarries in Vermont; Office in Granville, N. Y. Roofing. Sea green, purple, red.

H. G. Williams Slate Company. Quarries in Vermont and New York; Office in Granville, N. Y. Roofing. Purple, green, red.

GRANITE.

Vermont has been known as a marble State, as *the* Marble State, for many years and it still holds its front rank in the production and manufacture of this stone, but within a few years it has so forged ahead in granite production that it not only leads all other localities in supplying this stone, but has gone far ahead of all other stone industries in the number of quarries, and especially of cutting plants as well as the amount and value of stone sold. As has been noticed in former Reports, there are many more granite companies than there are either slate or marble in the State.

The accompanying lists show this plainly. During the last few years, however, there has been a consolidation of many of the formerly very numerous granite quarries. Formerly, there were many quarries, each owned and controlled by a comparatively small company, but of late many of these have been brought under the control of fewer and larger companies, several quarries being owned and worked by a single corporation. The "Cutting Sheds," always far more numerous than the quarries, have not been affected so much in this way and, as the lists show, are still many. As heretofore, some of the large quarries deal only in the unfinished stone, selling in the rough to the cutting firms. A few not only quarry, but also cut and finish their stone

and most of the cutting sheds do no quarrying. In the accompanying lists the quarrying firms are indicated by Q.

As has been said of all stone business, the granite industry has on the whole been very prosperous during the past two years and especially during 1920. Perhaps this good business is not so much in increased sales as in the higher prices obtained. Good granite now sells in the rough, that is as it comes from the quarry in blocks, at from $2 to $4 a cubic foot and finer quality or special sized blocks is sold at from $6 to $10 a foot.

Granite is found in many localities in eastern Vermont, but none west of the Green Mountains. So far as it has been quarried all Vermont granite is gray, varying very much in shade from the nearly white Bethel to the darkest Barre. One of the valuable qualities of Vermont granite is that while in different quarries the shade may vary, or even in different parts of the same quarry, yet in most localities there is a large supply of stone of uniform shade and texture or grain. Any amount of stone that may be required, blocks of any size can be obtained in many of our quarries. pink ?

There is red granite in Vermont, most of it of rather a light shade, but none has yet been used. As the Vermont granite is nearly all of it uniform in origin, mode of deposit, etc., though varying greatly in quality and other characteristics of importance in the trade, the following account is given as generally applicable.

At a meeting of the Vermont Society of Engineers, held in Barre in October of this year, the Geologist was asked to speak of the Geology of that Granite District and as much of what was said appeared to be welcome to these who were present, especially to those interested in quarrying and manufacturing granite, it may not be out of place in this connection to repeat in substance the statements which were made at that time. This will be the more useful, because the geology of the Barre Granite Area does not differ in most respects from that of any other of the Vermont granite districts as Newport, Kirby, Robeson Mountain in Woodbury, Bethel or Dummerston. With very slight exceptions, all that is written here in regard to the Barre quarries applies equally to the others named.

The location of the granite areas of this State is noticeable, for without exception, all are east of the Green Mountains, between the mountains and the Connecticut River. There is no granite in the mountains nor west of the range. The range of granite hills, except in a mountainous country like Vermont they would be called mountains, begins in Canada and comes into this State in Derby and Newport, from there running south in a series of more or less isolated elevations through Kirby, Barton, Woodbury, Calais, Barre, Ryegate, Groton, Bethel to Dummerston. These are barren masses, in general flattened domes, or broad rounded hills a few hundred feet high, the lower flanks in contact with micaceous schists, which, as will be seen later, once wholly covered the granite.

As to geological age, it is well established that these granite hills, which as was shown in the last Report, really form a fourth range of elevations in the State, are more recent in origin than the Green Mountains, although they are by no means of late formation. The probable order of formation in this State was: the Green Mountains, the Taconics, the Redsandrock Hills and the Granite Hills, though the Green Mountains as they are now were not finished until later than the Redsandrock Hills, such as Mt. Philo, but they were certainly begun and to a large extent built up earlier. The axis or backbone of the Green Mountains is undoubtedly very old, but many additions were made later. Reference to the article on The Physiography of Vermont, in the Eleventh Report of this series, will help the reader to a fuller understanding of this phase of Vermont geology. A brief review of the conditions which the geological record in any of our granite districts reveals will perhaps best present their geological history. It matters little whether we take for an example of the others, Robeson Mountain in Woodbury or Millstone Hill in Barre or some other granite mass. The history is the same in all essential details.

The axis of the Green Mountains was formed in what geologists called pre-Cambrian time. Then followed the Cambrian, in which in Vermont the oldest well defined fossils occur. This is the age of Mt. Philo and other red sandstone elevations. Then follows the Ordovician, a long age during which the great layer of schist, gneiss, etc., which covers the Green Mountains was formed as sandstone, limestone, etc., and transformed into the present rocks which are what one sees as he looks at the mountains. This is the age of the Rutland marbles and of the slates and schists of eastern Vermont, including those now found in contact with the granite.

Then follows the Devonian Age and it was probably during this age that the granite appeared. Many geological ages followed those named and I doubt if anyone can fully appreciate the immensely long time that must have passed since the granite of our State came to the surface. All that we can think is that it was very long ago. How long no one can tell us. In studying the geology of any region it is never possible to begin at the beginning, for even geological history is far too hazy and uncertain after we have gone back towards the beginning to make it possible to discover what was then the condition prevailing.

It is only possible to choose, somewhat arbitrarily perhaps, from a definite point where a start can be made with reasonable certainty, and proceed from this. Beginning then with a time when a wide extending sea covered eastern Vermont, it is easy to find abundant evidence that with the Green Mountains as the

western shore this great sea rolled its waves in from the east. In this sea were living many and strange creatures of lower orders, and over the sea bottom and along the beaches were deposited sands, mud and the cast off shells or whatever remains of the animals that lived and died in the waters. Thus were formed beds of limestone, sandstone, shale or slate to be later raised above the ocean and become dry land, probably the first land of eastern Vermont. How thick these beds of strata were we have never been able to determine. As is always the case where rock is exposed to air and water, a great deal was undoubtedly carried off, but the beds were unquestionably thick.

This was the state of the country after the close of Ordovician time and during the next, Silurian age, and a part at least of the Devonian. Certainly not before, and probably during, the Devonian a new series of activities came into action by which great masses of melted stone were forced upward from below the surface, how far below is not known, and came up against the beds which covered the surface. By this time these beds were no longer in their original condition, but they had become much changed. Very likely much of this change occurred at the close of the Ordovician, when the Green Mountains were finally raised and without question many great transformations took place.

Before the granite came up the sandstones, etc., had changed to the schists we now find all around the granite. I suppose that if one can imagine a belt of land reaching from the Green Mountains to the White Mountains, fairly level, covered by only low forms of vegetation, or by none at all, he would have before him very nearly what did exist during Devonian times, at least in the earlier part of this time. At sometime during Devonian time, or possibly later, began the volcanic disturbances which resulted in the formation of the granite deposits from which the stone is now quarried.

The structure of the granite is such as to prove conclusively that the molten streams which welled up from beneath did not at first appear on the surface but formed what are known as laccoliths, that is as the streams came up under the beds of schist, they did not push their way through it but remained covered by it and slowly pushed it up into more or less dome-shaped elevations, so that at this time the granite hills were not as now, wholly bare granite masses, but much higher than now and capped with schist, no granite being visible. Plate XLVII, showing Millstone Hill gives the general form of these granite elevations as they now appear, though it does not show the quarries.

Thus they remained for no one knows how long, but long enough to allow the ice and snow of winter, the rains of summer and all those silent, but powerful agencies which disintegrate and wear down the ledges to entirely remove from the higher portions all traces of the capping schists, except now and then a bit of greater or lesser size, which is found included in the granite sheets. That the schist did originally cover the granite is shown not only by the uniform presence of that rock immediately about the granite at the base of each mass and the frequent schist inclusions in the granite, but more certainly by the intimate structure of the stone itself.

The granite shows by its mode of crystallization that it must have cooled and crystallized under heavy pressure and the adjacent schists show how this pressure came about. Indeed there is no other conceivable pressure which could act on the cooling granite except that produced by beds of rock on top of it. Without the adjacent schist it would be known that there was a weight resting on the granite, but what this weight was could not have been known had not some of the schist remained to tell. In any erosion of a land surface the more prominent portion would of course be first worn off as the tendency in such cases is always to reduce an uneven surface to a uniform level. Of course, difference in the hardness or resistant quality of a rock must affect its erosion and may thus cause exceptions to the above.

The great ice sheet, which has not yet been mentioned, must have played a very important part in the history of this as of all parts of Vermont. To reach this Pleistocene, or Ice Age, it is necessary to pass over a long series of geological ages which cannot be even mentioned here. It must suffice to say that by some great and somewhat inexplicable change in the climate of this part of the world, an age-long winter set in and vast masses of snow collected in the northern regions towards Hudson Bay and enormous glaciers were thus formed which century after century slowly moved southward over the face of the country, destroying as only such an agent could.

Now, instead of the great ocean or the strip of land which after a time appeared, instead of long ages of quiet when erosion slowly but steadily wore away the land and carried it back, much of it into the primeval seas, instead of volcanic activity when the granite masses were formed, instead of the recurring erosion which bared these masses, the landscape must have presented a strange appearance, for it was that of Greenland of today, a vast expanse of desolate ice and snow. During its greatest thickness, this glacier must have been thousands of feet thick and covered all the Vermont mountains. Necessarily, whatever of erosion had not already been accomplished was still further accomplished by the ice. The present form of our mountains, large and small, is due mainly to the wearing, carving of the ice.

Undoubtedly, all the surface of the land, mountain or plain was greatly affected by the glacier or glaciers, for very likely here, as in many other places, there was a series of ice sheets. At first enormous wearing, crushing, breaking of rocks and later, when the immense quantity of ice melted, terrific floods, by which

the loosened material was widely distributed, acted to produce the sort of surface we see all about us. Sand plains, gravel and sand banks, most of our lakes, the basins of which were scooped out by the glacier, indeed all the varied features of any Vermont landscape owe their existence to the activities of Pleistocene time.

For example, the level plain where Montpelier Seminary is located is an old stream delta, where after the ice age a body of water stood into which some no longer existing stream poured its sand-bearing water, so the plain on which Barre City stands and which affords such excellent sites for granite sheds, is the bottom of a glacial lake and the sand hills around the plain are piles of material brought down by glacial streams.

Leaving further consideration of the general geology of the granite regions of Vermont it will be interesting to turn to a brief discussion of the stone itself. With few exceptions, Vermont granite, all that is now quarried, is gray of many shades. Pink or reddish granite is found in Newark and a little elsewhere. The Vermont granites that are now quarried and sold may be placed in one of two groups.

Granites like the Barre and Woodbury stone are biotite granites. That is, the mica is mostly a black iron mica known as biotite. These granites are composed of three main minerals, quartz, mica, feldspar. The quartz is usually clear and glass-like in appearance, the mica is in little scales which vary very much in different stone and if the mica is a biotite the scales are generally black, though sometimes gray, the feldspar is a dull or chalky white. Very plainly the shade of a granite depends upon the relative amount of each of these minerals. When biotite is in excess of the white quartz and feldspar of course the granite is dark and is light in proportion as the dark biotite is less. Hence there are many shades from nearly black, though rarely, to dark, medium light and white. In the Barre White the biotite is gray.

There is another mica of somewhat different composition and less iron. This is usually very light and may be silvery, but in the Barre granite there is not a large amount of muscovite and it therefore does not greatly affect the appearance of the stone. What are called "knots" are places in the granite where the biotite has, for some reason, collected in unusual abundance and when these are very numerous and large in a quarry they seriously injure the appearance of the stone. It is scarcely necessary to say that when the materials of granite are in very small bits the granite is very fine and all varieties are found because of this variety in the size of the bits of quartz, mica and feldspar.

The white granite of Bethel is not like that of Barre or other localities, but is what is technically called Quartz monzonite, that is it is a granite in which there is little biotite and much muscovite and the feldspar is sometimes different. Some of the Ryegate granites are also Monzonites. Besides the difference in the mica in the two granites, there is a difference in the feldspar, but it is not necessary to go into details of composition. The so-called granite of Ascutney is not a granite, but if different composition, though like granite, it is originally a molten rock.

It may be well to notice that in writing of granite here I am speaking only of Vermont granite, for the granites of other states often differ widely in composition from that found in this State. Though mineralogically our granite has a very simple composition, chemically it is complex as the feldspars and micas are made up of a number of chemical elements and there are often several kinds of feldspar and mica in a single variety of stone.

The following analysis of a specimen of Barre Dark will serve to illustrate this.

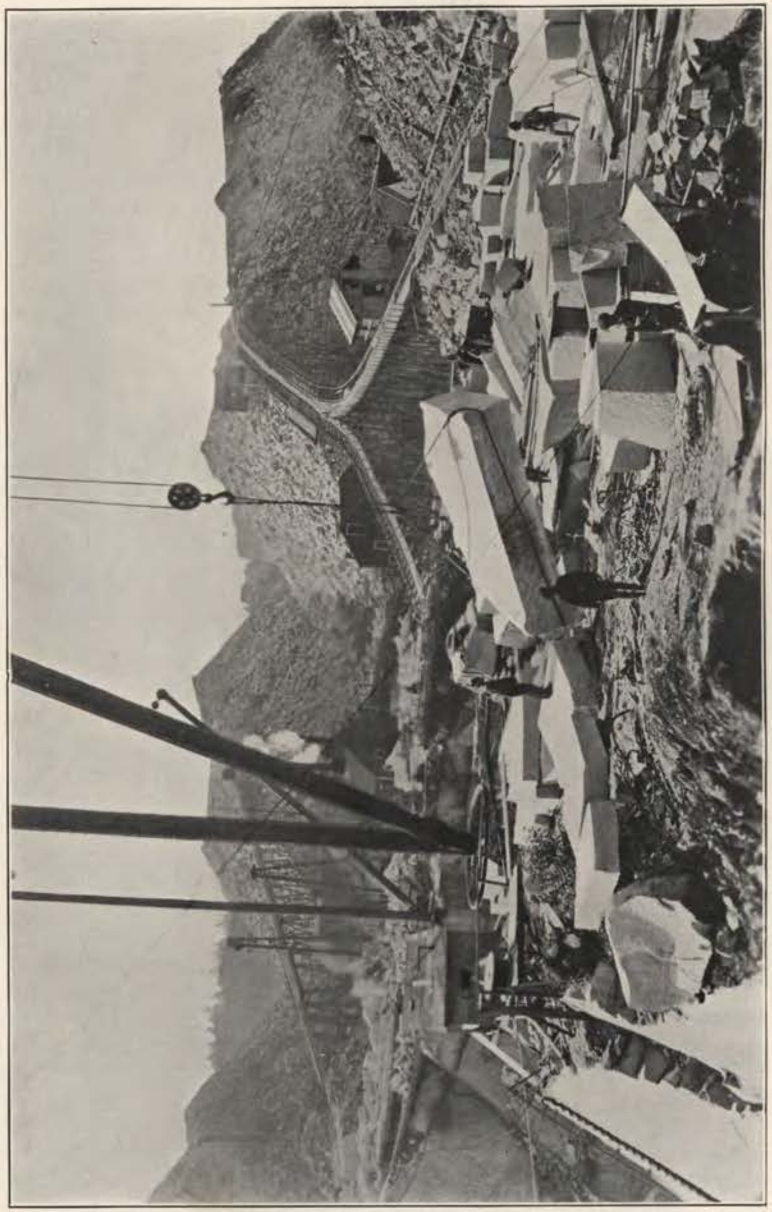
SiO_2	69.89
Al_2O_3	15.08
Fe_2O_3	1.04
FeO	1.46
MgO	.66
CaO	2.07
Na_2O	4.73
K_2O	4.29
H_2O (at 110)	.31
H_2O (ignit.)	.39
	99.76

For fuller and more technical details of the granite quarries of the State anyone interested in the subject should consult the Seventh Report of the Vermont Geologist, in which will be found a reprint of a Bulletin, 404, U. S. Geological Survey, by T. N. Dale (Seventh Report, pages 77-197, 1909-1910. Maps and illustrations).

As the granite business has from year to year increased and consequently the amount of stone taken from the quarries has increased, necessarily the waste has accumulated and to a wholly unforeseen amount. Plate XLVIII, from a photograph by Mr. Barclay, shows some of these mountainous piles of waste, "grout," at one of the larger quarries. All the heaps in the background are waste. This waste comes from several sources. Blocks of several tons may be often seen, though most is a pile of comparatively small sized pieces.

The larger blocks are such as are in some way imperfect. They would be entirely satisfactory for building material or paving blocks, but the cost of transportation to available market is prohibitory. The smaller pieces are those broken away in shaping the stone. Most of this is not only waste, but it so covers the ground around the openings of quarries that it prevents access to valuable stone underneath. It is needless to say that, first

PLATE XLVII.



Waste heaps, Barre.

and last, no little thought has been given to the problem of disposal of this waste.

Boutwell, Milne and Varnum have attacked the problem more vigorously than would be possible to a smaller company and are apparently solving the difficulty, but it is an expensive though satisfactory solution. This company have installed a very large steam shovel, considerably larger than any used in excavating the Panama Canal and have set it at work removing a huge pile of grout. The experiment has now been tried long enough to prove its value and already a large amount of débris of all sorts of granite has been dug out from the pile, loaded on cars and carried to a more suitable dumping ground.

This shovel, weighing 140 tons, with a capacity in the shovel of 64,000 pounds, which can be increased to 82,000 if necessary. It is a most impressive sight that this monster presents when in action, as it relentlessly digs into the pile to be removed, seizing stone several tons in weight, or tons of smaller pieces, lifting them, turning and dropping them into iron-bound cars that wait for their load.

At present there seems to be no better way of getting rid of the waste than this, just picking it up and carrying it away, but the time may well come when instead of throwing it away and spending thousands of dollars in doing this, some real use will be found, as for so many waste products, and then instead of an expense the waste will become an asset. Numerous experiments to accomplish this have been tried and are still under way. Some crushed have been used for road making, some more finely crushed for sand-lime brick, some to extract the potash in the feldspar and not a few others, but none as yet can be called a success.

It has been difficult to obtain figures that accurately told the amount of granite sold from Vermont. It would not be difficult to find how much was actually quarried, but only a small part of that quarried goes out of the State in the rough and that which is sold in the form of monuments, etc., carries, of course, much greater value. If, however, all the stone quarried and all sold in a finished condition be added, the sum is too great because the stock sold finished has already been reckoned in quarry products.

In this dilemma the Geologist appealed to the Barre Granite Manufacturers' Association for correct figures, as he felt certain that none had ever been published. In response to this appeal, the above named association has furnished the figures here given, through Mr. A. R. Bell, the secretary. I am assured that these figures are, except in a few minor instances, not estimates, but that they show the actual sales as recorded on the books of the different firms involved. It is to be understood that these figures do not refer to the entire State, but only to the district indicated.

BARRE GRANITE OUTPUT IN 1919.

Total rough stock valuation of Barre granite quarried in 1919, $3,566,220.

Total rough stock valuation of Barre granite consumed in 1919 by granite manufacturers in the Barre District (Barre City, Barre Town, Montpelier, Williamstown, West Berlin, Northfield and Waterbury), $2,881,804.80.

Total manufactured valuation of finished Barre granite shipped by manufacturers from the Barre District in 1919, $9,012,173.94.

Combined valuation of finished Barre granite manufactured in the Barre District and rough granite quarried in Barre, but shipped outside the District, in 1919, $9,688,189.14.

Barre granite (rough) quarried in 1919 aggregated 212,275 tons, or 1,273,650 cubic feet. The average price per cubic foot was $2.80.

Barre granite (rough) manufactured in the Barre District in 1919 aggregated 171,536 tons, or 1,029,216 cubic feet.

Barre granite (rough) shipped to points outside the Barre District to be manufactured elsewhere aggregated 40,239 tons, or 241,434 cubic feet.[1]

The figures for 1920 are not available, but all the granite men with whom I spoke declared that the business has been larger during the last year than ever before. If the product of other granite localities in the State be added to the above we have a total production for the whole State of at least $10,500,000 for the year 1919 and certainly as much more for 1920.

As from year to year changes in ownership come about, especially in the cutting sheds, any list to be up-to-date needs frequent revision. The list which follows is intended to include all the granite workers at present doing business, not including the monument makers, who in a smaller way and larger numbers, work up no small quantity of stone in the course of each year. The Geologist alone is quite helpless in preparing such a list, so far as completeness goes, but with the aid of granite workers in different parts of the State he has been able to compile a list that he hopes is in the main accurate. In collecting the material for the list I am indebted especially to Mr. Athol R. Bell, Secretary of the Barre Granite Manufacturers' Association; Mr. George James, of the Woodbury Granite Company; Mr. R. Farquharson, South Ryegate; Mr. F. R. Lewis, Barton.

[1] Probably one-eighth (around 5,000 tons, or 30,000 cu. ft.) of the latter total was shipped to points outside the Barre District (Morrisville, South Ryegate, Newport, Burlington, etc.) but to points within Vermont and there manufactured. The remainder was divided among the different States and Canada.

LIST OF GRANITE COMPANIES IN VERMONT, 1920.

BARRE.

American Granite Co.
Anderson & Johnson.
Anderson-Friberg Co.
Apollo Granite Co.
A. Barclay & Co.
Barclay Brothers.
Barre Memorial Co.
E. J. Batchelder & Co.
Beck & Beck.
J. O. Bilodeau & Co.
George E. Bond Co.
Boutwell, Milne & Varnum, Quarries.
Brown & DeMerell.
Brozecevic Brothers.
Bruza Brothers.
E. A. Bugbee & Co.
Burke Brothers.
Buzzi Granite Co.
Canizo & Co.
Canton Brothers.
Carroll Brothers.
Carswell-Wetmore Co.
Casiani Brothers.
Celente & Bianchi.
Central Granite Co.
Chioldi Brothers Granite Co.
Ciresoli & Co.
William Cole & Son.
Cook-Watkins Manufacturing Co.
Comolli & Co.
J. P. Corskie & Son.
Davis Brothers, West Berlin.
DeRegibus Granite Co.
Frank Dibetetto.
Dessureau & Co.
Dewey Column and Monumental Works.
Freeman & Wasgat.
Gasparello Brothers.
Gelpi Granite Co.
Genest & Beaulieu.
Gerrard-Barclay Granite Co.
E. C. Glysson & Co.
Grearson & Lane Co.
Guidici Co.
Guidici Brothers Co.
Harrison Granite Co.
Hebert & Ladrie.
Hedburg & Gustafson.
Hoyt & Mine.
Industrial Granite Co.
Johnson & Gustafson.
Jones Brothers Quarry Co., Quarries.
Jones Brothers & Co.
Jones Granite Co., Williamstown.
LeClair & McNulty.
Littlejohn & Milne Quarry Co., Quarries.
Littlejohn, Odgers & Milne.
Marr & Gordon.
Marrion and O'Leary.
Martinson Estate Co.
Paul Mascitti.
Alexander Milne.
Milne Granite Co.
Mutch & Loranger.
McColl, Abear & Co.
McDonnell & Sons.
McGovern Granite Co.
McMillan Granite Co.
T. J. Newcomb.
North Barre Granite Co.
Novelli & Calcagni.
Oleson & Nelson.
Olliver Granite Co.
Parnigoni Brothers.
Parry & Jones Co.
Peerless Granite Co.
J. K. Pirie, Quarries.
Pratt Granite Co.
Presbrey-Coykendall Co.
Provost & Son, West Berlin.
Puente Granite Co.
Redmond & Hartigan.
Rizzi Brothers.
L. G. Rizzi.
James C. Robertson.
Robins Brothers.
Frank Ross & Co.
Ross & Ralph.
Rossi & Caselini.
Roux Granite Co.
Royal Granite Co.
Russell & Brand Granite Co.
Saldi & Rossi.
Sanguinetti & Co.
J. P. Saporiti & Co.
Saporiti Granite Co.
James Sector & Co.
E. L. Smith & Co., Quarries.
South Barre Granite Co.
Standard Granite Co., Quarries.
Steele Granite Co.
George Straiton.
E. Tosi & Co.
Union Granite Co.
Valz Granite Co.
Vermont Manufacturing & Quarry Co.
Victory Granite Co.

Wells-Lamson Quarry Co., Quarries.
Wetmore & Morse Granite Co., Quarries.
World Granite Co.
Young Brother Co.
Giovanni Zorsi.

MONTPELIER

Aja Granite Co.
Ariole & Co.
T. Beaudet.
Beaudette & Doucette.
Bianchi Granite Co.
Bonazzi & Bonazzi.
Boutwell, Milne & Varnum, Office.
A. Canas.
Capitol Granite Co.
Columbian Granite Co.
Doucette Brothers.
H. C. Emmons.
Excelsior Granite Co.
E. Fernandez.
R. M. Fraser, Garand & Forgue.
C. P. Gill & Co.
Higuera Granite Co.
Johnson Granite Co.
Jurras Granite Co.
Robert Lawrence.
R. A. LeClerc.
Lillie Granite Co.
Maloney & Clossey.
Menard & Erno.
Mills & Co.
National Granite Co.
Pilini Granite Co.
P. Poma Granite Co.
Sheridan & Poole.
George Slevwright.
Wetmore-Morse Granite Co., Office.

NORTHFIELD.

Cross Brothers Granite Co.
Northfield Granite Co.
Pando Granite Co.
Pelaggi & Co.
Phillips & Slack.

WATERBURY.

Drew, Daniels Granite Co.
O'Clair Granite Co.
Union Granite Company.

GROTON.

A. Checchi.
Groton Quarry Co.
C. H. Hendry.
Hosmer Brothers.

SOUTH RYEGATE.

American Gray Granite Co.
James Beaton Granite Co.
J. F. Beaton.
Blue Mountain Granite Works.
James Craigie.
R. Farquharson.
Gandrine & Androletti.
Charles E. Gibson.
J. L. Heartz.
M. F. McDonald & Co.
J. M. McKinnon.
Newbarre Granite Co.
Rosa Brothers.
Hilbert Samuelson.
G. Zambelli.
Peter Zambon.

HARDWICK AND WOODBURY.

M. G. Ambrozini & Co.
American Granite Co.
Atkins & Scott.
M. J. Couhig.
Crystal Brook Granite Co.
DeNichilo & Guaraldo.
E. R. Fletcher.
Floyd F. Fuller.
George & Somes.
Peter Good.
James Granite Co.
Hardwick Polishing Co.
John Hay.
V. W. Merriam.
E. R. Murch.
Nunn & Fordyce.
Paz & Co.
G. Y. Ralph & Co.
Woodbury Granite Co., Quarries in Bethel and Woodbury, Works in Bethel and Hardwick.

BARTON.

L. R. Lewis.
T. F. Roy, Quarry.

CONCORD.

Concord Granite Company.
Willard Keach.
Kirby Mountain Granite Co., Quarries.
E. Lillicrap & Son.
J. Lillicrap.
L. E. Smith.

OTHER LOCALITIES.

Eureka Granite Co., Adamant, Quarries.
Patch & Co., Adamant, Quarries.
C. S. Haselton, Quarries, Beebe Plain.
Stanstead Granite Co., Quarries, Beebe Plain.
A. J Goss, West Danville.
Newport Granite Co., Quarries, Derby.
G. E. Lyons Granite Co., Quarries, Dummerston.
Union Granite Co., Morrisville.

MARBLE.

As we have repeatedly noticed, Vermont has for many years supplied by far more of the marble used in building and monumental work than any other State in the Union. For a long time this State produced far more than half of all sold in the country and although of late years other states have produced an increasing amount, yet Vermont holds a decided lead in this industry, producing about half of all the marble sold.

Naturally, the same causes that have brought reduction in the quantity of all sorts of stone over the country have affected the marble business, but yet this is reported as good. Because of shortage in help, fewer men than at times heretofore have been employed in the marble mills and quarries, but higher prices have been obtained for what was sold.

Those interested in marble will find much of interest concerning this stone in the full treatment of it which is given in the Ninth Report of this series.

The following companies were in business in 1920:

Clarendon Marble Company, Quarries and Mill, Clarendon.
Eastman Marble Company, rough stock only, Quarries at West Rutland.
Manchester Marble Company, Quarries and Mill, Dorset.
Meadow Brook Marble Company, Quarry and Mill, Brandon.
Middlebury Marble Company, Quarries at Middlebury, Office at Brandon.
United Marble Company, Quarries at West Rutland and Florence, Mill at Rutland.
Vermont Marble Company, Main Offices at Proctor,
Quarries at Proctor, West Rutland, Florence, Brandon, Danby, Dorset, Swanton, Isle La Motte, Roxbury, Rochester.
Mills at Proctor, Center Rutland, West Rutland, Florence, Middlebury, Swanton.
Lime Plant at West Rutland.

The Vermont Marble Company is much larger than any other marble company not only in this but, probably, in any country. Additions are now building to some of the finishing works. A twenty-four gang steel mill is approaching completion in West Rutland and one of the twelve gangs in Swanton. These are not to replace old mills, but to add to present facilities.

This company also works quarries at Bluff Point, N. Y., where their "Lepanto" marble is obtained; at San Saba, Texas, where a very pretty gray marble is found; and at Tokeen, Alaska, where several most attractive light and dark veined marbles are quarried and finished in mills on the Pacific Coast owned by the company.

One of the most elegant and dignified varieties of "marble" produced by the Vermont Marble Company is the "Verde Antique," quarried at Roxbury and Rochester, Vt. This is a serpentine with numerous white veins of calcite or dolomite and more rarely quartz, which, more or less abundantly, run through the green rock. Eleven quarries have been opened in this stone, but now only one or two of these is worked. Professor Jacobs has in the Tenth Report discussed the geology of the verde antique.

As will be noticed by anyone who may compare the lists given in this Report, the marble interests are concentrated in a very few companies and largely in a single one, though the business carried on by others is important.

The value of the marble annualy quarried and finished in Vermont has been variously estimated, but here as elsewhere, as several of the smaller companies will not make any report of their business, accurate figures are not attainable. So far as I can arrive at approximately correct figures, the marble sold in Vermont in 1920 was not less than $5,000,000 and somewhat less in 1919.

The Vermont Marble Company are also operating their large and well equipped plant in West Rutland, which produces a high grade hydrated lime from the waste of the marble mills. This plant has been fully described by Mr. H. L. Smith of the company in the Tenth Report, page 100.

CLAYS.

Though clay is abundant in many localities in Vermont it is not worked except for brick making in but few establishments and during 1920 only two companies have reported active operations. These are The Rutland Fire Clay Company, located in the southern part of that town, and the Horn, Crockett Company, located in Forestdale.

The Rutland Fire Clay Company produces a dozen different sorts of cements, stove lining, pipe joint filler, roof covering, etc. All of these have proved in use to be fire resistant and excellent for the purposes for which they are recommended.

Horn, Crockett and Company are actively producing and selling a very fine pure white clay and report increasing business.

The *Lime Industry* was fully discussed in the previous Report by Professor Jacobs and there is little to add to what may be found in that article. There are at present nineteen plants burning and selling lime in the State, producing in round numbers, which are as nearly exact as it has been possible to ascertain, not far from 36,000 tons of lime annually.

INDEX.