REPORT

OF THE

STATE GEOLOGIST

ON THE

Mineral Industries and Geology of Certain Areas

OF

VERMONT.

THIRD OF THIS SERIES, 1901-1902.

GEORGE H. PERKINS, Ph. D.,

State Geologist and Professor of Geology, University of Vermont.

J. B. LYON COMPANY, PRINTERS,
ALBANY, NEW YORK.
1902.

CONTENTS.

LIST OF PLATES.

STATE OF VERMONT,

OFFICE OF STATE GEOLOGIST,

BURLINGTON, VT., *October* 10, 1902.

To His Excellency, William W. Stickney, Governor of Vermont:

SIR.—In accordance with the provisions of Act No. 6, Statutes of 1900, I have the honor to present herewith my report as State Geologist for the years 1901 and 1902.

The somewhat increased appropriation which has been at my disposal during these two years has made it possible to undertake more extensive work than could be accomplished in the preceding years of my term of office.

As a consequence, it is believed that the present report will be found more valuable than its predecessors.

Through the assistance of Dr. Richardson, of Dartmouth College, and Mr. Finlay and Mr. Shimer, of Columbia University, I am able to present a not inconsiderable amount of matter of no small scientific value.

My own work on Grand Isle is intended as a beginning of a complete geological survey of the whole State. This survey will necessarily occupy several years, but it is highly important that it be done and as rapidly as the means at the disposal of this office will permit.

In addition to the necessary field and office work connected with the survey of Grand Isle, there have been tested, and more or less completely analyzed, several hundred samples of ores, minerals and rocks which were supposed to contain something of value and on that account sent for examination. These, with the very large correspondence which has been carried on, have effectually prevented the office from being a sinecure.

I am very respectfully yours,

GEORGE H. PERKINS,
State Geologist.

INTRODUCTION.

The history of geological work in this State has been eventful and in some respects extraordinary. As early as 1836 the attention of the Legislature was called to the importance and value of a geological survey, and in 1837 Mr. (afterwards Governor) Eaton as chairman of the committee on education made a carefully prepared report in favor of such survey, but nothing was done until 1844, when an act was passed enabling the Governor to appoint a State Geologist who was to be a person possessing "a competent knowledge of scientific and practical geology and mineralogy" and who should "commence and prosecute a thorough geological survey of the State," etc.

A moderate sum was appropriated to enable the Geologist to carry out the instructions of this act. The Governor appointed as the first State Geologist Professor Charles B. Adams, at the time connected with Middlebury College, a man eminently fitted for the position. He began the work of his office in the spring of 1845. He did much exploring and studying, but the results of his labors were largely lost, as will appear later. He published four preliminary reports. Professor Adams died in 1853. Professor Zadock Thompson, who had been Professor Adams's assistant from the first, was appointed his successor.

Professor Thompson, though entering upon his office with enthusiasm, published no general report, still, as will be seen by reading his biography, he had planned a very extensive and complete work on the natural history of Vermont. To this as well as much other work, death, which came in 1856, put an end.

As Professor Thompson was so fully identified with not only the geological but all scientific work that was carried on in the State during the last twenty years of his life, it has seemed no more than a fitting testimony to the value of his labors that the following sketch of his life, originally published by the writer in The American Geologist, Vol. XXIX, p. 65, should be given in this connection.

ZADOCK THOMPSON.

Sketch of the Life of Zadock Thompson.*

There have been many reputable men of science in Vermont, men who have done much to discover and make known the natural resources of the State, but more than they all Zadock Thompson was the student and the interpreter of natural history in Vermont. For more than half a century his principal work, "Thompson's Vermont," has been the one constantly used reference book in many a rural home. From its closely printed pages hundreds of boys and girls have gained not merely instruction, but encouragement and inspiration to open their eyes and see the wonders that lie about them in the hills and in the streams, the plants and animals of their native town.

The life of Zadock Thompson is well deserving of thoughtful and reverent study as an example of a life, simple, earnest, full of true scientific spirit, patient, modest, and yet at all times ready to give forth to others the result of its labors. And these labors were usually carried on and the results reached in spite of great obstacles.

Professor Thompson was born in Bridgewater, Vt., on the 23d of May, 1796. He was the second son of Barnabas Thompson, one of the first settlers of Windsor county. He very early manifested a love of study, but throughout his school and college days he found it difficult to pay his way.

He earned a part of that which was necessary for his education by writing an almanac which he sold himself, going on foot from town to town. In 1823 he graduated from the University of Vermont. During the following year he published a gazeteer of Vermont, a work of 300 pages. This was followed by several arithmetics, geographies, histories, travelers' guides, almanacs, etc., as shown in the bibliography following this article. During these years he also taught school in several places. Before he entered college Mr. Thompson had formed a plan for col-

* Portrait of Prof. Zadock Thompson by courtesy of *American Geologist*.

lecting the material for a complete history, natural, civil, statistical, of his native State, and for more than twenty years he devoted much of both time and money to the execution of this plan.

In 1842 he had gathered and arranged his materials and was ready to publish, but now his funds were wholly exhausted and his manuscript seemed likely to remain hidden in his desk. At this juncture an old friend and neighbor, Mr. Chauncey Goodrich, who was a publisher and printer, came to the rescue and offered to print the work without the usual royalty and to wait for payment of all bills till returns should come from the sales of the book. The offer was accepted and an edition of five thousand copies was soon issued. The Legislature of the State ordered one hundred copies for the use of the State library and after the publication of the work voted five hundred dollars to the author in token of the popular appreciation of what he had done.

The work is in three parts each of which if less closely printed would make a fair sized volume. The first part is devoted to the natural history of Vermont and is quite fully illustrated, the second is a civil history, and the third is an enlarged and revised edition of the gazeteer. The unselfish spirit of the author is well shown in the price fixed upon this work. His publisher urged Mr. Thompson to sell the parts separately, charging two dollars each, or six dollars for the whole work, which contained six hundred and forty-six pages, and, as books then sold, would not have been considered dear at that price. Mr. Thompson, however, had all his life known the pain of wanting books that he could not afford to buy and he insisted that the price should be low so that those of limited means might not be deprived of the benefits of the work. The three parts were therefore sold together for two dollars and a half, though his own profits were thereby greatly lessened.

Although busily occupied in study of natural and civil history and in preparing his various publications, and in teaching, Mr. Thompson found time to study theology and in 1836 he was ordained deacon in the Episcopal church. On account of uncertain health he never settled over a parish, though he often preached in or near Burlington, where he spent most of his life.

In 1845 a geological survey was authorized by the Legislature and Prof. C. B. Adams of Middlebury appointed geologist in charge. He appointed Professor Thompson and Rev. S. R. Hall assistants. During the ensuing season, Professor Thompson with his fellow assistant explored a hundred and ten townships, and were most busily occupied in the prosecution of their work till the Legislature of 1847-8 summarily put an end to the appropriation. The field notes, specimens and instruments of the survey were stored here and there for some months, but the next Legislature ordered the scattered property to be collected and cared for and Professor Thompson was appointed to execute the order, which he did, and made a report of his work in 1849. No other report of the work of this survey was ever made, as the succeeding Legislature failed to vote necessary appropriations; and as the most important notes, those of Professor Adams, were taken in a peculiar shorthand which only he could read, these became useless at his death in 1853. In 1853 an appendix to the "History of Vermont" was published. This, a book of 64 pages, is mainly given to natural history.

In 1851 Mr. Thompson was elected Professor of Natural History in the University of Vermont, and about the same time some of his many friends, learning of his strong desire to visit the Exposition in London, kindly provided the means, and he spent three months in England and on the continent.

After his return he published as "A Thankoffering" an account of his tour in a volume of 143 pages.

In 1853 an act was passed by the Legislature which provided for completing the geological survey of the State, and under this act Professor Thompson was appointed State Naturalist.

Into the execution of this work he entered with enthusiasm, as it afforded him the opportunity he had long eagerly desired to complete his study of the natural history of the State. He had been preparing since childhood for just this task and his whole soul went into it. He at once planned an extensive work and wrote out the title pages and contents of the three volumes of which it was to consist. Each volume was to be entitled "Natural History of Vermont," the first was to be given to geology, the second to botany, the third to zoology.

The work never went far beyond the plan indicated, for the shadow of death, which for years had hovered over his life, at last fell and in 1856 he died at his home in Burlington.

It was a sore disappointment to Professor Thompson that he could not finish his work and at first, when it was apparent that he must leave it unfinished, he was sore distressed. The pathetic struggle was not long, however, and soon he patiently and quietly submitted to the will of the God in whom he had believed and trusted, and his end was peace.

As has been indicated, Professor Thompson was hindered and often baffled, at least for the time, by lack of funds. There were other hindrances and discouragements. In an address before the Boston Society of Natural History, given in 1851, he says that what he had accomplished in the business of natural history he had done without any associates engaged in similar pursuits, without collections and almost without books.

Personally, Professor Thompson was tall, angular, of a very quiet and sober, though gentle manner, amiable, sweet tempered, loved by all who knew him. His opinions were respected as those of a man of sound common sense and good judgment. He was unaffected and childlike and though naturally conservative, his scientific training made him hospitable to all new truth. His sober manner may have been largely due to the consciousness that was always present during the latter part of his life that the disease of the heart which afflicted him for years might at any time end his life. Because of this he did not trust himself far from home alone. His most frequent companion during these years was a Mr. Hills, himself a lover of nature and a most gentle, sweet spirited man, who

engraved nearly all of the illustrations in Professor Thompson's publications.

In an obituary published soon after Professor Thompson's death in the Geological Report of his colleague and successor, Mr. Augustus Young, we find the following: "At the time of his death Professor Thompson was a professor of natural history in the University of Vermont, an institution to which he had been greatly attached since his graduation, and the eminent self-taught naturalist who had devoted his life in a quiet and unpretentious way to independent scientific enquiry and the labors of authorship and the ministry, died in his humble home near the university with his intellectual armor on, ere his eye had grown dim or his natural force abated."

In the preparation of his works on natural history Professor Thompson was brought into friendly relations with many of the scientists of his time. One of these, Dr. T. M. Brewer, of Boston, thus speaks of his friend:

"His loss both as a citizen and a public man is one of no ordinary character. We have known him long and well, and in speaking of such a loss we know not which most to sympathize with, the family from whom has been taken the upright, devoted, kindhearted head, or that larger family of science who have lost an honored and most valuable member. Modest and unassuming, diligent and indefatigable in his scientific pursuits, attentive to all, whether about him or at a distance, whether friends or strangers, no man will be more missed, not merely in his immediate circle of family and friends, but in that larger sphere of the lovers of natural science, than Zadock Thompson."

It would be quite impossible to understand the later life of Professor Thompson unless the place filled by his wife be fully recognized, for he never could have accomplished all that he did without her efficient aid. Their attachment began when as children they wandered through the fields in search of anything strange or attractive and in after years, when as husband and wife they occupied a little white cottage that until a few years ago stood near the college campus, they continued in more mature and useful fashion the same investigations. Here many years after her husband's death, Mrs. Thompson lived in cheery old age, never losing her interest in the study of nature. Of more practical value was her shrewd and skillful management of the household finance by which money was saved that carried the family safely through many a crisis. Their home was a museum as well. It was in the midst of a very fine garden always filled with thrifty flowering plants and vegetables, when the season allowed, and inside on shelves, tables, anywhere, were pens, cages, boxes containing the creatures that were being petted and studied. To the kindly, sympathetic and efficient co-operation of his wife, Professor Thompson owed no small part of his success. Two daughters were born to them.

In the preparation of his work on the natural history of Vermont the author collected many specimens, some of them rare and valuable. Most of these are now in the state cabinet at Montpelier.

PUBLICATIONS OF ZADOCK THOMPSON.

The following list is believed to contain all the complete works published by Professor Thompson; though besides these, he assisted in the preparation of sundry almanacs and other works:

Gentleman's Almanac, 1820.

A Gazeteer of the State of Vermont, 1824. 12mo. pp. 310.

The Youth's Assistant in Practical Arithmetic, 1825. 8vo. pp. 160.

The Farmer's Almanac, 1827.

The Green Mountain Repository, 1828. A monthly periodical edited by Professor Thompson. Published only one year.

The Iris, 1828. Semimonthly. Also edited by Professor Thompson.

The Youth's Assistant in Theoretical and Practical Arithmetick, 1828. pp. 68.

Thompson's New Arithmetic (Improved Ed.) 1828. pp. 216.

Thompson's New Arithmetic, Improved Edition, 1829. pp. 168.

History of the State of Vermont, from its earliest settlement to the close of the year 1832. 1833. pp. 252.

Geography and History of Lower Canada, 1835. pp. 116.

History of Vermont, Natural, Civil, and Statistical. In three parts, 1842. pp. 224, 224, 200.

Guide to Lake George, Lake Champlain, Canada, etc., 1845. pp. 48.

Geography and Geology of Vermont. For the use of schools and families, 1848. pp. 218.

Report of Proceedings and Instructions in Relation to International Exchanges, 1848. pp. 80.

First Book of Geography for Vermont Children, 1849. pp. 74.

Natural History of Vermont. Address before the Boston Society of Natural History, 1850. pp. 32.

Journal of a Trip to London, Paris and the Great Exhibition of 1851. 1852. pp. 143.

Appendix to the History of Vermont, 1853. pp. 64.

Northern Guide, 1857. pp. 45.

History of the State of Vermont. For the use of schools and families. 1858. pp. 252. This appears to be only a reprint of the work published in 1833, and the preceding a reprint of the Guide published in 1845.

After the death of Professor Thompson, in 1856, Augustus Young was appointed his successor. Mr. Young appears to have been in failing health when appointed, and he died before the close of the year, having, however, prepared and printed a report. In the fall of the same year a fire in the State House almost wholly destroyed the specimens, maps, notes, etc., which had been accumulated since the survey was organized. As no final report had as yet been prepared, the results of the work thus far were largely blotted out by this loss. In 1857 President Edward Hitchcock, who was already one of the foremost of American geologists, was invited to take charge of the geological work in Vermont. He accepted the call and began what was practically a new survey of the rocks of the State. President Hitchcock carried on the survey with energy and skill for the following four or five years, associating with himself as assistants Mr. A. D. Hager and his two sons, Professor Edward Hitchcock, Jr., and Professor Charles H. Hitchcock.

Three preliminary reports were published, and in 1861 the large final report in two quarto volumes was published.

After President Hitchcock's death in 1864 Mr. Hager was appointed State Geologist. Mr. Hager held the office until 1870. In 1871 Dr. H. A. Cutting was appointed State Geologist and Curator of the Cabinet, which office he held until 1886, when Rev. George W. Perry was placed in the office, where he remained until 1898, when the present incumbent was appointed.

The State made no appropriation for geological work between the years 1861 and 1896, and the so-called State Geologist was really only Curator of the State Cabinet. Whatever geological work was done was carried on without State aid.

As the earlier reports on the geology of Vermont are not only long since out of print, but hardly to be found in most libraries, the following annotated list will, it is hoped, be found useful to those who may be interested in Vermont geology:

List of Reports on the Geology of Vermont 1845–1900.

First Annual Report on the Geology of the State of Vermont, by C. B. Adams, State Geologist, Burlington, 1845, pp. 92, Figures 5.

This report contains an introduction of eight pages, in which the author states what he considers the objects of such a survey and how they have been carried out during the year. He acknowledges the assistance of Zadock Thompson and S. R. Hall, and the occasional service of several others.

Then after some general statements of the principles of geology, the author takes up the principal minerals of the State and gives the leading characters of each. After thus characterizing an ore or mineral he names the locality in the State where it is found and the character of the deposit.

A long letter from President Hitchcock on the geology of

Vermont, a report by Messrs. Thompson and Hall, and several more or less important letters giving information respecting the deposits in some of the towns, close the report.

Second Annual Report on the Geology of the State of Vermont, by C. B. Adams, State Geologist, Burlington, 1846, pp. 267, Figures 44.

This is the largest and in some respects the most valuable report published before the final report of 1861. After an introduction, pp. 9-18, Part I, pp. 19-108, consists of "Elementary Geology" in general, having no especial reference to this State. Part II, pp. 109 and 110, mention some of the finer varieties of mineral which have been discovered in Vermont. Then follows Part III, "Concretions," pp. 111–119. Concretionary structure is herein discussed with a short account of these formations in this State. Part IV, pp. 120-169, is more specifically concerned with the local geology. Particular attention is given to surface geology, the drift, etc., though some account of older formations is given. Part V, pp. 170-246, is devoted to "Economical Geology," i. e., such subjects as Relation of Rocks to Soil, Improvement of Soil, Ores, Building Stones. The remaining pages, 247-267, are occupied by brief reports, letters, etc.

Third Annual Report on the Geology of Vermont, by C. B. Adams, State Geologist, Burlington, 1847, pp. 32.

This report gives a brief history of the work of the year, some account of the building stones of the State, evidences of glacial erosion on various ledges, certain chemical analyses, etc.

Fourth Annual Report on the Geological Survey of Vermont, C. B. Adams, State Geologist, Burlington, 1848, pp. 8.

This is only a report of progress.

Preliminary Report on the Natural History of the State of Vermont, Augustus Young, State Naturalist, Burlington, 1856, pp. 88.

The first part, pp. 5-27, contains a statement of what has been accomplished by former geologists, the author's plans for future work, and recommendations as to methods of conducting the work.

Pages 29-35 are given to a report by A. D. Hager, which is mainly a report of progress and statement of plans. The Appendix, pp. 37-47, contains an obituary of Professor Zadock Thompson. Then follow two legislative acts for the government of the survey. After this pp. 55-57 contain Professor Thompson's report as assistant, in which he gives the details of his disposal of the property of the survey. This is followed by a report from the Committee on Education of the Senate respecting the survey. Pages 65-73 give extracts from an address given in Boston by Professor Thompson on The Natural History of Vermont.

Next is given the text of an act setting apart a room in the State House for the arrangement of the collections of the survey.

This is followed by the elaborate plan including proposed contents of the final report which Professor Thompson had drawn up not long before his death. The report closes with two other unimportant appendices.

Report on the Geological Survey of the State of Vermont, by Edward Hitchcock, State Geologist, Burlington, 1857, pp. 12.

This is little more than an outline of work done and contemplated.

Report on the Geological Survey of the State of Vermont, by Edward Hitchcock, State Geologist, Burlington, 1858, pp. 13.

This is like the preceding, a report of progress with suggestions as to a final report.

Preliminary Report on the Geology of Vermont, by Edward Hitchcock, State Geologist, Montpelier, 1859, pp. 16.

This report opens with a brief account of what has been done from the beginning of Professor Adams's work, and a statement of the contents and design of the final report to which this appears to be preliminary. In fact it is printed as a sort of introduction to the final report in the first volume.

Report on the Geology of Vermont, two volumes, quarto, pp. 988, Plates 36, Figures 365, by Edward Hitchcock, Edward Hitchcock, Jr., Albert D. Hager, Charles H. Hitchcock, Claremont, N. H.

These volumes contain a great deal of material to which the student of Vermont geology must often refer and which is of real value. It is very much to be regretted that some parts of this report are lacking in scientific accuracy and exactness of statement. Soon after the publication of the final report President Hitchcock retired from the work, and his death followed in 1864.

As the two volumes of the final report are much more commonly found in libraries than those previously mentioned, a detailed account of their contents is not necessary. Briefly, the main topics treated are as follows: Part I, pp. 55-250, consists of a discussion of the drift and allied glacial phenomena and of the Tertiary beds of Brandon with over sixty figures of the fossil fruits. Lesquereux's descriptions of these are given in volume II, p. 712. Part II treats of "The Hypozoic and Palaeozoic Rocks," pp. 251-451. In this section the different formations exposed in Vermont are more or less fully and more or less accurately taken up. A few of the characteristic fossils are figured. Part III, pp. 452-556, takes up "The Azoic Rocks," i. e., gneisses, schists, slates, etc.

Part IV, which forms the first part of the second volume, treats of similar rocks, though in a somewhat different manner. This covers pages 559-594.

Part V, pp. 595-682, gives notes on thirteen sections taken across the State, with lists of the specimens of stone collected.

Part VI, pp. 683-690, gives a list of mineral localities and of the mineral species in the State Cabinet at Montpelier.

Part VII, pp. 691-718, contains sundry chemical analyses and other items, including the descriptions of fossil fruits mentioned above.

Part VIII, pp. 718-732, contains S. R. Hall's report on the geology of Northern Vermont, which is interesting and useful, and a very brief report by Mr. Hager on the geology of Plymouth.

Part IX, pp. 733-870, on the "Economical Geology" of the State is perhaps, at least at present, one of the most valuable sections of the work. It takes up the various building stones, ores and minerals, with notes on their locality, occurrence, etc.

Part X, pp. 871-941, is devoted to an account of the scenery of the State. A very valuable appendix by Mr. E. Billings describes some thirty species, many of them new, of Ordovician and Cambrian fossils found in the State.

In 1861 Mr. Hager, who as has been noticed was for some years assistant under Dr. Hitchcock, was appointed State Geologist. I cannot find that Mr. Hager published any reports. In 1870 he resigned the office and Dr. H. A. Cutting was appointed his successor. I do not find that Dr. Cutting published any geological report, but he issued several reports upon the condition of the State Cabinet, and several which were zoological rather than geological. These reports, usually of only a few pages, were published in the reports of the State Board of Agriculture for 1872, 1874, 1876, 1878.

In 1886 Dr. Cutting was followed by Rev. George W. Perry. Mr. Perry published two reports, mainly statistical, in the volume of State Officers Reports for 1893-94.

In 1898 Mr. Perry resigned the office on account of illness, and the writer was appointed to take his place.

The present Geologist has published two reports.

Report on the Marble, Slate and Granite Industries of Vermont, by George H. Perkins, Rutland, 1898, pp. 68, Figures 23.

Report of the State Geologist on the Mineral Resources of Vermont, George H. Perkins, Burlington, 1900, pp. 83, Figures 29.

It is believed that the above list includes all the official writings on Vermont geology, but there are other papers, some of them of the highest value, which have appeared from time to time in various scientific periodicals, proceedings of societies, etc. I am not sure that the following list includes all of these, but it certainly does most of them, in the order of publication.

List of Publications on the Geology of Vermont.

Natural History of Vermont, Z. Thompson, Burlington, pp. 222-224, 1842. Appendix, pp. 14-20, 40-58, 1853.

Geological Sections across New Hampshire and Vermont, C. H. Hitchcock. Bulletin Am. Mus. Nat. Hist. Vol. I, pp. 155-179, Plates 16-18, 1884.

Notice of Geological Investigations along the eastern shore of Lake Champlain, conducted by Ezra Brainerd and H. M. Seely. Bulletin Am. Mus. Nat. Hist. Vol. I, pp. 293-345, 1886.

The Marble Border of Western New England, by Ezra Brainerd and H. M. Seely. Proc. Middlebury Historical Society, Vol. I, Part II, 1885.

The Winooski Marble of Vermont, G. H. Perkins. Am. Naturalist, Vol. XIX, pp. 128-133, 1885.

A new Genus of Chazy Sponges, H. M. Seely. Am. Jour. Science, Vol. XXX, pp. 355-357, 1885.

The Genus Strephochetus, H. M. Seely. Amer. Jour. Sci., Vol. XXXII, pp. 31-34, 1886.

Studies on the Cambrian Faunas of N. A., C. D. Walcott. Bulletin U. S. G. S. No. 30, 1886.

An Account of the Discoveries in Vermont of the Rev. A. Wing, J. D. Dana. Am. Jour. Sci., Vol. XIII, pp. 332-405, Vol. XIV, pp. 36, 1887.

The Original Chazy Rocks, Ezra Brainerd and H. M. Seely. American Geologist, Vol. II, pp. 323-330, 1888.

The Taconic of Georgia and the Report on the Geology of Vermont, J. Marcou. Memoirs Bost. Soc. Nat. Hist., Vol. IV, pp. 105-131, 1888.

The Taconic System of Emmons, C. D. Walcott. Am. Jour. Science, Vol. XXXIII, pp. 229-242, 307-327, 394-401, 1888.

Observations on Fossils from the Calciferous Sandrock of Lake Champlain, R. P. Whitfield. Bulletin Am. Mus. Nat. Hist., Vol. II, pp. 41-63, 1889.

The Calciferous Formation in the Champlain Valley, Ezra Brainerd and H. M. Seely. Bulletin Am. Mus. Nat. Hist., Vol. III, pp. 1-27, 1890.

Observations on the Fauna of the rocks at Fort Cassin, Vt., R. P. Whitfield. *Bulletin Am. Mus. Nat. Hist., Vol. III, pp. 25-39, 1890.*

Review of Dr. R. W. Ells' Second Report on Geology of a Portion of Province of Quebec; C.D. Walcott, *Am. Jour. Sci., Vol. XXXIX, pp. 101-115, 1890.*

The Chazy Formation in the Champlain Valley, Ezra Brainerd and H. M. Seely. *Bulletin Geological Society of America, Vol. II, pp. 293-300, 1891.*

On the Lower Cambrian Age of the Stockbridge Limestone at Rutland, Vt., J. E. Wolff. *Bulletin Geol. Soc. Am., Vol. II, pp. 331-337, 1891.*

Correlation Papers, Cambrian, C. D. Walcott. *Bulletin U. S. G. S. No. 81, 1891.*

An Ottrelite-bearing Phase of a Metamorphic Conglomerate in the Green Mountains, C. L. Whittle. *Am. Jour. Sci., Vol. XLIV, pp. 270-277, 1892.*

On Plicated Cleavage Foliation, T. N. Dale. *Am. Jour. Sci., Vol. XLIII, pp. 317-319, 1892.*

Trap Dikes of the Lake Champlain Region, J. F. Kemp. *Bulletin U. S. G. S. No. 107, 1893.*

Structure of the Ridge between the Taconic and Green Mountain Ranges in Vermont, T. N. Dale. *Fourteenth Annual Report U. S. G. S., Part II, pp. 531-549, 1893.*

Fossil Localities in the Early Palaeozoic, A. Foerste. *Am. Jour. Sci., Vol. XLVI, pp. 441-444, 1893.*

The Pleistocene History of the Champlain Valley, S. P. Baldwin. *American Geologist, Vol. XIII, pp. 170-184, 1894.*

The General Structure of the Main Axis of the Green Mountains, C. S. Whittle. *Am. Jour. Sci., Vol. XLVII, pp. 347, 1894.*

On the Continuation of the Rensselaer Grit in Vermont, T. N. Dale. *Thirteenth Annual Report U. S. G. S., Pt. II, pp. 337-340, 1894.*

Structural Details in the Green Mountains Region, T. N. Dale. *Sixteenth Annual Report U. S. G. S., pp. 543-570, 1896.*

Precambrian Rocks in the Green Mountains, C. R. Van Hise. *Sixteenth Annual Report U. S. G. S., pp. 827-896, 1896.*

The Chazy of Lake Champlain, Ezra Brainerd and H. M. Seely. *Bulletin Am. Mus. Nat. Hist., Vol. VIII, pp. 305-315, 1896.*

Description of New Species of Silurian Fossils from near Fort Cassin, Vt., and Elsewhere on Lake Champlain, R. P. Whitfield. *Bulletin Am. Mus. Nat. Hist., Vol. IX, pp. 177-184, 1897.*

Occurrence of Algonkian Rocks in Vermont, C. S. Whittle. *Journal of Geology, Vol. II, pp. 396-429, 1894.*

Upper Ordovician Faunas in the Champlain Valley, T. G. White. *Bulletin Geol. Soc. America, Vol. X, pp. 452-462, 1898.*

Slate Belt of Eastern New York and Western Vermont, T. N. Dale. *Nineteenth Annual Report U. S. G. S., Pt. III, pp. 153-307, 1898.*

A study of Bird Mountain, Vermont, T. N. Dale. *Twentieth Annual Report U. S. G. S., Pt. II, pp. 15-23, 1900.*

Notes on the occurrence of Asbestos in Lamoille County, Vt., J. F. Kemp. *Min. Resources U. S. 1900, pp. 6-12.*

Although some of the titles in the above bibliography are duplicated in that given by Dr. Richardson at the close of his article on Orange county, yet, as each list has a special object, it has been thought best to let them stand as originally and independently prepared.

In connection with the above bibliography it is, I think, quite fitting that there be given a reprint of the account of the work of Mr. Wing, since so much of interest and value appear in his work which was exceedingly fundamental in Vermont geology. The account is taken from the *American Geologist, Vol. XXVIII*, pp. 1-8, 1901, and was written by Professor Seely.

Sketch of the Life and Work of Augustus Wing.*

In this loving record of a portion of the life and work of the Rev. Augustus Wing, the writer can scarcely proceed without at once calling attention to two facts that come incidentally into the story. The first of almost universal recognition is that the science of geology up to a very recent date has largely been wrought out by persons engaged in teaching. Their results have in the main been made possible by the wise husbandry of school vacations together with the economical use of hours between exacting class-room duties.

The preparation of an address that fellow-workers will care to remember or of papers which they will care to read and reread are the results of long time and labor, and these contributions represent only a fraction of what they have really accomplished. This labor of love may properly be regarded as an overflow. The field of science has been made fertile by this irrigation.

Exceptions, indeed, there are that at the same moment startle, inspire and depress, as when some favored genius sends forth in quick succession notable contributions to science. This is the exception; the rule holds. The rare occasional papers have been the revelation of thoughts and researches of well filled hours coming between lecture and lecture, or left over from other professional work.

The other fact of rarest recognition is that science may be the richer from the good service rendered by one who never made a popular address nor presented to society or editor a valuable scientific paper.

The subject of this sketch, the Rev. Augustus Wing, was born at Rochester, Vermont, November 19, 1808.

* Portrait of Augustus Wing by courtesy of *The American Geologist.*

Yours Truly
A. Wing

We need not go far back to establish the character of the stock. James Wing, of Hardwick, Mass., the grandfather, was a member of the "Committee of Correspondence" in the early days of the American Revolution. The father, also James, was a volunteer from Hardwick in the second war with Great Britain.

To the home of the first James, the grandfather, came thirteen children. The third son, the sixth of the family, named for his father, grew to early manhood in Hardwick. He was noted for great ingenuity and sturdy self-reliance, qualities much needed in those days of pioneer life. This James, with other enterprising men, found his way to Rochester, where for a little he spent his summers. When, however, the place at Rochester had in part been prepared as a home, he with his young wife, Hannah Wetherbee, in the spring of 1804, left Hardwick for a permanent place in Rochester. It was a horseback journey they had. Blazed trees marked the way to what was to be their home nest, husband and wife each carrying a fledgling perched on the saddle.

To the two sons brought from Hardwick was added the third, Augustus, at the above-mentioned date, November 19, 1808. Other children, sons and daughters, came to the family, until the number in all was eleven.

The children enjoyed such school privileges as Puritan pioneers were always and early accustomed to give. The father of Augustus prized the advantages of higher schools of which he had been deprived in part, and he looked with favor on the plan of the son when he proposed to carry his studies beyond the range which the home school afforded. On the other side of the Green Mountains, to the west, settlements had been made earlier than that at Rochester; the comforts and privileges of such life had outrun those of the eastern side. High schools and academies had already been founded. So when young Augustus wished to pursue his studies further he had to cross the mountain range. A school of past and present high repute, the Burr and Burton Seminary, at Manchester, Vt., attracted him, and here with his father's approval he entered upon college preparatory studies. In 1835 he was admitted to Amherst College and graduated with his class in 1839. His studies were of great interest to him; mathematics, physics and the languages especially were a great delight to him. After his college graduation he went to Andover Theological Seminary, where from 1840 to 1842 he studied in preparation for the gospel ministry.

The records in the hands of the writer are too scant to permit him to speak with authority in regard to this early period of Mr. Wing's professional life; and of his ability as pastor and preacher. This, however, may be asserted: Friends, acquainted with his high attainments at Amherst and Andover, and knowing his rare mental endowments, thought him to be entering a field wide in influence and rich with the promise of usefulness. They say of his discourses, that they were logical, sympathetic, impressive and often eloquent.

But Mr. Wing's work was not to consist alone in preaching. Early in his ministry a sudden wrench, perhaps a great disappointment "where he had garnered up his heart," came to him. He stepped aside from the path that had seemed so plain, but now uncertain to him, and walked alone in another, that of teaching. Teacher and investigator he became. Not at all did he abate his interest in the studies he loved in his years of preparation. The truths of the Scriptures and the languages in which they were originally written were a source of interest to him. And so when the week day teaching was done or the week's exploration was over, he was ready to give Sunday and Bible instruction to such as were waiting for a mental and spiritual replenishment.

Academies and high schools were fortunate when they secured Mr. Wing as principal. His pupils never forgot his impressive ways of instruction. His method of teaching looked to the arousal of the highest intellectual powers of his scholars. Thought stimulated, investigation undertaken, individual judgment exercised, were in Mr. Wing's estimation of far greater value to the pupil than the acquisition of many facts from printed pages. The young people he trained never forgot their teacher. His example impressed them powerfully, and under his training they acquired an originality of investigation and an independence of thought that were of life-long value to them.

It may not be quite possible to say why a single one of the branches of Mr. Wing's well-rounded study should have passed to the front. But the fact remains! Geology took the lead and became first the prominent then later the all absorbing topic; the constant theme of his study. Teaching itself became in a way only subservient in carrying forward his geological investigations. A generous enthusiasm came to his aid in the pursuit of his favorite research. So all available time and means were made contributors to the great object of solving self-imposed geological problems.

Geology is richer for this devotion to the advancement of the science. Vermont geology especially has profited by taking to heart of a great unanswered question. Passing over many suggestions that readily arise as to the cause of his entrance upon this particular field we may go at once to the great subject of Mr. Wing's investigations. He himself states that in 1865 he came to the "determination to ascertain, if possible, the geological age of the limestones, slates and quartzytes of the Otter Creek valley."

A few words here regarding the field, as well as the rocks, may help to a clearer understanding of the self-imposed task.

Otter creek, better Otter river, the longest stream within Vermont, has its source in Dorset, Bennington county, flows north through the western part of the State, receives many affluents in its course through the counties of Rutland and Addison, and has its mouth at Fort Cassin, on lake Champlain, in the north part of Addison county. The region studied by Mr. Wing is part of an area of the crystalline limestone of middle and western Vermont. To the south the rocks are connected with those of Massachusetts and Connecticut, while on the north they are related to those reaching up to the Canadian line. The more special field of exploration was the part of the limestone region lying between Rutland and Monkton north and south and the adjoining region reaching westward to Lake Champlain. The crystalline limestone of the Otter valley had in the Vermont geological report of Hitchcock been designated as the " Eolian limestone."

This limestone, this " Eolian," with its sandstone beneath and its slates above; what its geologic age? This was the question which Mr. Wing asked and which he set himself resolutely to answer.

The task for one of Mr. Wing's surroundings was immense. The problem was intricate and one that took years to solve. In the solution appeal must be made to the rocks themselves. It is asserted that the feet of this explorer have stood upon every square rod of exposed rock within the region of his survey. The lithological character of the rocks, their dip, their order, their fossil contents, all must be known. He carefully noted the superposition of the rocks, measured the dip with a clinometer of his own construction, and sought with wonderfully observant eyes for traces of fossils.

The rocks of this region had been so folded, broken and worn that at first their true position was uncertain. The fossils, too, in the partly metamorphosed rocks were mostly faded and obscure; their identification difficult. But as the secret of the age of the formation must be unlocked by these fossils, this key was most carefully and in time successfully sought. Many of these fossils Mr. Wing himself determined, but for verification and in cases of doubt he turned to Mr. Billings, of the Canadian geological survey, from whom he received courteous attention and generous help.

So the search went on for years, summer and winter, holidays and vacations. Holidays gave Mr. Wing opportunity for investigating the near-by rocks, vacations afforded him time to visit far-away places in the State or in adjoining states, wherever he hoped he might get light upon his problem. It was as though he were working at a broken and tangled skein. By

study of the composition of the rocks, by the use of the clinometer, but above all by the careful comparison of fossils, he disentangled the knotted, broken skein and by placing the separate threads beside each other, he arrived at a knowledge of the true relation of thread with thread; he determined the right order, the real sequence of the rocks. His problem was solved!

The problem: the age of the limestones of the Otter valley, with the associated sandstones and slates. The rocks were those designated Lower Silurian; the sandstones were the Lower and Upper Potsdam, the semi-crystalline limestone, the " Eolian," was not a single formation, but was made up of rocks of the age of the fossiliferous formations along the lake shore, now known as Beekmantown, Chazy, Black River and Trenton; the slates were mostly the Utica slate, lying in many cases conformably above the Trenton limestone.

So the views of Mr. Wing may be fairly expressed in a few words. The limestone region of the Otter valley lies within a great syncline. On the east it is bordered essentially by ridges of quartzyte, which extend along the western foot of the Green Mountains; on the west by the red sand rock whose elevation and fracture forms the great fault north and south, seven to nine miles from the Champlain shore. The axis of this syncline descends southward, while on the north it rises until the worn rims of the siliceous rocks, the quartzyte and red sand rock very nearly approach and unite. Within this trough lie the limestones and slates. These are of the age of those that lie west of the great fault, the fossils of which long ago placed them with the Lower Silurian. These strata, originally deposited in regular order by some grand mountain-making movement, have been folded, compressed, snapped and displaced; the fossils by the same movement largely obliterated. The great syncline was left with subordinate north and south anticlinals and synclinals; the whole complex was exposed to the subsequent abrasions of geologic time.

It was the planing down and the enormous wastage from without, together with the great modifications of structure and position of strata within, that disguised their true character and relationship, made the order and age of the rocks such a hard problem. Time, diligence, ability were needed. And we have seen how Mr. Wing solved it. It was to him a ten-years' problem.

Mr. Wing had been slow to make known his researches, wishing apparently to put his theory beyond any possible overthrow by adverse criticism. Typical localities were re-examined that every weak point might be strengthened. He at length was clear in his own conclusions. He now wished the geological world to share with him in the results of his labors.

It was a rare day to Mr. Wing when he secured the promise from Professor J. D. Dana to look into the facts, the basis of his theory. By arrangement a party consisting of Professors Dana, Genth, Prime and Blake came together on July 9, 1875, at Great Barrington, Mass. A friend acquainted with the facts writes: "It was the climax in his life when Mr. Wing met Professor Dana and a party of geologists at Great Barrington, Mass., and there began to unfold his theory, verifying each position as they traveled through the Berkshire hills and Hoosac valley, and made their way north, traversing the entire length of his native State, crossing and recrossing the Green mountain range, by which time his theory had given place to a deep conviction that it was correct. To Mr. Wing this, without doubt, was a moment of great triumph, when the great importance of his contribution to science was thus recognized by the highest authority in America—perhaps the highest in the world."

It is not to be asserted that all obscurities of the region, such as the relations of the lower to the upper Potsdam, the slates at the middle and southern part of the State, the exact age of the most disturbed and metamorphosed strata near the quartzyte, have been fully removed. But in the main what was to be done had been done, and Mr. Wing made good his early assertion,

"That all the rocks in Addison, Rutland and Bennington counties between the great break on the west and the quartzyte on the east were Lower Silurian." The minor facts he could put over for later time, or leave indeed to others who should catch enthusiasm from the work and the success of the master.

It would have been fortunate for science if Mr. Wing could have written out his observations and discoveries. This work he fully intended to do. But he found so much in the field that, as he thought still demanded his attention, the writing was put off. He was ever finding his delight, as well as his reward, in his discoveries; so he neared his bound without having received personally the appreciative acknowledgment his fellow-workers would have gladly accorded him.

The work in the field of the season of 1875 had been severe and exhausting to him, now advancing in age, and he retired to Whiting, Vt., to accept the ministries of a sister and her family. Here this stalwart man, with large frame and great heart, with the broad intellectual range of the mature man, and yet with the simplicity of a child, of great good nature and incapable of resentment, overflowing with enthusiasm and kindling like enthusiasm in others, came to take a needed rest.

Undiscovered truths of his loved science were beckoning him on. But there were other discoveries and other beckonings. A fever set in; his peaceful death came too soon for science, for on January 19, 1876, he made the great discovery.

As before intimated there is no bibliography. And yet his line has gone out into all the recent literature of the rocks of his region. Probably a part of Mr. Wing's work has been lost beyond recall; but from field notes, letters, and incomplete papers, these latter evidently designed to be elaborated for publication, the greater part through Prof. James D. Dana's sympathetic labor has been recovered.

This writing gives but an inadequate idea of the real work of Mr. Wing, and so the writer most earnestly requests the reader to turn to an article in the *American Journal of Science*, Series III, Vol. XIII, page 332 and subsequent papers, that he may get a more nearly correct estimate of this work and its influence.

Fragments of significant paragraphs from Professor Dana's article read:

"Mr. Wing, by the use of his spare time amid the duties of teaching, accomplished vastly more for the elucidation of the age of the Vermont rocks than had been done by the Vermont Geological Survey. * * * * Mr. Wing's discoveries shed light not on these rocks alone" (Eolian limestone and adjoining formations), "but also on the general geology of New England and eastern North America."

But the whole article and related ones should be read, for with this incomplete sketch in hand one gets but a glimpse of Mr. Wing's real work. Yet, with even this, the reader may recognize something of the obligations science is under to one who with his surroundings did his best for geology and did so well. Wherever his careful, helpful, self-denying researches are known there an appreciative recognition of Mr. Wing's contributions to science is sure to be accorded.

REPORT.

The present report is the third issued by the writer. The first and second were largely devoted to the three great quarrying industries of the State, marble, granite and slate, and those especially interested in these industries are referred to the reports of 1898 and 1900 for many details concerning methods of quarrying, character of deposits, etc., which are there presented.

Again, as in former reports, I am obliged to offer somewhat incomplete statistics because those to whom blanks have been sent have failed to reply. Most of the important companies have responded fully to requests for information as to their business, but there are numerous small ones which have sent no replies, and these, taken together, affect the sum total to an appreciable degree. On this account it is very probable that the whole production of the quarries and mines of Vermont is considerably larger than that which I have here given.

I doubt if many of our citizens realize how large a revenue is annually brought into the State from the sales of stone. These sales are rapidly increasing and consequently the importance of the industry which makes them possible is growing greater, and therefore it seems quite certain that great as has been the past the future is to be much greater.

As nearly as I can estimate, there are at present not less than ten millions of dollars invested in our quarries and mines, not less than eight thousand men employed as workmen in them; these men with their families representing a population of twenty-five thousand persons. The product of these industries during the last two years, 1901-2, has been not less than twelve millions of dollars.

During the decade between 1890 and 1900 the total income to the State from quarries and mines was not far from forty millions of dollars. This, it should be remembered, is largely net gain, for it has come from the sale of material which, in its natural condition, had no value, and the removal of this material from the State has in nowise impoverished it. Somewhat more of detail will be given in the following pages, but enough has been said to show that the mineral interests of Vermont are sufficiently large to demand attention and such further encouragement as may be possible.

For convenience, what is to be said concerning the mineral industries of the State will be grouped under several heads, viz: Metallic Products, Useful Minerals, Building and Ornamental Stone.

METALLIC PRODUCTS.

GOLD.—Mining for this has been often attempted in this State and sometimes successfully, but far more often at a total loss, and I suppose that this experience will be repeated for a long time to come. There are evidently now living in the State men who are ready to be led astray by men who care more to exploit some bit of property or some pet idea than to know and make known the truth. There are those who, having seen quartz ledges in Colorado or elsewhere which bore gold in paying quantities, thoughtlessly infer that a ledge in Vermont which appears to be the same must also bear gold and contain a fortune for anyone who will work the rock. Such a conclusion is wholly without foundation and wholly misleading, and the advice of such persons has often cost those who followed it both money and labor, the only return for which has been valuable experience. It is most true that all is not gold that looks like gold, and it is also true, unfortunately perhaps, that many of our Vermont rocks contain minerals which resemble gold, but which are valueless. It is also true that many of our Vermont rocks contain a small amount of gold, and this is unfortunate so long as the amount is small, for no mining trap for catching the unwary is more dangerous or more enticing than a gold mine which pays a little, but not enough to meet expenses.

Hence it is very important for those not experts in the matter that they secure the advice of some competent and disinterested person before spending labor or money in developing any mineral outcrop which may have been discovered. It may not be out of place to state that it is one of the prescribed duties of the State Geologist to advise citizens of the State in such matters without expense, so that there is little need that anyone go to work unadvisedly.

There are three minerals very frequently found in our rocks which more or less closely resemble gold, and, as numerous specimens sent for examination show, these have deceived many who have come upon them. One of these, *iron pyrites*, sometimes called fool's gold, though many who were far from being worthy of such a title have been misled by it, is yellow and shining; but it is brighter and much harder than gold and when found in crystals, as is often the case, it is in cubes.

Similar, but usually of a deeper shade of yellow and not so hard, is *copper pyrites*. This is also harder and brighter than gold, which is usually not very bright—that is, it is not glistening, but a dull yellow, and is soft like lead. The third mineral, and one which has been especially noticed during the past year, is *yellow mica*. Small scales of this mineral are often found scattered through granite, gneiss, or similar rock, or in the sand which comes from the disintegration of such rock, and it is not strange that it should be mistaken for gold dust. I have had many specimens of this yellow mica sent for assay during the past six months, and a chemist in Boston wrote me not long since that he had received numerous samples of it from Vermont parties. It is needless to say that money spent in paying for assays of mica is wholly thrown away.

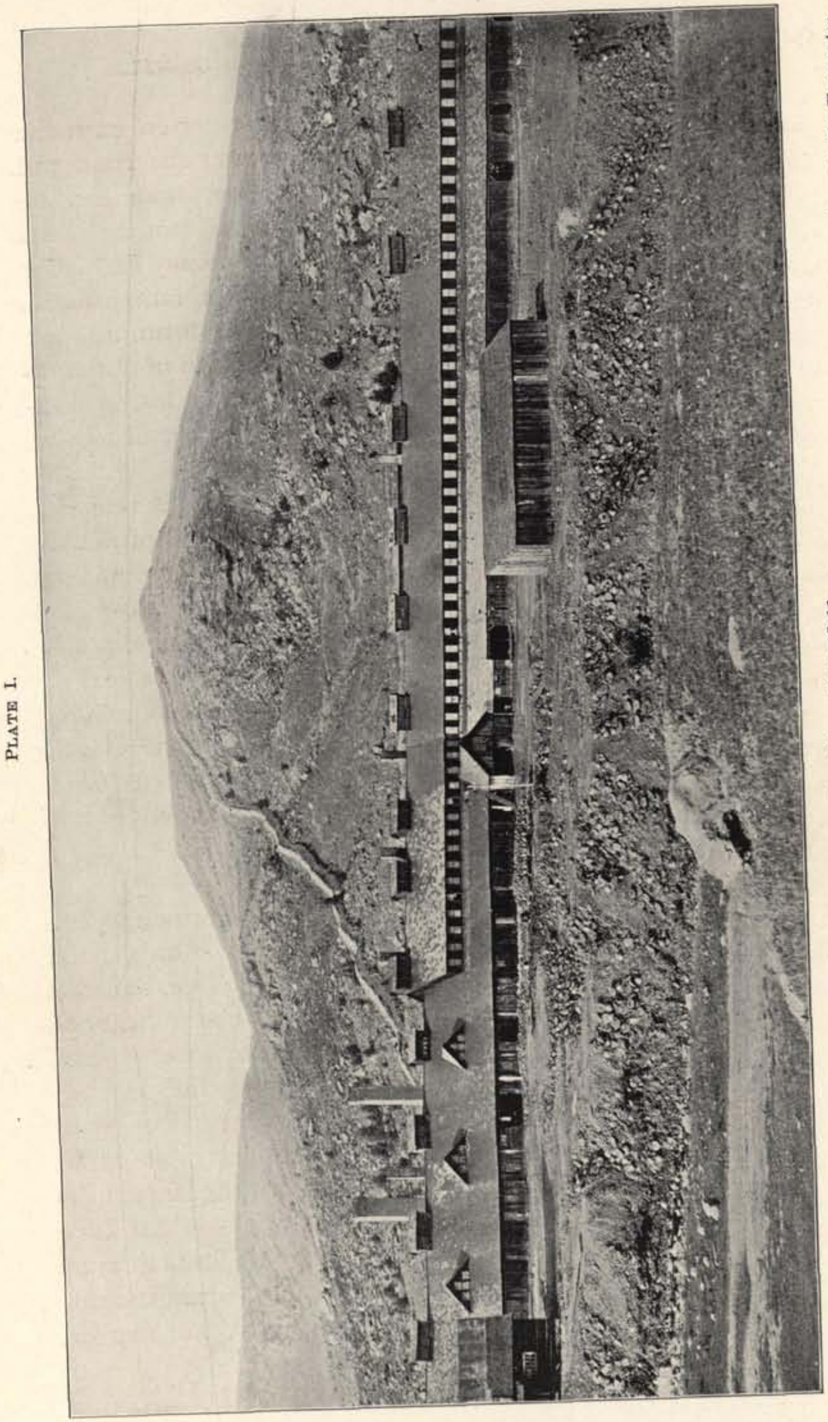
The lesson to be learned from all this is that it is never wise to put time, money, or labor into any mining scheme carelessly or hastily or without competent and disinterested advice. There is gold in Vermont. It is widely distributed, but it is, so far as I know, always in so small amount that the cost of collecting it is far greater than the value of the gold obtained.

I believe that there is far more gold to be gotten from the crops which may be raised on Vermont farms, uncertain and discouraging as farming sometimes may be, than can be pounded out of our ledges of quartz or washed from the sands of our streams. If a little of the enthusiasm, money and labor which has in some parts of the State been put into fruitless search for gold had gone into farm improvement during the last fifty years, Vermont would be richer to-day. Even in Colorado or California or elsewhere, gold mining is often a losing business and, while one mine here or there may pay enormously, many more do not.

I hope that no one will misunderstand the above remarks. It is not at all my intention to discourage any form of mining which can in any way help in the development of the mineral wealth of the State. On the contrary, I should be most glad to help any citizen to find a really paying deposit of gold or any other metal. But the chances in most if not all parts of Vermont are so overwhelmingly against success in gold mining that it is only plain duty to hang out the danger signal in order that money may not be put into mines from which it can never be taken out. So far as I am aware active gold mining is now carried on in only two localities, Bridgewater and Readsboro, but thus far with no important results.

COPPER.—The only metal at present mined in Vermont, aside from the little gold mining, is copper. This is the only metal which has ever brought much revenue into the State, and this only for a short time apparently, though the present indications are good for future business in two at least of our localities and very likely more. There is no doubt at all as to the very extensive deposits of copper ore in eastern Vermont. The quantity is very large, but the quality is not as good as could be desired, yet it would seem quite possible to work the larger beds at a profit so long as copper sells for the prices which have ruled during the last three or four years. The Elizabeth mine at South Strafford has been worked in one way or another for more than a century. In the early days copperas, not copper,

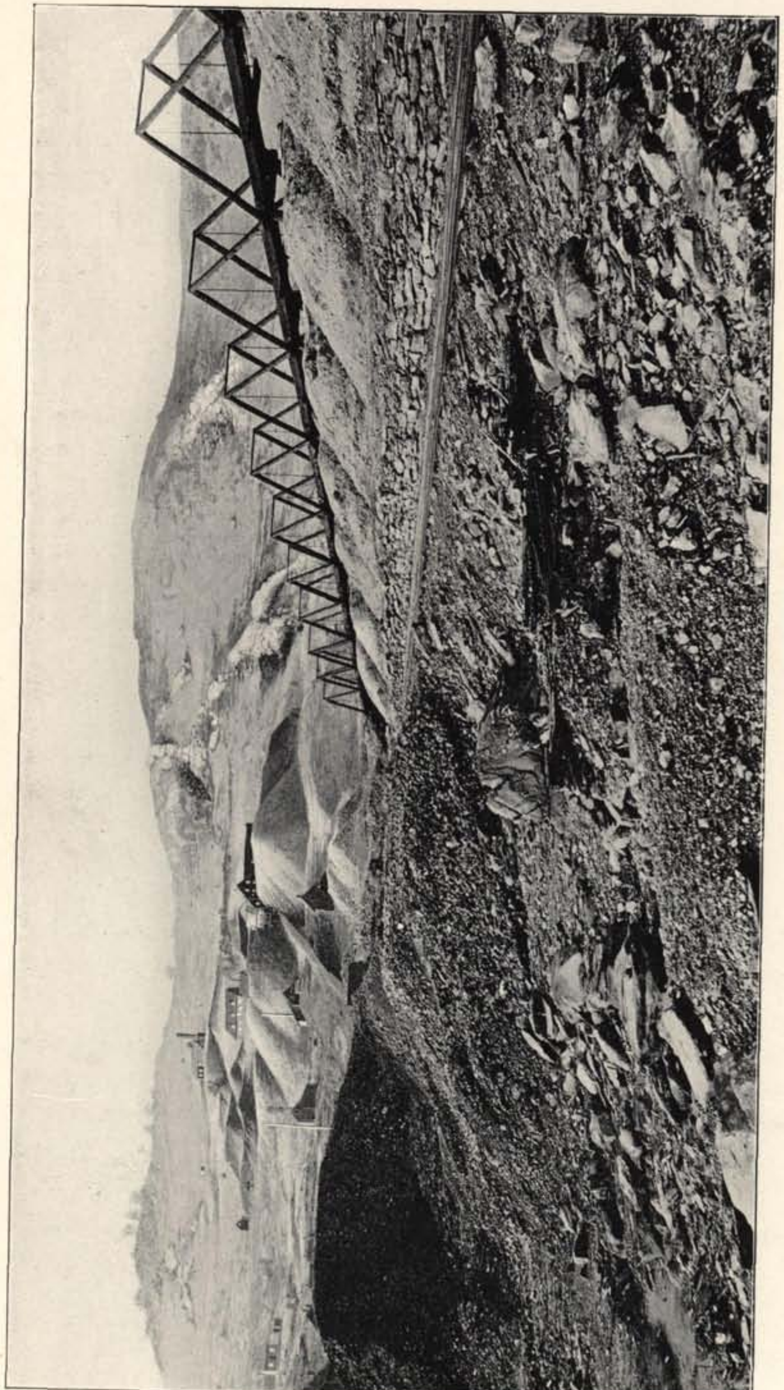
PLATE I.



Ely Mine, Copperfield.

By courtesy of *The Vermonter*.

PLATE II.



Dump Piles, Ely Mine, Copperfield.

By courtesy of *The Vermonter.*

was sought as a final product, but for years the ore, which, like almost all our Vermont copper ore, is chalcopyrite mixed with pyrite—that is, a mixture of copper pyrites and iron pyrites—containing usually only a small per cent, 2 to 10, of copper, has been mined only for copper, and this mine now has a furnace for reducing the ore to matte which contains a high percentage of pure copper, and during the year 1901, three hundred tons of matte, averaging 98½ per cent of copper were produced. The entire output of this mine for 1901 was about 25,000 tons of ore. Practically all the copper produced in Vermont for a number of years has come from this mine. The ore body here is very large and very favorably located for successful operation.

The old Ely-Goddard mine at Copperfield, of which Plate I gives a general view, which has for some years been idle and falling to ruin, was bought a couple of years ago by Mr. George Westinghouse, and since that time a large force of men have been busy putting it into working order.

Plate II shows another portion of this mine and especially the dump heaps.

At several other localities in the State more or less work has been expended in developing copper ore deposits, but none of these has as yet produced any metal.

USEFUL MINERALS.

SOAPSTONE.—There is some quarrying done in a few of the soapstone deposits, but so far as I have been able to ascertain only a small quantity of the material has been sold.

TALC.—This mineral is found in numerous localities in the State and at some of them it occurs in large quantity. This is especially true of the beds at Stockbridge and Moretown.

MICA.—This mineral, while it is found in small flakes all over the State, does not occur in any quantity except in one locality, at Sherburne. This deposit, when I last saw it, promised well. As very few beds of usable mica have been found anywhere, even a moderately small bed of it may be valuable.

Plates I and II by courtesy of *The Vermonter.*

Asbestos.—There are two varieties of this mineral which are used commercially, both of which have been found in several localities in the State. One variety, often called tremolite, is a silicate of calcium and magnesium. This variety is often snowy white, but is likely to be brittle and is less useful than the other, which is the more common asbestos of trade. This latter is really a fibrous serpentine, a hydrous silicate of magnesium, called chrysotile. It is this chrysotile which is found in the localities where most attention has been given to the mineral.

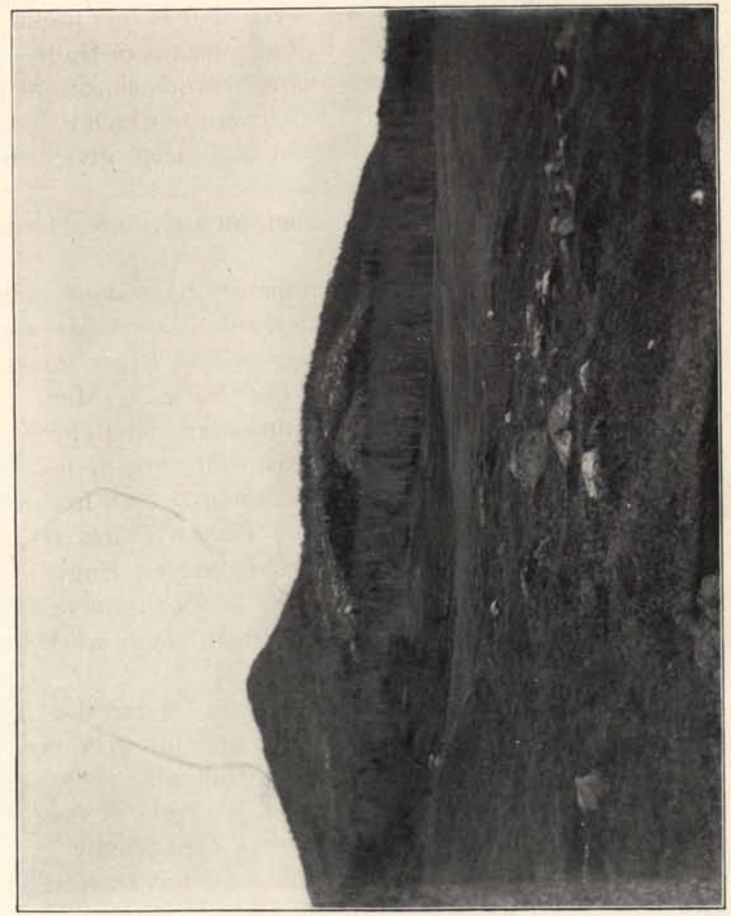
The principal deposits are in Eden, on Belvidere Mountain, in Lowell and in South Duxbury.

On Belvidere Mountain five companies have done more or less work. These are; The New England Asbestos Mining and Milling Company, with headquarters at Fall River, Mass., on the south side of the mountain; The National Mining and Development Company, on the southeastern side; The Tucker Asbestos Company, on the northeast side, and a few miles northeast The Vermont Asbestos Company, which has opened a ledge in Lowell, and recently the United States Asbestos Company have opened the ledge east of the New England, and still further east the Lamoille Asbestos Company have bought the mining right. The last two expect to begin work in the spring.

The New England Company has done by far the largest amount of work, and erected a large mill for grinding, etc. Plate III gives a view of Belvidere Mountain, showing the southern side. The large mass seen at the right of the mountain, forming a sort of shoulder, is composed wholly, at least so far as I could discover, of serpentine, which is traversed here and there, and often abundantly, by veins of chrysotile. This ridge is about 100 feet above the valley at its base. The highest part of the mountain, that which is at the left of the illustration, is not serpentine, but a great mass of hornblende schist.

Professor J. F. Kemp, while working with the United States

Plate III.



Belvidere Mountain from the South.

Geological Survey, visited the locality in 1901, and his report is published in Mineral Resources of the United States. From this report the following is taken:

"Just to the south of the excavation made by the National Asbestos Company an important fault is visible, which strikes into the mountain in a direction 15° west of north, according to magnetic compass, but since local attraction sometimes appears in this region, the observation may not be exact. At all events, the fault brings the hornblendic or chloritic schist abruptly against the serpentine, and cuts off the latter from extending farther to the west. Several feet of fault breccia mark the location of the fault. The serpentine belt appears to be a broad one, but its approximate width can not be readily stated, because it is concealed by forests and because the writer's observations were of necessity made without a map. It is evident that the location of the New England and the National companies is on the northern edge of the serpentine, while the prospects of Mr. Tucker are on the eastern edge, and much lower down. The New England and National exposures are fairly near to the outcrops of the hornblende schist forming the mountain on the north.

"In all the exposures where the asbestos appears the serpentine forms precipitous cliffs and the excavations have been made in the face of these escarpments. For a long time, therefore, the rock can be blown out from open cuts which will be above the general surface of the ground. In the openings made by Mr. Tucker near Tucker's Mill the conditions are very similar. A hillock or shoulder of serpentine projects from the mountain side, and is bounded by gulches on the west, south and east. The openings near the town of Lowell are likewise situated in a ridge of serpentine, and have been driven in on both sides and from the northern end.

"*The character of the asbestos.*—The asbestos occurs in two distinct and contrasted varieties. In one case it forms veins which ramify in every direction through the serpentine. The asbestos fibers are perpendicular or at a high angle to the walls, and vary from a maximum length, as at present exposed, of three-fourths of an inch down to not more than one-sixteenth of an inch. The variety is similar in all respects to the Canadian product, but it is met only in the prospects owned by Mr. Tucker at Tucker's Mill and near Lowell. The second variety of asbestos is what, for lack of a better name, I will call 'slip-fiber,' because it occurs upon the slickensided surfaces that are common to this exposure of serpentine just as to all others the world over. These fibers form layers of varying thickness, seldom more than a quarter of an inch, but as they run parallel to the slickensided surfaces they may themselves be of various lengths, from a fraction of an inch up to 3 or 4 inches. The fiber is coarser than that of the veins, and will not furnish so good a grade. At the same time it occurs in larger quantity. This is the variety of fiber which will be produced by the New England and the National companies. It also appears in a minor degree in the other openings.

"There is little doubt that the region will become commercially productive, and that very considerable amounts of asbestos will be contributed by it to the markets. It is possible that in time larger veins may be discovered which will give the first grade, but at present all estimations of value should be based upon a product of second and third grade. Under present conditions there seems to be an excellent opportunity for these to prove remunerative. The serpentine belts, as shown by the geological survey of Vermont, run for great distances to the north, and while it is impossible at this time to report other definite discoveries, the area within which the geological formations are favorable for the occurrence of asbestos appears to be considerable. At the same time, the existence of serpentine does not necessarily imply the presence of asbestos. Even in the belt on Belvidere Mountain the fiber is sharply limited to restricted localities. Although the serpentine has been somewhat carefully searched already, and was in large part traversed by the writer, in company with Mr. Tucker, yet no other exposures were observed which appeared to be anything like as favorable as the ones which have been opened. In many ledges no fiber appeared at all."

While the existence of asbestos on and near Belvidere Mountain has long been known, it was not until in 1899, when Mr. Melvin E. Tucker, who has extensive lumber interest in the region, gave his attention to the development of the mineral, that the extent and value of the asbestos bearing serpentine was realized. I have carefully examined the serpentine shoulder of the mountain, and I think that the asbestos is more widely distributed than would be indicated by Professor Kemp's last paragraph.

In a report of one of the meetings of the New York Academy of Sciences, October 21, 1901,* Professor Kemp is quoted as saying: "The serpentine seems to have been derived from enstatite, diallage and probably olivine, since unaltered nuclei of these minerals are found in it. * * * It is difficult with the data in hand, * * * to trace the geological history of the serpentine, but it must have been originally either an igneous pyroxenite or peridotite or else a richly magnesian siliceous limestone. There are such slight traces of calcium-bearing minerals, however, that the former supposition has greater weight. The hornblende-schist consists in largest part of common green hornblende, but one may also observe epidote, zoisite and some minor accessories."

The South Duxbury locality is also in many respects very promising. The asbestos here is of the same chrysotile variety as that at Belvidere Mountain. So far as I could judge from surface indications and an examination of the few places where small blasts have been made, the quality is quite as good, and I should think the chance of obtaining long fiber better.

We find here a serpentine ledge which extends from South Duxbury southward over the line into Moretown. The general trend of the ridge is nearly north and south, being a little east of south at the south end. I should estimate the length of the ridge at about two hundred rods, and its width at an average

* Science, Vol. XIV, p. 773.

of twenty rods. At the highest portion it is about two hundred and fifty feet above the main road which passes Mr. Somerville's house. The outcrop occurs on the farm of Mr. Somerville and that of Mr. Bruce, which adjoins it on the south. There is some talcose schist in the ledge, but by far the greater part is asbestos-bearing serpentine.

Talc is also found on both farms, and on the Bruce property there is a bed of very good steatite or soapstone.

BUILDING AND ORNAMENTAL STONE.

MARBLE.—As is well known, the great mineral industries of Vermont are found in the quarries. Although one of the smallest of the States, Vermont is second only to Pennsylvania in the value of rock products sold. According to the latest returns, the total value of the building and ornamental stone sold in Vermont during 1901 amounted to five and a half millions of dollars and the amount for the present year will undoubtedly be more.

Vermont marble, granite and slate are sold not only in America, but are sent to the most distant parts of the world, so that there is probably not a civilized country in which Vermont stone can not be found.

From the earliest days in the settlement of the country Vermont has been pre-eminent for the quantity, quality and beauty of the marble produced from the ledges of the State, and the fame of Vermont marble is now greater than ever. To meet the growing demand new companies have been formed of late, and the future will undoubtedly be greater than the past. At present not less than $8,000,000 in capital is invested in the marble business in Vermont. Over 3,000 men are in the employ of the companies, and the sales for 1901 were $2,753,583, and as several large companies have not yet begun to put marble on the market, but will do so soon, the sales for 1902 will probably be not less than $3,000,000.

Some fourteen or fifteen States are now producing and selling marble, but none of them can approach Vermont in the

quality of the product, so that more than five-sixths of the finer grades of marble, such as is alone suitable for ornamental and monumental work, comes from this little State.

Since the account of the marble industry given in the last report was published, there has been a marked increase in the production and sale of marble, and several new companies have been formed, largely by the consolidation of those already existing.

It is unnecessary to say much concerning a company so long known and so highly esteemed as the Vermont Marble Company. This company, which is probably the largest marble concern in the world, has increased its business and acquired new property.

Early in 1901 a new and strong company with a capital of $1,000,000, known as the Rutland-Florence Marble Company, was formed.

This new company bought the quarries and property of the True Blue, Beldens Falls and several other companies. An article in the Rutland Herald thus describes the property:

"It includes 500 acres at Whipple Hollow, which was the original True Blue property, and property at Florence, in Pittsford, consisting of the Central Vermont quarry, the Tennien farm, the Newbury estate and what is known as the Hall lot, making a total of 800 acres, running along a ledge of marble about a mile and a quarter long. This notably rich marble deposit lies in the west part of the town of Pittsford, and is connected with the Florence station on the Rutland railroad by a branch spur two miles long. The transfer, which was made at the Bardwell house last evening, also carries with it the Corona marble mill at Brandon.

"The marble deposit at Florence, we are informed by experts, contains about a dozen varieties of marble well known to the trade, running from deeply clouded stone to pure statuary marble. It is thought by those who have examined the property that it contains the largest bed of absolutely white marble that has yet been discovered in this country. Its tension and toughness are much above that of the Italian marble, and it will thus yield itself more completely to the purposes of sculpture and decoration.

"The Beldens Falls property, which changed hands at the sale, comprises 300 acres of marble land in the town of Pittsford, with three quarries, a mile and a quarter of railway, several farms and a marble mill at Beldens Falls. The marble land extends from the north line of the True Blue property nearly to the Hollister quarry. The railway, in connection with the True Blue track, makes a line two and one-half miles long, commencing at the Rutland railroad main line and extending back westerly into the hills to what is known as the Florentine quarry. The marble found on the property is blue, white and variegated.

"The two purchases make a total of 1,200 acres of marble land now in the hands of Vermont's new company, the Rutland-Florence.

"In order to understand the significance of this, the largest series of purchases of marble deposits in Vermont for many years, it will help the reader to understand the geology of the calcareous formations in these parts. There is a 'hog back,' or low range of hills, beginning south of the highway leading from Rutland to West Rutland. This hog back extends about eight miles north to the town of Pittsford. This range of hills contains about all of the commercially valuable monumental stone produced in Vermont, except the outcropping owned by the Brandon Italian Company in the town of Brandon.

"On the southwest side of the hog back is the famous 'Rutland vein,' located in West Rutland. This vein is about a third of a mile long. Two miles north at the base of a range of hills are found the Esperanza and True Blue outcroppings. No other outcropping of marble has been found on this range until we reach the small opening made by the late John N. Baxter. From this point going north it is evident that the 'West Rutland vein' again appears at the surface for about two miles in Pittsford, where the recent purchases were made.

"Returning to the south end of this range of hills we go north about three miles before any marble of consequence is exposed. There we find the Columbian Marble Quarrying Company's outcropping, which is the extreme southern exposure of what is now known in Pittsford as the 'Florence vein.' Perhaps a hundred rods to the north of the Columbian exposure and slightly to the east, geologically, the so-called 'Sutherland Falls vein' makes its appearance, which vein has been worked for some 70 years. A short distance north of these quarries practically all evidence of marble is obliterated, except here and there where irregular exposures occur.

"Continuing north one or more miles all three of these famous veins appear to have converged to the extent that all are found within a distance of a comparatively few feet from outside to outside, and continue side by side for at least two miles to the Hollister quarry, near the Florence railroad station.

"At West Rutland the 'Rutland vein' inclines, on an average, about at an angle of 40 degrees to the east. Across the hill, some three miles away, the Columbian quarry strata inclines to the east, while a few miles north the Sutherland Falls quarry inclines to the west. But in Pittsford the entire combination of veins stands absolutely vertical, as is evidenced by the Hollister quarry, which is on the 'Florence vein,' and has been worked to a depth of 200 feet. The properties combined by the Rutland-Florence Company cover practically all of this two miles of vertical strata, and include the Florentine quarry, which corresponds to the Esperanza and True Blue properties in West Rutland, lying west of the 'Rutland vein.'"

Other marble companies are also increasing their facilities for supplying the demands of the trade. The Brandon Italian Company, with quarries at Brandon, have put up and are operating large mills at Middlebury, where they have the water-power of Otter creek. At Dorset the Norcross and West Company have bought and put into extensive operation one of the formerly worked but long idle quarries. Mr. S. H. West writes of this that "The quarry we are now operating is about five hundred feet in length by one hundred in width and twenty-five feet in depth. We are working ten channelers and six gadders. We are quarrying 40,000 feet per month. We have the contract for furnishing the marble for the new library in New York, which calls for 500,000 cubic feet of marble." This company have 250 acres of marble property and is doing "considerable prospecting by taking cores from different localities." It also has large mills for dressing marble.

There are several other smaller but not unimportant marble companies in the State. The demand for marble as a building stone appears to be rapidly and largely increasing.

SLATE.—The slate industry of this State was so fully considered in the last Report* that it will not seem invidious discrimination if little space be given to it here. For full statements as to the quarries, methods of quarrying, geology of the slate belt, etc., the reader is referred to the Report of 1899-1900.

For a few years the sales, and consequently the output, of slate in Vermont diminished rather than increased, but for the last few years this condition has been reversed and this year nearly all the companies reporting give very encouraging accounts of active business during the year and excellent prospects for the immediate future. The sales of slate for 1901 were large, amounting to $1,162,191. Besides the vigorous working of most of the quarries in the great slate belt of Rutland county, there has been renewed activity in the Northfield region. There is here a fine series of deposits of black slate which apparently only needs sufficient capital and energy to become very productive. At present there are but two companies engaged in the business. These are the Dole-Brill and the Union Slate companies.

The Northfield slate is a good clear black which does not fade and is of first class quality.

GRANITE.—While, almost since it became a State, Vermont has been famous for its marble, it has been known as a granite producing State only during the last few years, and now it is almost as widely and favorably known through its granite as through its marble, and I do not think that it is too much to say that in quality, if not in quantity, Vermont is excelled by no other State or country in the world. Two other granite producing regions, Maine and Massachusetts, furnish a greater quantity, all grades being considered, but of the finest grades of granite, such as are used in monuments, Vermont last year sold more than twice as much as any other State. The greater quantity sold elsewhere goes into paving stone, foundations, etc., for which uses Vermont sells comparatively little, while most of our granite goes into finer work. Vermont also sells more granite in the rough to be worked elsewhere than does any other State. When we consider the fact that our granite deposits are scarcely touched as yet, only a very small part of them having been quarried at all, and that the supply is thus practically unlimited and therefore inexhaustible, and that the demand for Vermont granite is rapidly increasing, we easily understand that a great future awaits this industry. The growth of the business in Barre shows what may happen elsewhere and in many localities, for granite is widely distributed over the State, from Derby to Dummerston, and while much of it is unsalable, much is of the very best quality. No red granite is found in Vermont, but we have all shades of gray and all grades of hardness and texture. The present capital invested and quantity and value of stone produced is very large, but we may confidently expect that it will soon be much larger.

*Report of State Geologist, 1899-1900, pp. 17-30, figures 1-5.

The granite industry is much less concentrated in this State than either the marble or slate, and I have found it difficult to get at exact statements respecting it. It appears certain that not less than $1,000,000 is invested in the business. Not less than 3,000 men are employed in quarries and cutting works, and the output in 1901, as given by the United States Geological Survey Report, was $124,828. Nearly all the firms report increasing business, some of them that during the present year, 1902, the sales will be double those of any previous year.

Mr. G. I. Finlay of Columbia University has made a special study of the Barre granite region, and it is with great satisfaction that I am able to include Mr. Finlay's valuable paper in this report.

The Granite Area of Barre, Vermont.

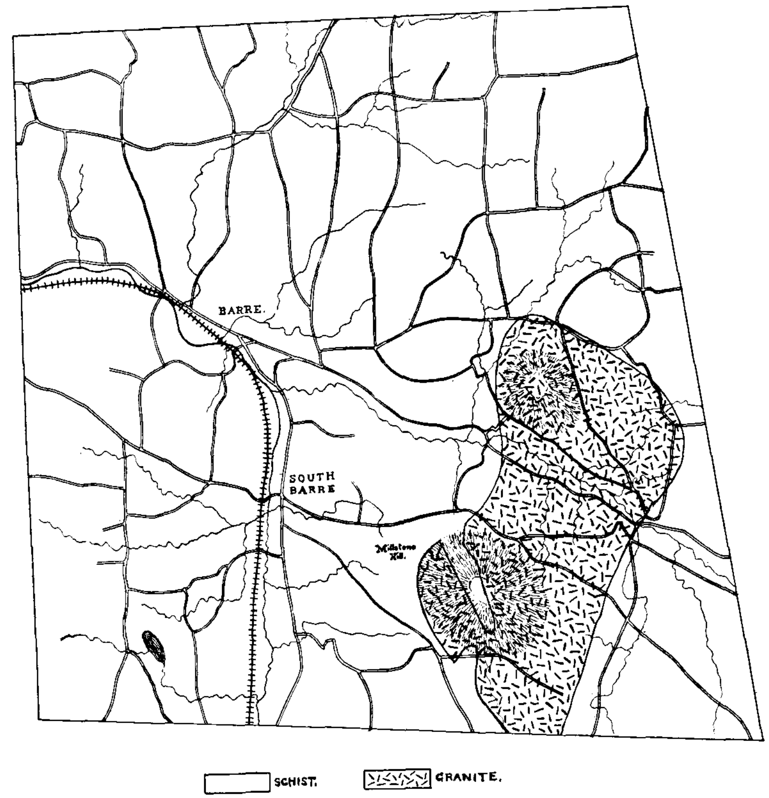
GEORGE I. FINLAY.

The present study was undertaken by the advice of Professor Kemp, of Columbia University, and pursued under his direction. The writer must first acknowledge his great indebtedness to him for his kind assistance and encouragement at every point. The field expenses were borne by the department of geology of Columbia University. To the many gentlemen at Barre, Vt., whose quarries were visited, and to their representatives on the ground, the writer desires to express his sense of their courtesy to him, for at no time in his work did they fail to help him as occasion made possible. To Dr. George H. Perkins, State Geologist of Vermont, public acknowledgment is due for his kindly interest in the present paper, and for his generous aid in its completion.

Topography and surface geology.—The city of Barre is situated nearly in the center of the township of that name in Washington county, Vt. Montpelier is six miles distant to the west in the great central valley of the State. By reference to the sketch map of the township (Plate IV)* it will be seen that the drainage is in general toward the pronounced hollow in which the city lies, and along the valley west of it. The railroad follows this general course. On leaving Barre in any other direction one has to climb steep grades to reach the upland, which is fairly even above the valley bottom. The highest point is at Millstone Hill, four miles southeast of Barre. The country presents an immature stage of dissection, with the lesser valleys invariably narrow and steep sided. The relief is not above four or five hundred feet.

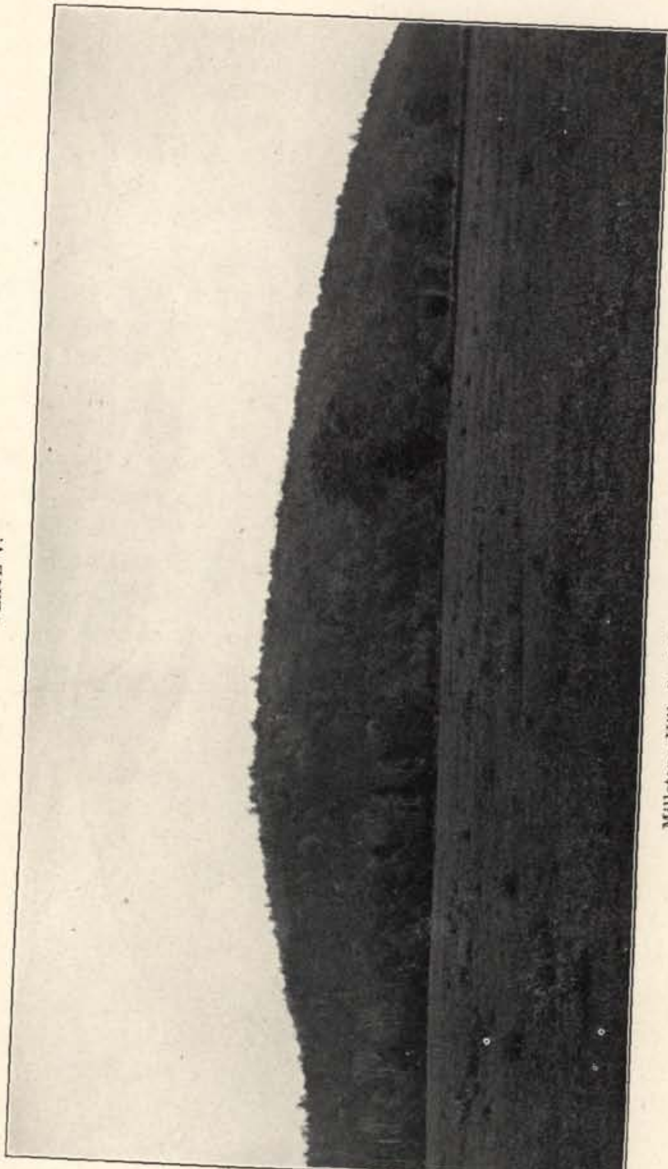
* Scale 1 in–125,000.

PLATE IV.



Sketch Map of Vicinity of Barre, Vt. Scale 1=125,000.

PLATE V.



Millstone Hill, Sand Plain in Foreground, Barre.

The key to this topography is to be found in the disposition of the heavy mantle of glacial drift which lies over the country. Barre is situated in the depression once occupied by a body of standing water in the ice times, and the newer portions of the city are built on the lowest of a series of delta deposits which were then formed. The resulting sand-plains come down to the city from three sides. They are well stratified, and show fore-set and top-set beds of clays and gravels. Coarser layers composed largely of rolled and rounded pieces, often three or four inches in diameter, are occasionally met with. The upland is formed at the level of the upper surface of these sand-plains. The foreground of the view of Millstone Hill, Plate V, represents the top of a sand-plain covering over two square miles, which stretches from beside Millstone Hill toward the city of Barre. The material round the periphery near its head stands at the angle of rest, and this line marks the position of the ice contact. The slope radially outward from the head, for two miles to the north, is very gentle. No characteristic terminal lobes were found. Half a mile to the west of Millstone Hill lies a small esker marking the winding course of the stream which carried down the materials deposited in the sand-plain. The crest line of this esker rises and falls abruptly. The angle of slope on either side is nearly 30°. Just beside Millstone Hill is a second esker, lying almost against its western flanks. Athough of no great length, it possesses unusual interest as meeting the conditions which Woodworth has shown to have made necessary a subglacial course for such streams as would have formed it.* The line of slope on Millstone Hill at this point is even and fairly steep. Had the stream, the position of which is now given by the esker, flowed out in any other way than from under the ice, as, for instance, along an ice walled canyon open to the sky, there must have been opportunity for the ice which rested on the hillside to slide down, until it came fairly against the opposing mass on the western side of the stream course. A canyon in the ice could not have remained

* *Proceedings Boston Society of Natural History*, vol. xxxi, p. 215.

open at this point, therefore, and the stream must have been subglacial.

General geology; Petrography of the schists.—The schistose and slaty members of a series of metamorphic rocks are found over almost the whole of Barre township, underlying the glacial drift, and appearing in frequent outcrops through it. The area occupied by these rocks is indicated by the unshaded portions of the map. They are older than the granite, as being the country rock into which its mass was intruded. They show considerable uniformity in field habit, and in their areal relations. They are prevailingly slate colored or dark gray rocks, generally with a well developed cleavage and the shimmering appearance due to abundant minute flakes of mica. By differences in mineralogical composition an alternation of excessively fine lighter and darker bands is produced. The larger of these differences, between the portions rich in lime and those high in silica, may at times be traced continuously for several hundred yards. They afford the best means for observing the areal relations of the schist. The strike is found to be uniformly northwest and southeast. The dips are high. Very frequently the rocks stand on end. At times they show much contortion by pressure over short distances, as in the railroad cuts to the southwest of the city. Here numerous lenses of quartz are found, which elsewhere in the series are not so well developed. Usually, however, the schists are not greatly disturbed. They present the appearance of metamorphosed sediments, but their sedimentary origin can not be set down as proven. No chemical analyses have been made which might offer the means of deciding between their possible igneous or sedimentary originals. No occurrence of marble is met with in the metamorphic series throughout the area studied. No unaltered sediments were found in it which could be traced continuously over to their metamorphosed representatives. Still in the field the rocks present an appearance as of sedimentary beds, but little disturbed by metamorphism from their original relations, and when seen under the microscope they are found to contain

the minerals which would be furnished by limy shales and impure sandstones. The study of their sections shows that the minerals commonly present are quartz, biotite, calcite, and magnetite. More or less feldspar is usually found. Quartz grains, fractured and angular, and magnetite, with occasional large flakes of biotite, often make up a large portion of a single band. Again a member of the series, two or three feet in thickness, will be found which is very rich in calcite and low in quartz. Magnetite and biotite in greater or less amounts are invariably present.

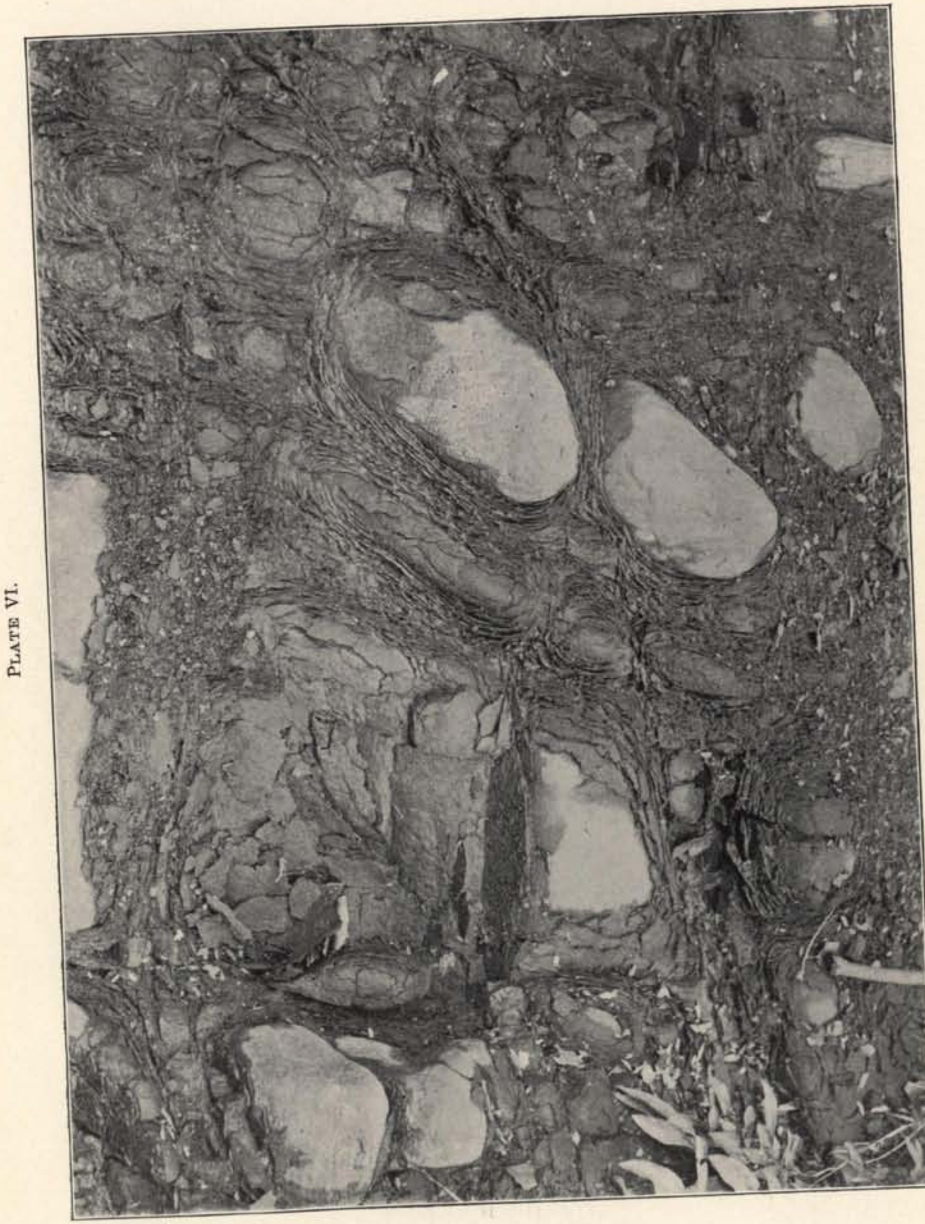
The series of schists is cut by dikes of pegmatite and camptonite. The dikes or veins of pegmatite are in two kinds, those which have the mineralogical composition of granite and those consisting entirely of milky quartz. The former are found near the granite mass, while those in which quartz is the only mineral present occur at a distance of a mile or more from any of its outcrops. They represent, in all probability, the secretion from the parent magma at the most distant points along dikes of pegmatite. One of these quartz dikes, in the western part of the township and southward from Barre, is three feet in width. The most interesting of the normal pegmatites is the dike which occurs in the brook course along the road leading toward East Barre, two miles distant from Barre itself. It is about eight inches wide. The minerals present are feldspar, quartz, muscovite and tourmaline. The walls of the dike are nearly parallel with the beds of enclosing schist, and both are vertical. The incoming of the pegmatitic material has loosened plates of the schist, so that at one end they are still connected with the wall-rock, but are warped back at their distal extremities. They have taken the easy curve which is produced by a knife passing along a block of wood, but not detaching a chip wholly. These partly released and partially included portions of the wall-rock are found extending in either direction along the dike. They are about 18 cm. in length by .5 cm. in thickness. It has been pointed out to the writer by Dr. W. D. Matthew that the mere effects of heat might account for this warping from an original position as part of the wall-rock. No great amount of motion in the pegmatitic material would be needed to detach them altogether. An important dike of camptonite, five feet in width and nearly vertical, is found crossing the schist immediately south of Barre, along the road to the town of South Barre. A view of this dike is given in Plate VI. On weathering it gives rise to the "onion jointing" in such perfect development that often 15 or 16 shells may be seen to have broken away from the fresher core within. In the hand specimen this rock is of a brownish-black color. It is very fine grained. Numerous yellowish crystals of feldspar appear scattered through an unresolvable black ground-mass.

Microscopical study reveals the holo-crystalline character of the rock, and the minerals which compose it are seen to be feldspar, augite, olivine, magnetite, biotite, chlorite, and pyrite.

The feldspar, which is the most abundant mineral in the rock, is in large and small lath-shaped individuals, twinned usually on the Albite and Carlsbad laws simultaneously. Extinctions read from sections of such crystals cut perpendicular to M (010), fix the composition as that of labradorite, Ab_1An_1. The feldspars are older than the ferro-magnesian minerals, so that the tendency to a diabasic structure in the rock is often apparent. Augite occurs in pale green phenocrysts, at times .6 mm. in diameter, and again, in granular form, in a second generation, as a constituent of the ground-mass. Olivine was originally present in the rock, as is indicated by its alteration products, serpentine, chlorite, and earthy aggregates. The characteristic outlines of the mineral, often 1 mm. in length are still preserved. Next to the augite and feldspar, biotite is the most abundant constituent of the ground-mass. It is found in small but very perfect hexagonal plates, and in short rectangular pieces .15 mm. in length. Magnetite in skeleton crystals is abundant, and some pyrite and secondary hematite are present. Secondary chlorite is found throughout the rock in triangular patches filling the spaces between the feldspars.

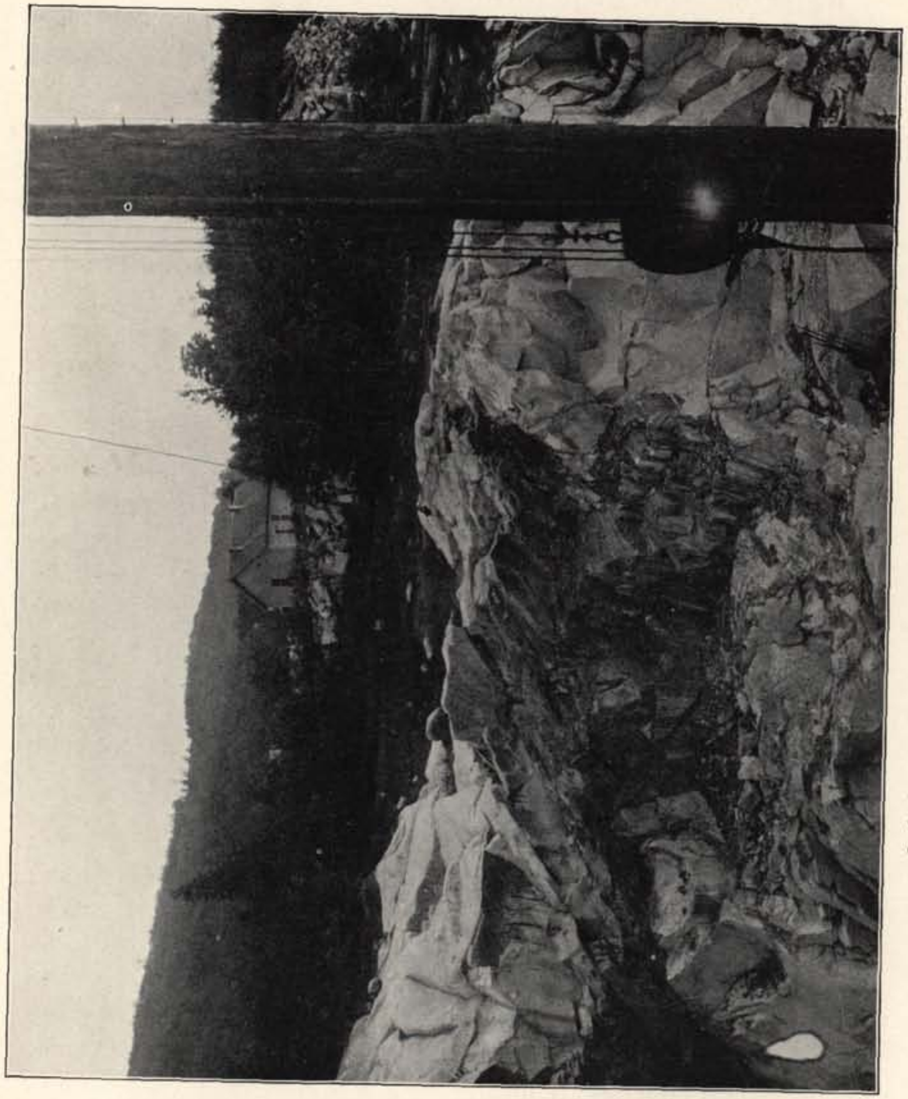
Many portions of the schist, large and small, have been

PLATE VI.



Onion Structure in Camptonite Dike, Produced by Weathering.

PLATE VII.



Inclusion of Gneiss in Granite Quarry Near Millstone Hill, Barre.

caught up by the granite, which is marked on the map by shading in the southeastern part of the township. These masses of the schist now appear as inclusions in the walls of the granite quarries. They are of all sizes from a few inches to thirty feet or more in length. One of the larger included masses is represented in Plate VII. It will be seen by an inspection of the map that a limb of the schist passes almost across Millstone Hill, as if to make two portions of the granite at that point. The outcrop of schist does not continue uninterruptedly over the area represented for that rock, from north to south, although the ledges are continuous over much of it. No granite, however, is found between them, until one comes to the southern border of the hill. Other lesser bands of the country rock, which are too small to be represented on the map, extend into the granite in the same way. It is evident, therefore, that at the time of intrusion of the igneous rock large portions of the schist were carried away, while others were left extending into the granite as broken bars.

The contact effects are everywhere slight. Usually a darkened rim, scarcely over a centimeter in width, marks the indurated metamorphic rock where it stands against the granite. No new minerals are developed, but biotite is here more abundant than throughout the remainder of the schist. In Plate VIII such a contact zone may be seen, extending between the granite on the right hand and the schist on the left.

Description and Petrography of the Granite Area.—Over much of the granite area the drift cover is heavy. The rock obtained on Cobble Hill, a mile and a half to the north of Millstone Hill, is of an inferior grade. Nearly all the more interesting exposures lie in the southern half of the granite area, as represented on the map, and this southern portion yields more than nine-tenths of all the granite produced by Barre township. All the important quarries are located on the eastern or southern slopes of Millstone Hill, or immediately to the south of it. Where the joints are irregular and crowded together "boulder quarries" only can be operated, and the output is of small-sized blocks. The more favorable quarry locations are cut by few joints, and pieces of any desired size can be taken out to the limit of transportation. For many feet below the surface the approximately horizontal joint-planes, roughly parallel with the outlines of the granite mass, give rise to a perfect development of the well-known "onion structure" in the quarries. The same tendency may be noted on the ledges in the woods along the western slopes of the hill, where at times four or five successive steps, cut out by sloping joint-planes in the same ledge, may be seen over a little space. The remarkably perfect and even slickensided planes standing at high angles, which are characteristic of granites everywhere, are often seen in these quarries. They are evidently due to pressure, and fall into two systems, nearly at right angles to each other. Surfaces showing well developed feather-fractures where there is no evidence against their being on the natural joint-planes are occasionally found in the quarries, but there is always a good chance of their having been produced artificially. The effects of weathering are not found deep below the surface in the main portions of the granite mass, but thoroughly weathered shear zones of fractured and useless rock are often met. No well marked schistosity, or gneissoid phase of the granite was observed, but the rock is characterized by the distinct grain which is known to the quarrymen as the "rift." This, with the "heave" and "lift," are the three planes of more easy parting at right angles to each other, which define the blocks as they are taken out.

Hand specimens of the granite collected from various points on and about Millstone Hill are widely different in general appearance. They vary little however in the proportions of the constituent minerals. Feldspar, quartz, and mica make up the rock, which is prevailingly medium grained. Its color is gray, or bluish gray. Upon the abundance or scarcity of black mica depend primarily the grades of dark, medium, or light stock known to the trade. Much of the granite on the western and southern slopes of Millstone Hill is relatively so poor in mica

PLATE VIII.

Contact of Granite and Schist, Millstone Hill, Barre, Vt.

as to be quite different in character from the main mass. It is not considered valuable, and but little of it has been quarried. The dark stock, which brings the highest prices, is found over the east-central portions of the hill, and well to the south of it. It tends to become slightly more basic in depth, as well as locally, near the contacts, where large inclusions of the schist are met with. The darker granite is often finer grained than the light and medium grades. It differs from them in the distinct bluish cast which characterizes its feldspars, as well as in its larger content of mica. In the light colored granite the feldspar crystals are seen to be hardly tinged with blue. Basic segregations, known to the quarrymen as "knots," are occasionally found. In them the mica is extraordinarily abundant, and quartz is rare, as compared with the feldspar. The "knots" are seldom above six inches in diameter. They are sporadic in their distribution, so that no portions of the rock can be quarried which have any value from their occurrence in it. Miarolitic veins and pockets occur at many points. The quarry operated by Messrs. Lamson and Wells, some distance to the south of Millstone Hill, contains a very coarse grained miarolitic seam which runs across its western face. A small pocket of similar character exposed in Messrs. Jones Brothers' quarry is of especial interest, as showing the same coarse grained variety of the rock, in association with the rare porphyritic facies of the granite magma where a ground-mass is developed. A brief description of these variations from the normal quality of the stone will be given later.

Examination with a hand lens will very seldom make plain twinning striae on the cleavage faces of the feldspars. Carlsbad twins are seen to be very rare. The quartz is dull in appearance. Biotite is found in small black or rusty brown patches, and silvery scales of muscovite may often be noted. Pyrite is almost never seen.

Microscopical study reveals abundant microcline, quartz and biotite, with lesser amounts of plagioclase and muscovite, as the essential constituents of the rock. Some orthoclase is also present. Apatite, magnetite, titanite, tourmaline, and epidote are the remaining accessories. Calcite, part of the muscovite, and chlorite are of secondary origin.

The microcline of this rock commonly shows the delicate polysynthetic twinning which generally characterizes the mineral. Its substance is usually quite fresh and glassy, but it is at times slightly altered and clouded at the center. Minute lenses and spindle shaped bodies of plagioclase are intergrown with the microcline. Their index of refraction is higher than that of their host, and from the extinction angles they are believed to be oligoclase.

The quartz is perfectly clear and glassy as a rule, but at times the mineral is clouded over with gas inclusions and cavities containing bubbles. A rude approximation to crystal outlines against anhedra of microcline is occasionally noted, but generally the outlines of the mineral are very irregular. The inclusions are microcline, magnetite, and the long, very perfect needles which have been referred to rutile. These occur with a definite orientation in three planes, making angles of 60° with each other. The pronounced cracks which are seen to cross from one crystal to its neighbor, without interruption, are an indication of pressure phenomena in the magma after its consolidation. These cracks are notable as containing microscopic dendritic growths, which are analagous to the arborescent forms of MnO_2, and possibly identical with them.

Biotite is present in brown patches. It sometimes shows a metallic luster. The lamellae are often bent or broken. The absorption is strong. Rays vibrating at right angles to the cleavage are brownish yellow. The figure is nearly that of a uniaxial substance. The effects of weathering are apparent in the chloritized lamellae, and in the rims of chlorite which surround the mineral.

Plagioclase feldspar is very generally present but only in small amounts. It is invariably finely twinned on the Albite law, while lamellae, due to Pericline twinning, may often be observed. Carlsbad twins are extremely rare. In the absence

of any section perpendicular to M (010) which might show Albite lamellae in the two halves of a Carlsbad twin, the optical determination as oligoclase, with the composition Ab_3An_1, rests upon the observed symmetrical extinction angles of 6° or less. The plagioclase is much more deeply weathered than the microcline, and its substance is commonly clouded over by earthy alteration products. The twinning lamellae often show the effects of pressure, as being noticeably bent. Micrographic intergrowths with little club-shaped pieces of quartz occur, all the quartz crystals extinguishing simultaneously.

Muscovite is an important constituent of the rock. It may even be more abundant than the biotite, with which it is so generally associated. When originally present it occurs in broad flakes. Much of it is, however, secondary, as resulting from the weathering of the feldspar. In such cases it is in small, irregular patches and scaly aggregates. The muscovite shows faint absorption. The axial angle is wide.

Apatite is found sparingly in short, blunt prisms, which give the usual six-sided basal sections. Magnetite occurs, but not abundantly, in very irregular grains. Pieces .2 mm. across are seldom noted. Titanite exhibits perfect lozenge-shaped sections .25 mm. in diameter. It is one of the more rarely found accessory minerals. Tourmaline occurs at one locality. The prismatic crystals of this mineral may be 1 cm. in length. Original epidote in small needles is occasionally met with and minute amounts of secondary calcite are found.

A chemical analysis of the darker granite collected in the area south of Millstone Hill yielded the following percentages:

	I.	II.
SiO_2	69.89	68.55
TiO_2	.....	
Al_2O_3	15.08	16.21
Fe_2O_3	1.04	2.26
FeO	1.46	
MnO	.....	.45

	I.	II.
MgO	.66	1.04
CaO	2.07	2.40
Na_2O	4.73	4.08
K_2O	4.29	4.14
H_2O at 110°	.31	......
H_2O ignit	.23	......
P_2O_5	Trace	......
	99.76	99.13

I. Granite. Barre, Vt. G. I. Finlay anal.

II. "Shap" Granite. England. J. B. Cohen anal. Q. J. G. S. XLVII. 276.

An analysis of the English "Shap" granite, made for H. Harker, is put beside it for reference.

By the aid of the micrometer eye-piece three other varieties of the granite, as noted below, were measured for a quantitative estimate of their mineralogical contents. It is believed that the figures thus obtained, after calculating the percentage by weight for each constituent, are roughly expressive of the range in mineralogical composition throughout the granite mass.

	I.	II.	III.
Microcline	47.9	56.8	38.4
Orthoclase	7.5	2.1	8.9
Plagioclase	15.1	1.3	3.7
Quartz	26.0	28.5	18.4
Biotite	......	10.2	26.1
Muscovite	3.3	.1	.2
Titanite	......	.6	2.6
Magnetite	......	......	1.0
Apatite	......	......	.5
	99.8	99.6	99.8

I. Acid Granite. Southern end of Millstone Hill.

II. Granite. Medium Stock. Eastern slope of Millstone Hill.

III. Basic Segregation. Granite. Northern slope of Millstone Hill.

The most striking variations from the normal quality of the granite throughout its mass are found in rare miarolitic pockets. One of these, which is notable as showing three distinct types of rock side by side over a very small space, is figured in Plate VIII. In the center of the picture, in the upper half of that portion of the granite defined by its contact with the schist on the left, and the vertical crack in dark shadow on the right, a rudely **V**-shaped outline may be seen, delimiting a space of about two square feet. At the top smoky quartz is found. Its presence is significant, since the observation has been made by Dr. A. A. Julien that the occurrence of smoky quartz in the central portions of many pegmatitic veins marks the last stages of vein filling in such cases. At the bottom, in the point of the **V**, the excessively coarse-grained variety of granitic rock, which makes up the miarolitic seam above referred to in Messrs. Lamson and Wells quarry, is developed. The sides of the **V** carry a very fine-grained facies of the granite, lacking in the usual biotite, but abundantly supplied with muscovite. Between the patches of this muscovite-bearing rock on either side, and sharply outlined against them, as showing no gradual changing over to their substance, or into the coarse-grained member in the lowest portion of the **V**, a porphyritic facies of the granitic magma occurs.

In the hand specimen this rock is bluish by reason of the color of its ground-mass. Phenocrysts of white feldspar are far more abundant than those of quartz. Biotite in minute plates, strewn everywhere through the rock, is seen to be the most important dark constituent.

Under the microscope large porphyritic crystals of microcline and quartz, with much less orthoclase and plagioclase, and abundant biotite, appear in a coarse holocrystalline groundmass, composed of quartz and feldspar, in irregular grains. The quartz phenocrysts give at best only a rough approximation, on basal sections, to hexagonal outlines. Microcline usually shows but slight evidences of twinning. Its substance is glassy, rarely kaolinized. Some orthoclase is present in rudely automorphic individuals bounded by prismatic and pinacoidal planes. They are characterized by the development of a zonal structure, with inclusions of the ground-mass stage in the outermost zone. Plagioclase crystals are occasionally noted, not glassy but much weathered. They are rare, however, and small. The biotite does not differ in habit from that mineral in the granite. Irregular grains of titanite and needles of apatite are found.

Touching the above, and at the sides of the **V**, is developed the facies of the rock in which no biotite is present. Hand specimens show silvery scales of muscovite in great abundance, making, with glassy feldspar and quartz, a very fine-grained rock with no ground-mass.

Microscopical study reveals the presence of glassy microcline as the predominant feldspar, with much less of plagioclase and quartz, these last being in nearly equal amounts. A little orthoclase is also present. Muscovite, in large patches and scaly aggregates, is extraordinarily abundant. Magnetite and apatite occur in large grains. Occasionally small pieces of pyrite may be observed.

The extremely coarse-grained facies exhibits only biotite and feldspar to the unaided eye. The biotite is in thin brownish black leaves which are often 2 cm. in diameter. The feldspar is bluish gray. It does not appear to be twinned, and on its flashing cleavage faces no striations can be detected. The single pieces of massive feldspar are often 3 cm. across.

When viewed under the microscope the rock is seen to be made up of microcline and biotite. The feldspar is very generally characterized by the usual delicate twinning lamellae of microcline, and it is intergrown with quartz as in graphic granite. The crystals of quartz are often .8 mm. in length. They present triangular, spike-like, or more complicated forms. They may be readily recognized by their interference colors as compared with those of the feldspar, and they are large enough to answer to tests with convergent light. They extinguish simultaneously. Small crystals of plagioclase are also enclosed

by the microcline. Much chlorite has resulted from the weathered condition of the mica.

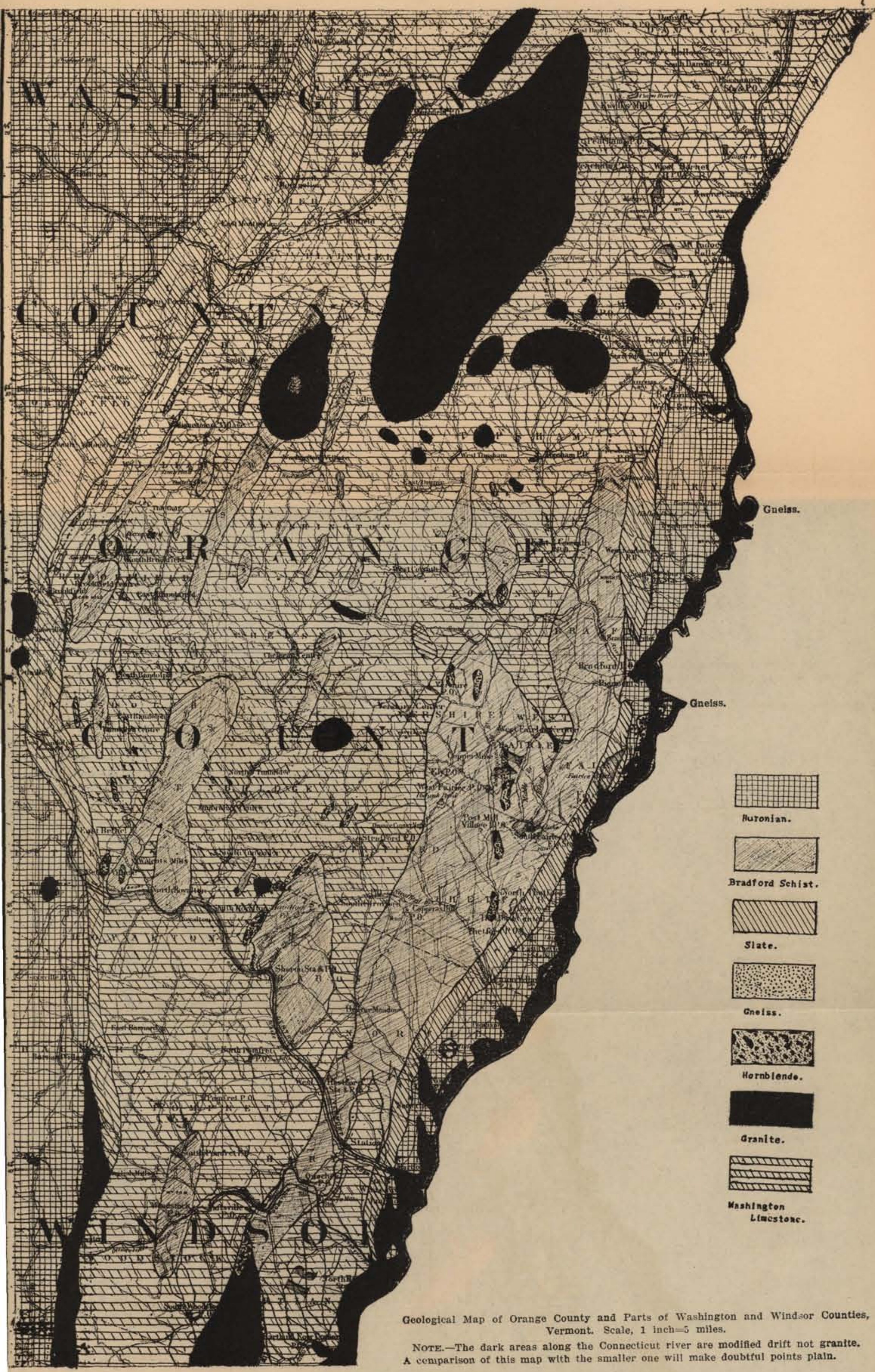
The granite industry at Barre, Vt., is of comparatively recent development. As far back as 1833 blocks of stone were drawn by ox teams to Montpelier to furnish the granite columns of the capitol, but the period of active work on Millstone Hill dates back only a score of years. It was the order for ten million paving blocks for the city of Troy which first stimulated activity on the hill. Now 2,000 quarrymen are engaged to work there. The quarrying operations have been conducted with extraordinary energy and ability. Before the introduction of steel hoisting machinery derrick sticks of wood, ninety feet in length, were brought from Oregon. The most improved appliances are used in the shops at Barre for shaping the stone. The sheds for working under cover at a nearly constant temperature summer and winter are the largest in the world.

The gray granite of Barre is remarkable indeed for its evenness and beauty in the rough and in polished pieces. Its qualities of resisting the agencies of weathering, and of continuing to look clean and bright after exposure, are greatly in its favor. It has become famous as well for its wonderful adaptability to tool treatment. On the singularly beautiful monumental stone over the grave of the two Gobbi children in the cemetery to the west of the city an armful of roses and lilies has been carved in the round with matchless skill. Such work would have been wonderful in marble. The monument to Robert Burns in the city of Barre, with its statue of the poet, and pedestal covered by illustrative tablets, is probably the noblest piece of granite carving to be found in any city.

Through the courtesy of Dr. C. H. Richardson, of Dartmouth College, I am able to publish, in addition to the special discussion of the Barre granites which Mr. Finlay's paper furnishes, a more extended account of the geology of Washington county, in which are located most of the important granite areas of the State, though others to the north and south are not to be overlooked, and particularly of Orange county, in which the Washington limestone is especially displayed, and also of Windsor county.

While Dr. Richardson does not primarily consider the granites, yet as these necessarily receive much attention, the paper naturally should be included in a discussion of Vermont granites. By these contributions we are furnished with a much more accurate and complete account of the region involved than has ever been published.

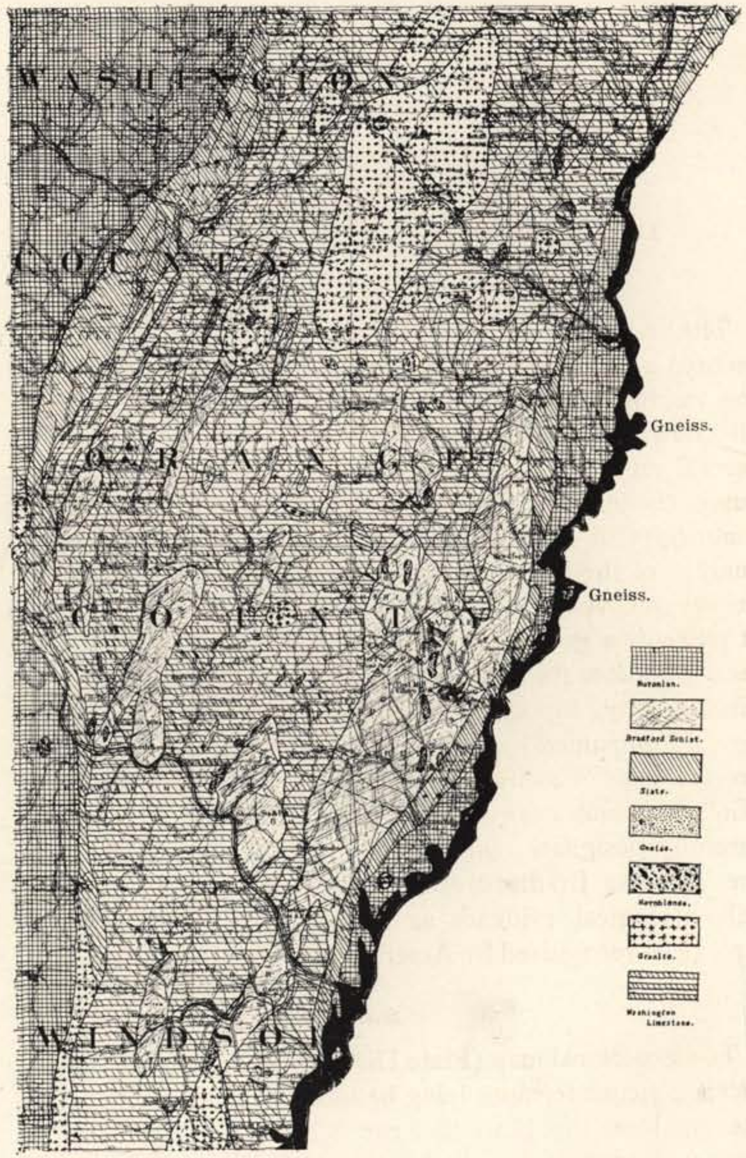
It may be proper to state that the papers are published as they came from their authors, and, therefore, they alone are responsible for such statements and conclusions as they contain.



Geological Map of Orange County and Parts of Washington and Windsor Counties, Vermont. Scale, 1 inch=5 miles.

NOTE.—The dark areas along the Connecticut river are modified drift not granite. A comparison of this map with the smaller one will make doubtful points plain.

PLATE IXA.



Geological Map of Orange County, with Parts of Washington and Windsor Counties, Vt. Scale, 10 miles=1 inch.

NOTE.—The black area along the Connecticut River is Modified Drift.

The Terranes of Orange County, Vermont.

DR. C. H. RICHARDSON, DARTMOUTH COLLEGE.

INTRODUCTION.

The treatment of the terranes of Orange county, Vermont, records a most searching and ultimate analysis of the Washington marble, which singularly carries more than one-fourth of all known elements. It shows the percentage of solubility in several surface samples of widely different localities. It discusses the olivine of Corinth, the source of the famous Thetford limburgite of Dr. Oliver Payson Hubbard. It embodies an analysis of the arsenopyrite of Braintree and the scales of phyllite set transverse to the planes of foliation in the shaly terranes. It presents a geological map of Orange county and protracted sections across the same, with legends. It gives chapters upon bibliography, topography, chemistry, geology and paleontology, accompanied by two maps and thirteen half-tone cuts. It divides the "Calciferous Mica Schist" of Professor C. H. Hitchcock into a calcareous and a non-calcareous member; and carefully designates the former as Washington limestone and the latter as Bradford schist. It locates these terranes from paleontological evidence as Lower Trenton, which formerly have been recognized by American geologists as Upper Silurian.

MAPS.

The geological map (Plate IX*) represents the distribution of heterogeneous terranes lying between the Connecticut River on the east and the Huronian rocks of central Vermont on the west. It extends from latitude 43° 30′ northward to latitude

* By an unfortunate error the Granite areas are shown in the same manner as are the modified drift, but the only drift area is that which borders the Connecticut river, all the remaining black spaces are granite.

44° 25′ and embraces the larger parts of Orange, Caledonia, Washington and Windsor counties. It also covers an area of more than 3,000 square miles of stratified, igneous and metamorphic rocks of Huronian and Silurian age.

The stratigraphical map (Plate XIV) represents five protracted sections, extending from the Connecticut River on the east through the Huronian and Lower Silurian terranes to the Huronian schists on the west. Their original trend is to the northwest, nearly at right angles with the average strike of the Washington limestone, north 20° east.

No attempt is made at plotting the dip of the planes of bedding save as they conform with cleavage, for the former is subsequently illustrated with half-tone cuts from several localities where there is a marked non-conformity of bedding and cleavage planes.

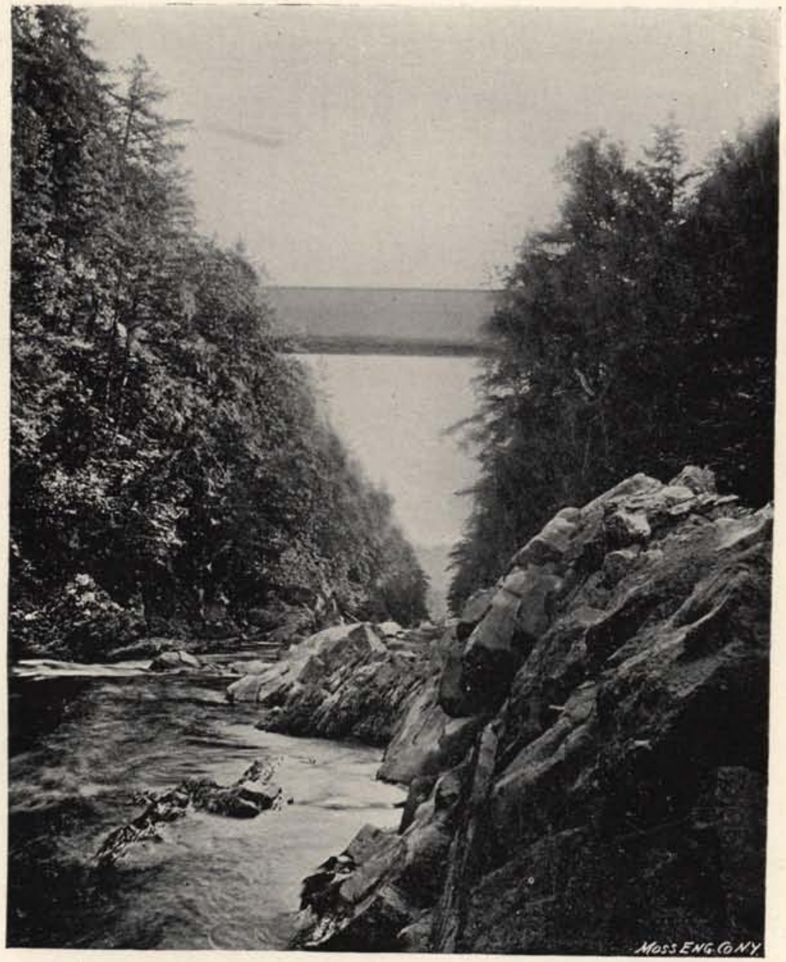
TOPOGRAPHY.

The topography of the area is unity in variety. Italy is a land of rarer sunsets and deeper sky; Switzerland is a region of more towering sublimity and unapproachable grandeur. Yet these do not surpass the majestic hills and beautiful valleys of eastern Vermont in the exquisite genius of creative art. They blend all that is beautiful and attractive with nothing to terrify the eye. It is a Silurian tableland sculptured by Tertiary denudations.

Plate X, Quechee Gulf, represents a Quaternary erosion. A channel buried by the sand and débris of the ice age turned the Ottaquechee River from its original course and has given Vermont the magnificent chasm, Quechee Gulf. The gulf is from one-half to three-fourths of a mile in length. The railroad bridge seen in the plate is 192 feet above the river and nearly 300 feet in length. At low water the stream is about 40 feet wide. The length of time required for such an erosion is not less than 10,000 years. The gulf is a popular tourists' resort.

Another beautiful gorge plowed out by a share of a furrowing torrent is found among the hills of Williamstown and Brookfield and known as Williamstown Gulf. It is five miles

PLATE X.



Queechee Gulf.

By courtesy of *The Vermonter.*

PLATE XI.

A Typical Schist Hill Near Chelsea, Vt.

in length and follows north and south along the line of the strike of the Washington limestone. Near the northern extremity it is very narrow, scarcely wide enough for a carriage drive. The tilted limestone rises upon either side from 100 feet to 500 feet above the roadbed. Where the gulf is the narrowest the sides of the cliff are too precipitous to be easily scaled. The entrance to the valley road from Williamstown is broad and beautiful. Its exit to the south is into a broad and fertile valley flanked by long limestone barricades. The Gulf House, encircled by conical hills of erosion, is about one-half mile south of the northern entrance to the gulf. Near it is a famous well, worn out in a perfect circle, about nine inches in diameter and of unknown depth. It remains nearly full of water yet seldom overflows. Near the northern entrance to the gulf is the watershed of the eastern fork of the Green Mountains. Here the meteoric waters divide, a part becoming a tributary to Stevens Branch, which finds its way to the ocean through the St. Lawrence River and Gulf; the other is one of the head branches of White River, which ultimately empties into the Atlantic through the Connecticut River and Long Island Sound.

In the western part of Brookfield is found a gulf extending to the north ten miles. The deepest and most beautiful part lies in the southwestern part of the town between Bear Hill and Moody Mountain. It lies partly in Washington limestone and partly in Bradford schist.

The remaining valleys are much wider and often beautifully terraced through sedimentary deposits from glacial rivers. To the east of the watershed they extend southeast; to the west, north and south. Yet on the latter side several streams flow into the Winooski.

Conical peaks may be observed at their maximum altitude along the line of the watershed, which is also the line of the great anticlinal of the Washington limestone. The highest of these are in Chelsea, Washington and Orange; varying from 1,800 to 2,500 feet above the sea level and arable to their very crests. So multitudinous are these cones in Corinth that they present the appearance of a garden filled with gigantic bee-hives.

Plate XI represents the western slope of such a hill near the village of Chelsea.

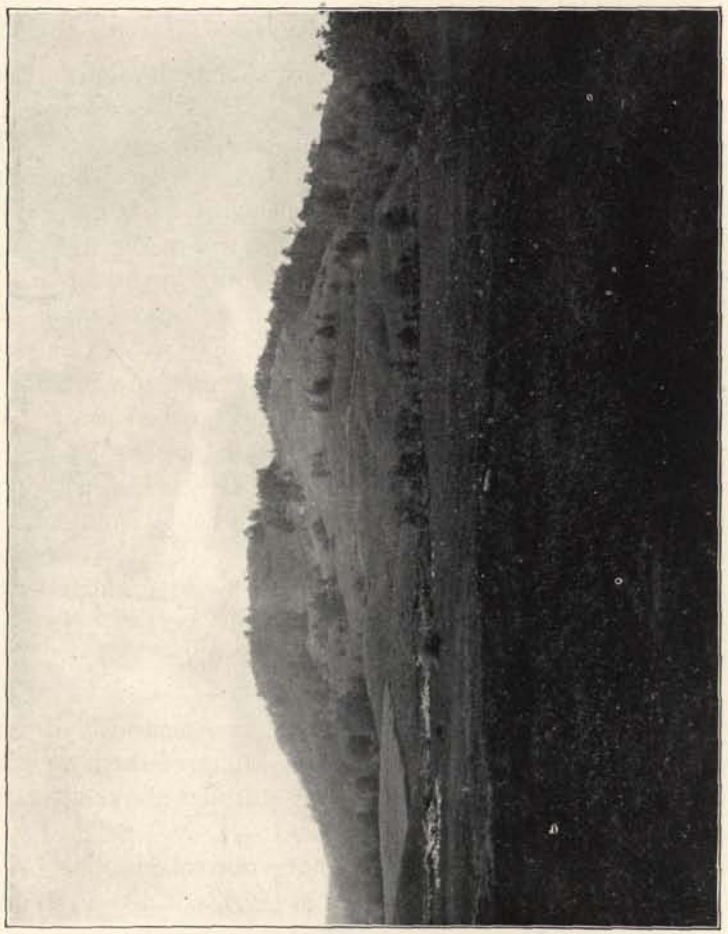
Plate XII shows the farm of R. F. Richardson in Washington, the boyhood home of the writer. The broad fertile valley, the ancient home of a runaway lake, is at an altitude of 1,500 feet, and the crest of the mountain in the rear 2,100 feet. Here the strata of the Washington limestone are perfectly horizontal. The planes of deposition and easy cleavage coincide. Where the valley narrows among the hills, as shown in the right of the figure, sheets of good marble, 40 to 50 feet in length, increasing in thickness with descent, lie upon the surface. There is little or no earth or waste material to remove to open large quarries of great value. One mile to the north is Washington Peak, 2,500 feet high. From its crest is one of the most beautiful panoramic views of the State. The lofty peaks of New York, New Hampshire, Vermont, and Canada stud the horizon, while at its base are valleys of disintegration and erosion from 1,000 to 1,500 feet in depth.

Plate XIII represents a typical granite boulder which rests on the brow of a conical hill at an altitude of 1,300 feet. It is situated one mile northeast of Washington village and weighs 80 tons.

Seldom are wanderers found more conspicuously dropped upon the hillsides than in this area. Many of them weighing from 50 to 100 tons have been left at altitudes above 2,000 feet. Their line of transit is south 10° east.

Disintegration and denudation have not toiled alone to produce so many marvellous changes in level, not alone mountain making by the folding of the strata of homogeneous and heterogeneous formations, but volcanic action bringing here and there gigantic masses of granite and amphibole to the surface. A good example of the former may be seen in Corinth southeast of the old copper mine; and of the latter in that range of granite

PLATE XII.



Hill of Washington Limestone, Washington, Vt.

PLATE XIII.

Granite Boulder, Washington, Vt.

hills, now extinct volcanoes, through Plainfield and Orange, Goshen and Harris Gores.

Some of the lowest altitudes have been observed along the banks of the Connecticut River at low water level. A few are here given.

	FEET.
White River Junction	318
Hanover	373
North Thetford	379
Fairlee	383
Bradford	389
Newbury	398
Wells River	407

An equally interesting series of observations have been made along the line of the Passumpsic Railroad on the summit of the track directly in front of the depot.

	FEET.
White River Junction	357
Wilder	400
Norwich	406
Pompanoosuc	410
Thetford	413
North Thetford	401
Fairlee	437
Bradford	410
South Newbury	412
Newbury	426
Wells River	442
Ryegate	471
McIndoes	487
Barton	467

Altitudes near the line of the great anticlinal do not present so striking a similarity; yet there is an increase to the northward until the mountains of Plainfield, Goshen and Harris Gores present the maximum.

	FEET.
Sharon, East Hill	1,000
Strafford, West Hill	1,125
Strafford, East Hill	1,202
Woodstock, Mt. Tom, South Peak	1,262
Woodstock, Mt. Tom, North Peak	1,357
Vershire, River	1,300
Vershire, near Heights	1,775
Chelsea, East Hill	1,710
Washington Heights	1,800
Washington Village	1,225
Washington, Quimby Hill	2,100
Washington, Washington Peak	2,500
Topsham, Willey Hill	1,850
Orange Heights	1,700
Orange, Knox Mountain, South Peak	1,975
Orange, Knox Mountain, North Peak	2,200
Plainfield, Plainfield Mountain	2,500
Goshen Gore, Goshen Mountain	2,600

CHEMISTRY.

(*a.*)

Washington Marble. Quarry of Huntington and Clough. Sample taken from the core of a diamond drill 35 feet below the surface of bed rock.

Summary of Analyses of Soluble Constituents.

	(*a.*)	(*b.*)
Silicon dioxide, SiO_2	.240	.241
Carbon dioxide, CO_2	22.860	22.870
Ferrous oxide, FeO	.940	.941
Manganous oxide, MnO	.076	.075
Calcium oxide, CaO	27.293	27.293
Magnesium oxide, MgO	3.233	3.230
Water, H_2O	.108	.107
Chlorine, Cl	.307	.307
Phosphorous pentoxide, P_2O_5	1.359	1.359
	56.416	56.423
Less O=Cl	.069	.069
	56.347	56.354
Calculated	56.450	56.452
Obtained	56.347	56.354
Difference	.103	.098

Composition of Insoluble Residue.

	(*a.*)	(*b.*)
Silicon dioxide, SiO_2	35.508	35.507
Titanium dioxide, TiO_2	.190	.189
Ferric oxide, Fe_2O_3	.010	.010
Aluminum oxide, Al_2O_3	6.113	6.112
Glucinum oxide, GlO	.313	.315
Barium oxide, BaO	.210	.210
Calcium oxide, CaO	.012	.011
Magnesium oxide, MgO	.015	.014
Sodium oxide, Na_2O	.186	.187
Potassium oxide, K_2O	.063	.064
Lithium oxide, Li_2O	.823	.824
Fluorine, F	.026	.026
	43.469	43.469
Less Oxygen=Fluorine	.010	.010
	43.459	43.459
Calculated	43.550	43.548
Obtained	43.459	43.459
Difference	.091	.089

Totals.

	(a.)	(b.)
Silicon dioxide, SiO_2	35.748	35.748
Titanium dioxide, TiO_2	.190	.189
Carbon dioxide, CO_2	22.860	22.870
Ferric oxide, Fe_2O_3	.010	.010
Aluminum oxide, Al_2O_3	6.113	6.112
Ferrous oxide, FeO	.940	.941
Glucinum oxide, GlO	.313	.315
Manganous oxide, MnO	.076	.075
Barium oxide, BaO	.210	.210
Calcium oxide, CaO	27.305	27.304
Magnesium oxide, MgO	3.248	3.244
Sodium oxide, Na_2O	.186	.187
Potassium oxide, K_2O	.063	.064
Lithium oxide, Li_2O	.823	.824
Water, H_2O	.108	.107
Phosphorus pentoxide, P_2O_5	1.359	1.359
Chlorine, Cl	.307	.307
Fluorine, F	.026	.026
Carbon, C	Microscopical trace	
	99.885	99.892
Less Oxygen=F & Cl	.079	.079
	99.806	99.813

100 — 99.806 = .194 difference.
100 — 99.813 = .187 difference.

The presence of so many unexpected elements and compounds, as well as the large percentage of SiO_2, may seem difficult to explain. In fact its complexity of structure is unparalleled by any analyzed marble. The excessive amount of SiO_2 arises from two sources: First, the intercallation of granules of sand when the vast calcareous beds were deposited in oceanic waters; second, the interjection of silicic anhydride in gaseous form prior to the metamorphosing of the marble.

Rutile is present in the eastern part of the formation in minute hairs or threads penetrating the crystalline limestone. Perhaps they occur most frequently in Sharon, Vt. The mineral is the dioxide of titanium, and silicon is often replaced by this element of the same quantivalence.

The unexpected glucinum manifested itself in traces of the mineral beryl, a silicate of glucinum and aluminium which is abundant in the adjoining heterogeneous terranes of New Hampshire.

Lithium occurs in the lithium aluminium silicate, spodumene, in the homogeneous terranes in Massachusetts. Here the mineral is so highly developed that commercial lithia may be extracted with profit. Perhaps traces of this element are scattered throughout the entire Lower Trenton terranes, for it occurs in the complex orthosilicate, muscovite.

Chlorine is probably present in combination with one of the alkali metals; and the fluorine with the complex orthosilicate, biotite. Surface samples of biotite yield fluorine in analysis and minute crystals of biotite more or less associated with muscovite grace the entire formation.

As the prevailing constituent is the carbonate of calcium with enough magnesium present to make it dolmitic, the rock may be known as a silicious marble. It carries a large percentage of silicic anhydride and many minute traces of complex silicates. Its complexity is so great that a single formula cannot well represent its chemical composition. The presence of the rare elements has been confirmed by most searching spectroscopic analyses. The carbon is found in microscopic thin sections.

(b.)

Table Showing the Percentage of Solubility and Insoluble Residue in Washington Limestone.

NAME AND LOCALITY.	SOL.	INSOL.RES.	SOL.	INSOL.RES.
Washington marble, Clough quarry	56.47	43.53	56.475	43.525

Waits River marble, Richardson quarry	58.24	41.76	58.26	41.74
Washington variegated, Richardson quarry ...	60.15	39.85	60.145	39.855
Unicolor marble, Richardson quarry	55.49	44.51	55.50	44.50
Chelsea limestone, West Hill	53.48	46.52	53.48	46.52
Tunbridge limestone, North Village	52.925	47.075	52.91	47.09
Vershire limestone, Ackerman Hill	53.28	46.72	53.27	46.73
Corinth limestone, Davis Hill	55.005	44.995	55.00	45.00
Stratford limestone, Upper Village	52.94	47.06	52.89	47.11
Washington marble, Warner Granite Co...	55.32	44.68	55.325	44.675

From the above table it is evident that the Washington limestone presents a varied composition; that within a radius of 25 miles the carefully selected surface samples range in their percentage of solubility from 52.92 in Tunbridge to 60.15 in Washington; that the increase of soluble carbonates is to the northward; and that the highest development of the marble is in the same direction on the crest of its great anticlinal.

(*c.*)

Analysis of Arsenopyrite from East Braintree, Vt.

	1	2	3	4
Per cent of arsenic	43.58	43.03	43.24	43.72
Value of silver per ton.......	\$1.00	\$1.29	\$1.60	\$2.58
Theoretical per cent of arsenic.	46.01	46.01	46.01	46.01

The mineral is arsenopyrite, commercially known as mispickel. It is therefore a sulph-arsenide of iron, carrying a little silver,

and conforming very nearly to the formula FeAsS. The silver is present in too small quantity for profitable extraction of the precious metal save as a by-product. But the ore is so rich in arsenic and poor in silica that it ought to become an abundant source of a useful commodity which the American manufacturers are beginning to prepare.

(*d.*)

Analysis of Olivine in Limburgite from Corinth, Vt.

	1	2
SiO_2	40.35	40.35
FeO	9.288	9.297
MgO	50.318	50.321
Total	99.956	99.968

The formula $(MgFe)_2SiO_4$ may be given to the mineral. It is an orthosilicate in which the ratio of the magnesium is to the iron as 9:1. The theoretical percentage of this ratio varies but little from obtained results.

Theoretical	SiO_2	41.0
	FeO	9.8
	MgO	49.2
		100.0

(*e.*)

Analysis of Hexagonal Crystals of Phyllite, Set Transverse to the Foliation in the Washington Limestone.

Summary of analyses:

	1	2
SiO_2	39.420	39.425
TiO_2	.245	.240
Al_2O_3	22.140	22.145
FeO	18.081	18.085
CaO	.510	.525

MgO	8.088	8.103
K_2O	8.636	8.637
Na_2O	.361	.360
H_2O	2.300	2.305
F	Trace	Trace
	99.781	99.825

This mica corresponds very closely to the complex orthosilicate biotite, for the third multiple of H_4SiO_4, orthosilicic acid, is $H_{12}Si_3O_{12}$ with 12 displaceable hydrogen atoms, and the following substitution meets the demands of the problem:

$$\left.\begin{matrix} H^{i}K^{i} \\ Fe^{ii}Mg^{ii} \\ Al_2^{vi} \end{matrix}\right\} Si_3O_{12}$$

(*f*.)

Analysis of Rhodonite from Waits River.

	1	2
SiO_2	45.27	45.28
FeO	8.08	8.10
MnO	46.33	46.42
	99.68	99.80

The mineral is a metasilicate of manganese, with formula $MnSiO_3$, in which a part of the manganese has been replaced by ferrous iron. It is susceptible of a beautiful polish and well suited for all decorative and interior work. A considerable amount of valuable material has been destroyed by fracture while prospecting for copper. Large pieces have been placed in the museum of Dartmouth College and in the National Museum of Washington, D. C.

(*g*.)

Analysis of a Selected Sample of Magnetic Iron from Bethel, Vt.

Iron protoxide		28.504%
Equivalent to metallic iron	22.170%	
Iron sesquioxide		67.896
Equivalent to metallic iron	47.527	
Total metallic iron	69.697	
Silica, gangue, etc.		1.973
Alumina		.251
Lime		.028
Magnesia		.263
Phosphoric acid		.014
Sulphur		.050
Water		.365
Titanium		......
Undetermined		.656
		100.000

The undetermined consists of carbonic acid and the oxides of sodium and potassium.

The analysis proves the ore to be of high grade, equal to the famous Franconia ore in New Hampshire, Chateaugay, N. Y., or Dannemora, Sweden. It is fitted, therefore, for all uses of iron where tenacity and endurance are desired.

It occurs in a metamorphic chloritic schist. The schist is soft and fragile, and can be easily worked.

I have followed the deposits some distance northward and find the massive magnetite frequently exposed to view. One mile north of the deposit it is reported observed upon the surface. In the vicinity octahedral crystals of magnetite are frequently found; and black magnetic sand, generally gold bearing, lines many of the neighboring streams.

The ore is ofttimes disseminated through the rock rather than concentrated into large veins. The evidence is in favor of a deposit of ore increasing in dimensions as you go below the surface. However, the opposite is possible, for the surface content is very small.

GEOLOGY.

The architecture of the heterogeneous terranes of Orange county, Vt., is somewhat obscure. The original horizontal series of sands, gravels, clays, and marls have their modern representatives in tilted and crumpled schists, argillites, limestone and crystalline marbles. These rocks have been compressed into great folds with a huge anticlinal along the center of the crystalline marble, with minor anticlinals and synclinals upon either side. As a direct result of this compression, linked with the injection of igneous material, many new minerals have been developed and the countenance of the original deposits disguised. Planes of cleavage were induced at varying angles with the lines of original bedding and the Lower Silurian rocks superimposed unconformably upon Huronian terranes.

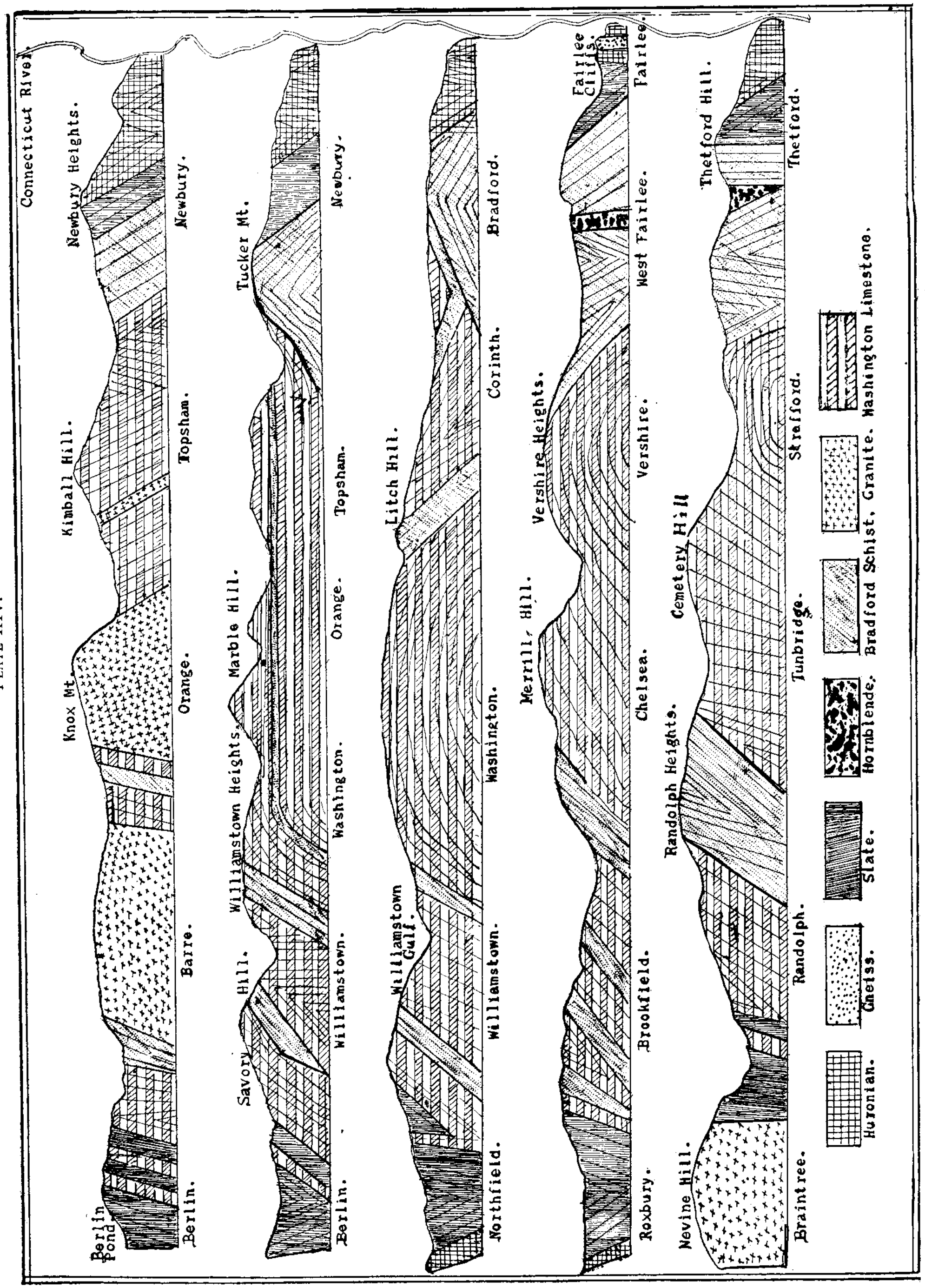
A.

HURONIAN.

The outer flanks upon the east and the west are Huronian. No attempt is made in the protracted sections to plot the western member save as it comes in contact with the Montpelier slate. The eastern member is plotted only to the Connecticut River. The former is largely hydromica and chloritic schist with beds of serpentine and soapstone as alteration products. These rocks are often studded with crystals of magnetic iron. The latter is of the same general nature and often highly garnetiferous. On the west side is found a light gray, fine grained economic granite in Braintree. The largest deposit is on Nevin's Hill. In fact the hill is all granite. Similar deposits are found in Moretown and Northfield.

The eastern member carries two large bunches of metamorphic diorite—the larger in Hartford, and crops out in abundance on the left of the road from Christian Street to Hartford

PLATE XIV.



Sections Across Washington and Orange Counties, Vermont. Horizontal scale, 1 in = 1600 rods.

village. The smaller is in Newbury to the east of Hall's Pond. Each contains large crystals of feldspar.

Two bunches of protogene gneiss grace this member.* The smaller is in Newbury on the Ox Bow, the larger in Bradford and Fairlee. It is the material of Bradford and Fairlee cliffs. The best exposure is just back of the hotel at Fairlee. The cliff rises by almost perpendicular ascent for about 200 feet; while at its base is a large talus of broken fragments of gneiss. The material is unlike the protogene gneiss of Hanover and Lebanon, N. H. The mica is more abundant and the parallelism greater at Fairlee and Bradford. At Hanover the mica is chlorite and the gneiss is brittle. It is not impossible that at Fairlee we have the relics of an extinct volcano. A narrow belt of hydromica schist lies between the cliff and Lake Morey. The lake is entirely in slate and the crests of the adjacent hills are Bradford schist.

Near the Connecticut River the Huronian schists are nearly vertical and ofttimes much crumpled. In Newbury there are at least three synclinal troughs and two anticlinal axes. In Thetford there is one of each. In Fairlee the dips are all between 85° and 90° slightly to the east.

In the summer of '96 there was reported to me from Newbury an Indian burying ground, situated about two miles north of Newbury Village, in a cut on the Passumpsic Railroad. A visit to the locality proved this Indian cemetery to be an interesting dike of diabase about 18 inches wide and exposed to a height of 10 to 12 feet above the track. The peculiar interest attached lies not in lithological characteristics, for herein it is not unlike many trap rocks, but in its striking surface decadence along multitudinous planes of fracture. The resultant presents the appearance of a stone wall set on end. The decomposing boulders lose their concentric shells, reveal the structure of a concretion, and ultimately remain as granules of coarse sand. The dike runs east and west. I tried to trace it over the hills

* These areas do not show well on the map. The word Gneiss printed on the margin indicates the localities.

and found in Washington, 25 miles distant, a dike one foot wide, with the same cardinal direction, the same concretionary decomposition, lithological similarity, and microscopical characteristics. Presumably it is the reappearance of the same dike.

B.

SLATE.

The second pair of parallel terranes, lying within the old Huronian deposits, have long been called Cambrian. They are narrow bands of soft, black, fissile, arenaceous slate resting unconformably upon the Huronian schists. The western band begins near Lake Memphremagog and suddenly terminates near Barnard Village. In Braintree, Brookfield, Williamstown and Berlin it is interstratified with the Washington limestone, and is referable to the same age, viz: Lower Trenton. Its highest development is in Montpelier and Northfield, where it has been extensively quarried as a fine roofing slate. Although the Montpelier quarries have been abandoned, those at Northfield are successfully operated by the Dole-Brill Slate Company, which produces a fine grained, excellent, permanent block slate. Few, if any, quarries in the State have less waste.

The general strike of this member is north 10° east. In Braintree and Randolph, north and south. In Bethel, north and south and north 10° west. In Barnard it becomes a narrow line with strike north and south.

One-half mile east of the city of Montpelier are the slate quarries of James T. Sabin. They have been worked to a depth of 100 feet.

In November, 1896, I visited the slate quarries of Northfield in company with Dr. C. H. Hitchcock and F. E. Austin, to discover, if possible, illustrations of planes of original bedding in contradistinction to the superinduced planes of cleavage. The highly satisfactory results were subsequently published by Dr. Hitchcock in a Bulletin of the Geological Society, Vol. VIII, pp. 289-390, in which he describes kindred phenomena in the quartzites of Hanover and Lebanon; a rock lithologically identical with the Lower Cambrian quartzites of western Vermont.

After renewed investigation I was successful in finding unquestioned differences and to photograph the same. These phenomena can be seen in illustration, Plate XV, Northfield slate quarry. The large distinct lines dipping 80° east are the superinduced planes of cleavage. The less distinct lines at the low angle of 30° to 35° west are planes of original bedding. It is along these planes that many graptolites may yet be discovered. Hitherto the search has been futile; in part, because made along lines of cleavage, while the true bedding was unknown; and in part, because the strata have become tilted and broken enough to obliterate many traces of Lower Trenton organisms.

This discovery of the true dip is deemed of vast importance in leading to the conclusion that this band of Trenton slate lies unconformably upon the Huronian terranes flanking it upon the west.

In a quarry one-fourth mile farther south similar deviations were discovered. The planes of bedding at a low angle to the west are clearer than the lines of fissility. This variation does not hold true in all the quarries, for occasionally distorted pebbles lie in the lines of cleavage. In such cases the planes of fissility and bedding are parallel. At Barnard, where the western member terminates, is the best locality to search for fossils.

The eastern member extends interruptedly through the State. In East Barnet it becomes very narrow, crosses the Passumpsic River, and with a strike of north 10° east traverses Waterford Mountain. The slate widens rapidly to the north. South from Barnet the band becomes lost until in the northern part of Newbury it reappears as a narrow band.

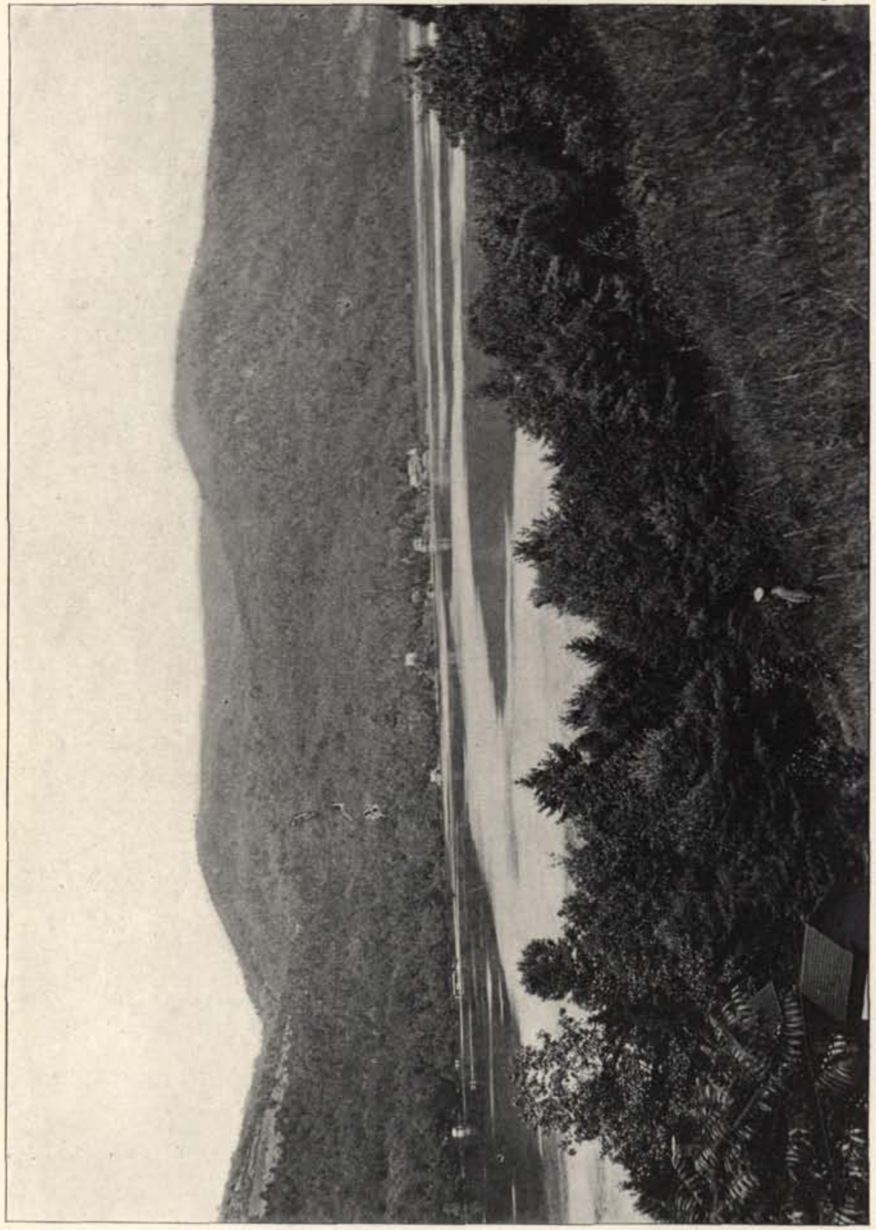
It is possible that for this short interval the slate underlies the Washington limestone; but more probably, as the beds are from 100 to 1,000 feet in thickness, it has been eroded.

About two miles north of Round Pond in Newbury this band suddenly increases its width threefold and extends south to

PLATE XV.

Sabin Slate Quarry, Northfield. Strike N. 10° E. Dip of Cleavage 75°-80° W.

PLATE XVI.



Lake Morey, Fairlee.

within one mile of Bradford Village. Here the slate terminates abruptly and the Huronian rocks take its place. It does not dip under the Washington limestone, for that rock lies 10 miles to the west; nor under the Bradford schist, for the strike of the Bradford schist is parallel with the slate, viz, north and south. The Huronian rocks are laid bare to the west until they touch directly the Bradford schist. It may be that here is the beginning of the great fault that lies farther up Waits River valley. Excluding the fault theory, the slate must suddenly increase in thickness, and disintegration and erosion must have obliterated the last relic of the slate.

Five miles to the south in Fairlee the deposit is 1,000 feet in thickness. Instead of a uniform cleavage dip to the east, I find a synclinal trough. It first makes its appearance a short distance north of Lake Morey. The lake is three miles long and one-half mile wide. Nearly all of it lies in the synclinal trough. Its greatest depth is 500 feet. It was here that Captain Morey's crude boat, the immediate forerunner of Robert Fulton's success on the Hudson, was sunk.

Near the north end of the lake on the east side the dip is 60° west. Directly opposite, on the west side, the dip is 85° east. At the southwest corner of the lake the dip is 60° west, at the southeast there is a little bunch of distorted argillite with strike east and west, dip 85° north. Plate XVI shows the lake with the hills of slate rising hundreds of feet above it to the west.

About one-half mile north of the head of the lake is the Fairlee gold mine, situated on the farm of Mrs. S. A. Davis. The vein of quartz carrying the ore is 7 feet wide; its length and depth is unknown. The analysis yields gold to the value of $9 per ton and silver $30. The vein is also well mineralized with galena and chalcopyrite.

A little south of the center of the lake, far up among the hills on the west side, is situated the beautiful cascade known as Glen Falls. The perpendicular descent of this babbling brook is now 25 feet. The stream has worn a channel through the slate 4 feet wide and 10 feet deep. It is a picturesque and popular resort.

Illustration, Plate XVII, shows the cascade, the eroded channel, and the rustic bridge above them.

In the northeast corner of Thetford, about one mile south of Ely station and 50 rods west of the Passumpsic Railroad, there is an old quarry of extremely fissile, soft, argillaceous slate, with apparent strike north 10° east, cleavage dip 85° east 10° south, strata dip 45° north. It affords a most striking illustration of the nonconformity of planes of bedding and fissility. Crossing the entire exposed surface of 100 feet by 25 remarkably distinct lines of original bedding are seen. The cleavage planes are induced by subsequent pressure at right angles to the lines of fissility.

About one-third of a mile to the northeast of Thetford Hill, at the old galena quarry, the cleavage is 40° east 30° south, with no evidence of characteristic planes of bedding, unless the dip of the mineral vein, 21° to the southeast, affords us that evidence. It carries galena and sphalerite in considerable abundance.

This Thetford argillite is a narrow band varying from one-fourth of a mile in width, in Fairlee, to 1 mile in Norwich. It was not known to extend continuously north of Ely station until the author succeeded in the summer of '96 in tracing it through Fairlee and into Bradford, where the hydromica schist takes its place.

The strike varies from north 10° east in Fairlee to north 50° east in Hartford. South of North Hartland it is north and south, and in Norwich north 45° east. The dip changes from 60° west in Hartford to 85° east in Fairlee.

With the general dip of the eastern flank to the west, or vertical, and a low dip of the planes of bedding just north and south of where the slate has been entirely eroded in Bradford, is sufficient evidence that it lies unconformably upon the Huronian hydromica schist. The lapse of time between the deposition of the Huronian schists and the Lower Trenton slates was

PLATE XVII.

Glen Falls, Fairlee.

long—sufficiently long for the former to have become the source of the latter. The chemical composition of the two is not too widely different. The ever active waters of the sea could easily wear away these older rocks, sift, redeposit the impalpable powder unconformably upon the Huronian rocks. The dip of the western flank is to the east, or vertical; but the planes of deposition of the slate have a low dip to the west, at Northfield 35° west. Along the entire line the evidence confirms an unconformity: 14 bands of slate, outside of the two large belts, are interstratified with the Washington limestone. Unlike the belt upon the east, which is older than the Washington limestone and Bradford schist, the western belt is the youngest of them all and lies above them all.

C.

BRADFORD SCHIST.

Bradford schist is the name which I have chosen for the non-calcareous member of the old "calciferous mica schist." The calcareous member is named Washington limestone from the town of Washington, Orange county, Vt., where it is extensively worked as a marble.

Bradford schist is named for the town of Bradford, Orange county, Vt., where the non-calcareous element predominates.

These, taken together, have hitherto been known as the "calciferous mica schist" of Professor Hitchcock, and no definite attempt had been made to separate the calcareous from the non-calcareous member until I took up the study of these terranes in the summer of 1895.

The larger part of the Bradford schist was originally a sandstone which is now represented by terranes of granular and micaceous quartzite and a foliated mica schist. This is characteristically true in the eastern half of the county.

The staurolite, actinolite and magnetite schist of Vershire may have once been a cherty, iron bearing sand, infiltrated with carbonates of lime and magnesia, while some of the original calcareous sand deposits, somewhat destitute of lime, may have been so highly transformed that its modern representative is manifested in patches of hornblende schist containing scarcely a remnant of the original carbonates.

Through Randolph, Williamstown, Chelsea, Corinth, Washington, and Orange are beds of graphitic schist once carbonaceous shaly material. In Chelsea, about three miles east of the village, it has recently been worked for graphite. Carbon is largely the coloring matter of both the Bradford schist and the Washington limestone.

The largest terrane of the Bradford schist lies directly in contact with the Trenton slate through Bradford, Fairlee, West Fairlee and Norwich. Through Hartford and Hartland it is interstratified with Washington limestone.

In Bradford the mica predominates and the rock is characteristically a mica schist, while through Norwich, Vershire and Thetford it is a foliated micaceous quartzite. It extends interruptedly through Corinth and Topsham. In the latter town it terminates as a narrow band about two miles north of Waits River. It carries a rich ferruginous rhodonite susceptible of a most beautiful polish. The rhodonite is four rods wide. The strike is north 75° east, with a dip of 75° south. Within 200 rods the dip of the mica schist changes to 45° north.

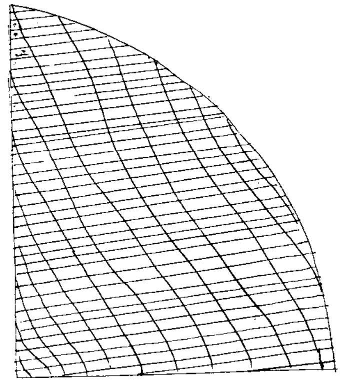
Through Vershire, West Fairlee and Norwich are found bunches of hornblende. One is found on either side of Eagle Ledge in Vershire, which rises abruptly 250 feet. By the intense heat from this eruption beautiful crystals of staurolite have been developed in the contact rocks. This line of laccolitic material crops out again one-half mile east of West Fairlee. Thirteen patches of hornblende are sketched in the drawings.

Wright's Mountain in Bradford, 1,500 feet high, is of similar origin; but the igneous material cropping out on both the northeast and southwest sides of the mountain is granite.

The general strike of this belt is north 20° east. The dip is mostly at a high angle, either east or west. There occurs one main anticlinal, the result of compression. A minor synclinal trough lies to the west in West Fairlee and Thetford.

Careful investigation has proven that here as well as in the clay slates the superinduced planes of cleavage do not conform to the original planes of deposition. The figure strikingly presents the fact as observed on a rock exposed on the farm of W. F. Davis in Thetford.

The Bradford schist carries four well known copper mines: the Elizabeth mine in Strafford, the Vershire mine at Copperfield, and the Eureka and Union mines in Corinth. The first of these is owned by the Tyson Brothers. With the new smelting plant the mine is worked with large profit. An adit has



Showing the superinduced planes of cleavage in Bradford schist, nearly at right angles to original planes of deposition.

been opened into the side of the hill, striking the large vein near its center. The stopes extend nearly north and south with a lateral expansion from 50 to 100 feet and a height of 10 or 15 feet. Very little artificial support is required and the mine is free from the seepage of waters. One hundred and fifty men are employed, and the mine can easily yield 2,000,000 pounds of copper per annum. The second mine, located in Vershire, is owned by Mr. George Westinghouse. It is about 10 miles from either of the others and has been worked more extensively. The adit has been extended 3,600 feet with a vertical depth of over 1,500 feet; thereby carrying the present location of the vein below the level of the sea. In 1880 there were 140 houses that would accommodate 1,000 officers and workmen. Its annual production was 3,500,000 pounds of copper. Although its history began before the world knew about copper in the Lake Superior region, it is neither exhausted nor less rich in the red metal.

The vein dips 24° northeast. The roof and the floor are virtually impenetrable to water; yet at a depth of a few hundred feet there is a little seepage of water from a vertical cross fissure. The lowest depths of the stopes now fill with water which is kept pumped out. The veins are true fissure veins formed by the great folds in the Bradford schist. They were filled by ascending solutions and subsequently enriched by descending solutions. The rocks upon either side of the vein are well mineralized, and the faulting occurred after the filling.

The third mine, the Eureka and Union mines in Corinth, lies 10 miles farther to the north and a little to the west. One mine is owned by Hutchinson & Waterman and the other by Darling & Smith. The vein dips 15° northeast, and for about 50 rods follows the slope of the hill so that the ore was raised only a few feet to bring it to the surface. The ore is richer in copper content than either of the other two. In fact native copper has been obtained.

A few men have been kept at work during the past year, and 300 tons of ore have been shipped to New York. Many rich dump heaps from the original sorting of the ore remain. The copper can be extracted profitably by electricity, while all its sulfids are of commercial value in the manufacture of sulphuric acid.

D.

WASHINGTON LIMESTONE.

This, as I have noted elsewhere, is the calcareous member of the "calciferous mica schist" of Dr. C. H. Hitchcock.

It crosses Vermont from north to south, and considered with the Bradford schist, with which it is so intimately interstratified, it is the most extensive formation in the State. The widest

PLATE XVIII.

Outcrop of Washington Limestone, Waits River.

portion of the limestone is in Canada between the east and west division of the Quebec group. Here it is much lighter in color than the corresponding beds in Vermont. Its greatest breadth in Vermont is in the northern part of the State, approximating to 40 miles. It narrows towards the south as the State itself narrows, and in the town of Hartford it divides by the intervention of the Bradford schist. The western member terminates suddenly in the southern part of Windsor county in Cavendish; while the eastern member crosses Massachusetts and is known there as the Conway schist.

In general it is a dark gray silicious limestone. The coloring matter widely disseminated is uncombined carbon. The darker portion may be found in the southern half, the western half, and through Danville and Wheelock of the northern portion. In Derby and east therefrom it assumes a much lighter hue. This is equally characteristic of the formation in Topsham, Corinth and Washington. In Topsham the beds are the lightest in color. The polished slabs very closely resemble the Columbian marble of Rutland, Vt., which is a deposit of the same age lying west of the Green Mountains.

The first discovery of this peculiarly variegated variety of the Washington limestone was made in September, 1893, about one mile east of Waits River Village by Henry C. Richardson, whose arable and pasture land is entirely underlaid with a rich deposit of marble.

It is the source of the marble now advertised as "Vermont Imperial Variegated Granite," quarried, manufactured and sold by W. M. Carnes & Co., Waits River, Vt.

Plate XVIII represents the thick sheets as they lie upon the surface of the ground. A close examination of the third sheet to the right in the illustration will reveal the intense distortion of the original planes of bedding and the beautiful curves of the intimately interstratified light and dark areas. The light areas upon the face of the quarry are planes of chemical precipitation; and the dark, planes of sedimentary deposition. To these alternations it owes a part of its beauty.

The second sheet is now exposed for 28 feet in length with a thickness of 6 feet. Hundreds of tons of most excellent marble have already been removed from the two upper sheets. Neither end of the third sheet has been found nor its thickness determined.

The strike of the rock is 45° west and the dip is very low, 15° north 45° east. One mile to the east the strike changes to north and south and the dip is 10° west. Two miles to the south the strike is north 10° east and the dip is low to the west. A few miles toward the west and the strike is east and west with a dip ranging from 0 to 10° north.

The general strike of the Washington limestone to the south of the Waits River valley is north 10° east, to north 20° east. With its sudden change to east and west, and with a low dip to the north I believe that here lies a great fault extending more than 10 miles toward the west and determining the drainage of the area.

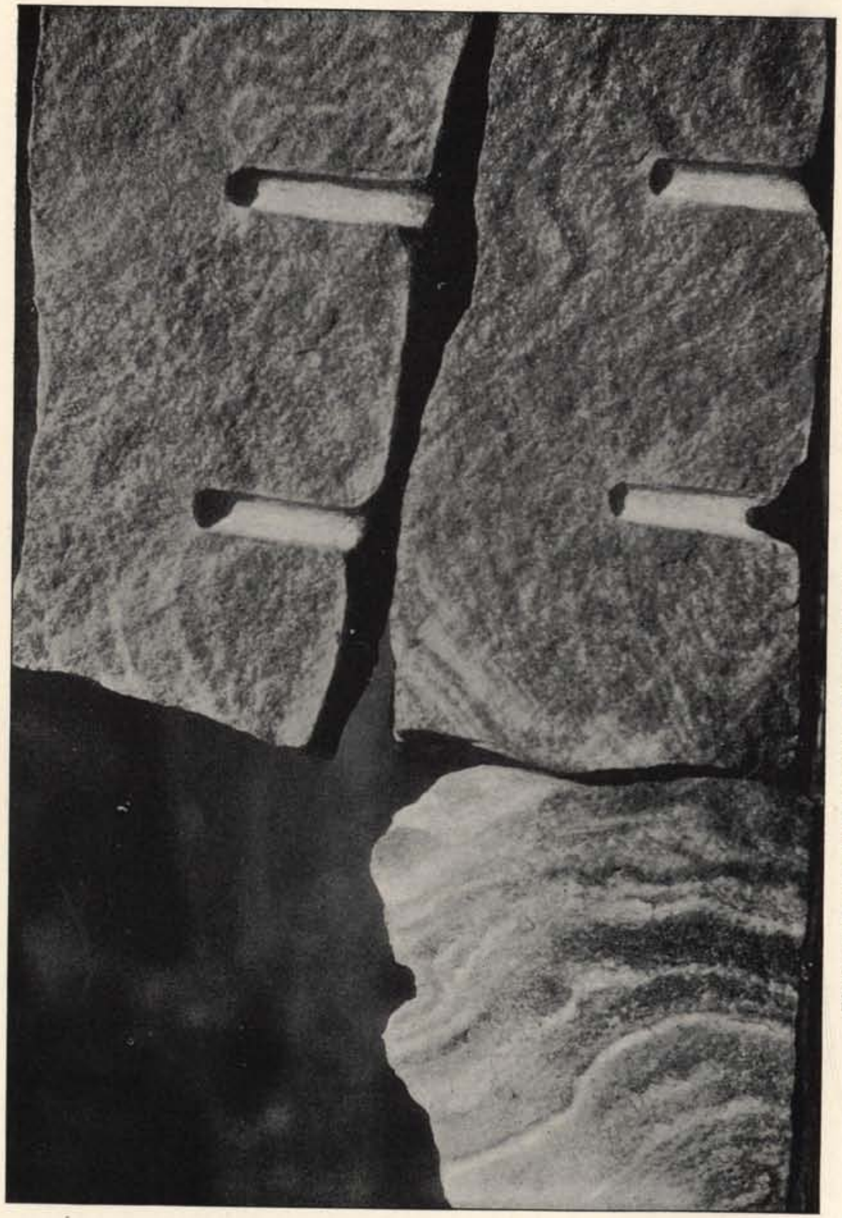
The discovery of marble in Washington antedated that of Waits River by six months. Enormous deposits of the rock were brought to the attention of Willard Clough, of Washington, and in May, 1893, the first quarry was opened and worked by the firm of Huntington & Clough. The first monument cut from the Washington marble was taken from this quarry and set in the cemetery at Washington. Later the quarry was owned and worked by C. L. Slack & Co. Within five years more than twenty-five quarries were opened by different parties, and the demand was in excess of the capacity of the sheds and polishers to meet the supply.

Plate XIX represents the first quarry opened by Dr. F. A. Warner. It is situated about three miles east of Washington village at an altitude of 1,920 feet. The strike of the rock is north 10° east and the dip 15° west. Beneath it is a bunch of igneous matter which has given an upward bend to the strata and shattered it into smaller blocks. Dr. Warner has since opened up several new quarries under the name of the "Warner Granite Company."

PLATE XIX.

Quarry of Washington Limestone, Washington, Vt. Strike of rock N. 10° E. Dip 15° W.

PLATE XX.



Blocks of Washington Limestone, Showing Banding as Seen on Freshly Broken Surfaces.

The first marble quarry of R. F. Richardson was opened in the summer of 1894. It is situated three miles east of Washington village and one mile south of Dr. Warner's first quarry. Here the strike of the rock is east and west and the dip 5° north. The first sheet is 4 feet thick and lies upon the surface. The second is 28 feet long and of unknown depth.

Within five rods of this quarry the rock lies perfectly horizontal with a strike due west. About twenty-five rods towards the south is found the darkest, the most uniform in texture, and the most desirable marble of the whole formation. It is susceptible of a higher polish than any other and its lettering is legible to a greater distance.

A few rods to the north is found the purest limestone of the entire area. Its percentage of soluble constituents is greater than that of any other sample analyzed. These areas of untilted strata, with planes of deposition coinciding with cleavage planes, may be seen in the right of Plate XII.

Through the eastern part of Washington the lighter varieties of the marble quite closely resemble the Waits River deposit. The former is a dark variety with light bands; the latter a light variety with dark bands.

A close inspection of Plate XX reveals the large curves in the strata in a hand specimen of the Washington marble with the other half of the block superimposed. The fragment in the left-hand corner shows the curved bands in the Waits River marble. Not infrequently a multiplicity of ovals can be seen on a single slab. These vary in size from a robin's egg to 4 feet in diameter.

It only requires capital and good management to make for Washington a marble industry equal to that of Rutland.

The strike of the limestone at Corinth Corners is north 20° west; dip 35° east. Here a slab 75 feet long, without a single seam, could easily be obtained. Within three miles the strike changes from north 40° east to east and west, and the dip from 35° east to 15° north.

Compression Tests.

Rutland, white marble	11,892
Italian	12,150
Rutland, Mountain dark	12,833
New York, Tuckahoe	12,950
Lee, Mass	13,400
Rutland, blue	13,864
Kingston, N. Y.	13,900
Washington, Vt.	15,675

The Washington marble is a crystalline limestone of finer grain, more compact in texture, greater specific gravity, and capable of being cut to a finer edge than any granite on the market. On the highly polished surface of the uniformly dark varieties it takes a lettering legible at a greater distance than any known rock. I have personally compared it with more than 5,000 monuments in the east, central and western states.

The dark steel gray and bluish varieties, as well as the banded and mottled varieties, hammer white, so that when cut into bases they form a striking contrast with the die upon which the inscription is placed.

Ordinary marbles, largely carbonates of calcium and magnesium, soon become dull and corroded with vegetation and traces of iron; but pieces cut from this marble seventy-five years ago simply for building stones are still lively and untarnished.

No rock more stoutly resists decomposition and alteration by the action of the atmosphere than quartz, and the silicious character of this marble makes it preeminently fitted for all structural and ornamental purposes.

Its mean depth is between 5,000 and 6,000 feet, hence the supply is inexhaustible. The thickness of the sheets everywhere increase as the quarries are opened.

This formation has plotted in Washington 5,821 feet, Waits River 5,500, Chelsea 5,000, Tunbridge 4,680. It decreases somewhat in depth towards the south and towards the west.

One locality plotted in the western part of Williamstown gave 4,900 feet.

From this point the rock assumes a darker hue, a more shaly texture, a more nearly vertical position, until it is intimately interstratified with the slate, and ultimately the slate becomes free from Washington limestone.

Limestone exposed to the action of the ever-active atmosphere assumes peculiar shapes. These forms resemble both animals and inanimate objects. They result partly from the chemical decomposition of the water that settles upon them, and partly from erosion. When limestones are exposed at high altitudes they are badly furrowed and crossed by deep washed-out channels.

This result of disintegration, of imperceptible but effective wearing away, is again due to the heavy summer rains, to the deep winter snows, to the scorching of the sun which makes the rock brittle and the freezing which makes the rock crack and split off from the main body of the mass. In fact, it is the result of the constant exposure of the limestone to the ever-changing action of the atmosphere.

The possibilities of erosion are beautifully illustrated at Old City Falls in Strafford, where the water rushes with 30 feet perpendicular descent over ledges of Washington limestone.

In the northwest corner of Corinth there is a very peculiar variety of the intermediate member. It is best catalogued as a calcareous quartzite. The rift is so perfect that a few taps with a sharp-edged tool will split off long slabs like wood. The uncovered sheets are over 100 feet in length with strike north 50° west; dip north 40° east. It is well suited for flagging stone or bridge construction.

Just outside the western band of the slate, the youngest of these Lower Trenton series, there is in Roxbury, within 30 rods of the depot, a most beautiful serpentine marble, well adapted for all kinds of decorative and interior work. Although there are white veins of soft talc and bright green fibres of serpentine running through it, nevertheless it is susceptible of a fine polish and in its richness surpasses many marbles.

The quarries have been opened by the American Verdantique Marble Company. The thin slabs split easily along the line of the serpentine fibres; but with modern methods of cutting, polishing and handling, it ought to become a valuable marble production of the State.

E.

ERUPTIVES IN THE WASHINGTON LIMESTONE.

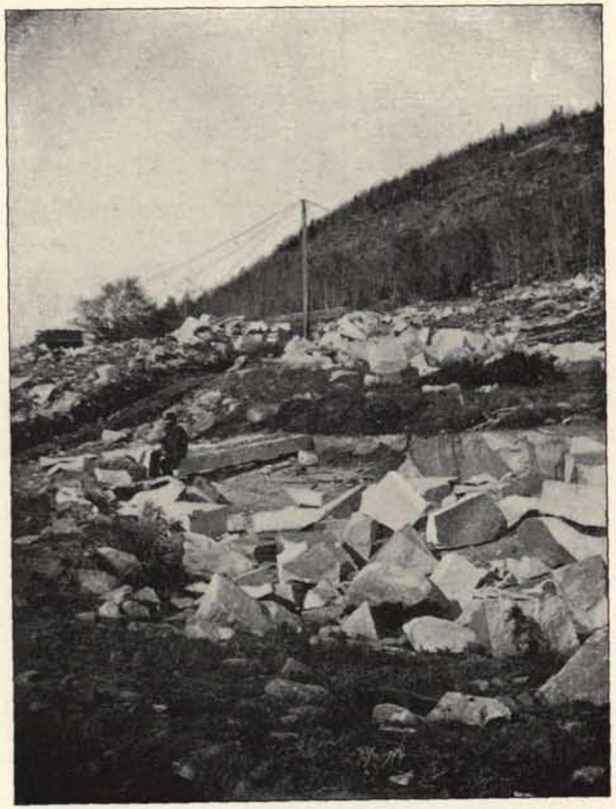
These are composed of granite, syenite, amphibolite, limburgite, camptonite, and a large number of dikes of diabase and trap.

They have developed many crystals of calcite in the Washington limestone by melting the edges of the adjoining rock and then crystallizing out. This is also true of the work of the intrusive fused quartz present in varying proportions throughout the entire area.

Of these eruptives, the Barre granite plays the most important part. The area is about eight miles long and four miles wide, mostly in Barre, but with a small area in Williamstown. It is a fine granite, composed of quartz, feldspar and mica. The mica is both muscovite and biotite. The higher the percentage of the former, the lighter is the granite; the higher the percentage of the latter, the darker the granite. To these varying percentages, therefore, is due a part of its beauty.

When the State House at Montpelier was built in 1837 out of Barre granite from the Harrington quarries, the prophecy was made, "This is the last structure that will ever be built of Barre granite, and the last load that will ever be drawn from Harrington Hill." That locality is the present site of Graniteville. From it there moved a single shaft in 1897 valued at $90,000. The annual output now exceeds $1,000,000. The granite is suited to all kinds of decorative and interior work, for all monumental and structural purposes. Its compression test is 19,000 pounds to the cubic inch—greater than many other well known New England granites. Its reputation is not local but international.

Plate XXI.



Blue Mountain Granite Quarry, Ryegate, Vt.

It has been considered by some eminent geologists metamorphic in origin—the alteration of sedimentary deposits through heat and pressure. It is unquestionably igneous in origin. By volcanic action this molten magma now so highly crystallized was brought to the surface. I have found both the Washington limestone and the Bradford schist in actual contact with the granite and indurated by it. Large crystals of calcium carbonate have formed from the fusion and these are not infrequent in the contact zone. Near Graniteville there is a large patch of phyllite schist. According to the metamorphic theory, this inclusion would be impossible. With the volcanic theory it is in perfect harmony. It cannot be older than the Washington limestone through which it penetrated. This, as is often noted, is Lower Trenton. The granites of Orange county, with twenty-five localities represented on the map, may all be catalogued of the same age.

The granite of Orange Mountain is much coarser and in many places lighter than the Barre granite. The crystals of feldspar are ofttimes very large. When the coarse exterior has been removed, there may be revealed a fine granite equal in many respects to the famous Barre neighbor. It is not a continuous body with the Barre granite, for it is separated from it by a band of sedimentary rocks two miles in width. Beautiful contact phenomena can be found on the side of the mountain facing Orange Center. In the contact rock are crystals of calcite two inches in diameter.

Plate XXI represents the granite quarries of Blue Mountain, Ryegate.

This granite, like the Barre, is susceptible of a beautiful polish. The mica constituent is both muscovite and biotite. The quartz sometimes assumes a reddish hue, giving a great variety in color. The mountain, like Ascutney, is the modern representative of an extinct volcano, and the Washington limestone, which encircles it, shows abundant evidence of excessive heat.

Plate XXII represents Mount Ascutney from the Windsor side. The mountain is situated in Windsor and Weathersfield. In approaching the mountain from Windsor, the Washington limestone resembles the half cooked lime of an old kiln. The degree of heat utilized becomes more intense, the induration greater, and finally the geologist stands with one foot on the metamorphosed limestone and the other upon the eruptive granite. Contact phenomena have been observed upon the south side as well as upon the north. The history of the mountain records at least two eruptions. The larger gave rise to the main body of the mountain, which reaches an altitude of 3,325 feet. The granite flowed out over the encircling limestone like molten lava and calcined the lime to a distance of more than 500 feet. Little Ascutney, 1,700 feet high, represents the second eruption. It occurred in the Bradford schist and affords a most excellent opportunity to study contact phenomena. The rock of Little Ascutney is in part a beautiful granite of great value for all monumental and structural purposes. These mountains are of the same age as the granite areas already described, Lower Trenton.

Other granite areas, not here described, but found on the geological map, are represented in Cabot, Marshfield, Groton, Topsham, Orange, Chelsea, Strafford, Tunbridge and Bethel.

From the smaller as well as the larger areas there extends many ramifying dikes of granite through the Washington limestone and Bradford schist. These calcine, indurate, and glaze the limestone, and metamorphose all schist not hitherto made crystalline. These dikes more stoutly resist decomposition than the contiguous limestones and schists, and often rise from 6 inches to 1 foot above them.

In Corinth, about one mile south of East Orange, on the farm of Orrin Prescott, is a beautiful illustration of resistance and disintegration. A dike of granite rises above the limestone like a stone wall. I have traced it over the hill for about half a mile. In one place it reaches an altitude of 10 feet. Where there are fissures in the granite the limestone has dissolved out and left the dike cavernous.

The following article by the author, relating to the limburgite, was printed in Science, October 22, 1897:

Plate XXII.

Windsor and Mt. Ascutney.

By courtesy of *The Vermonter.*

"SOURCE OF THE FAMOUS THETFORD LIMBURGITE.

"Nearly half a century ago Dr. Oliver Payson Hubbard, while a member of the faculty of Dartmouth College, discovered large boulders of olivine basalt in Thetford, Vt., and discussed their probable derivation from basaltic areas in Canada.

"Some of these boulders have found their way as museum curiosities to Chicago, Washington, New York and New Haven. They are particularly noted for their large rounded masses of olivine and crystalline, grayish green, glassy pyroxene.

"In 1894 Dr. E. O. Hovey presented to the scientific world, through the columns of the 'Transactions of the New York Academy of Sciences,' valuable information concerning the petrography of these basaltic boulders, and referred them to the limburgite division of the family.

"Professor J. F. Kemp has commented upon the striking resemblance of olivine diabase to these boulders and discussed the improbability of a meteoric origin.

"It has constantly been conjectured that their source was to the northward, since Vermont is in a region of extensive glaciation from that direction, yet geological research had failed to reveal their origin until last August.

"During the summer of 1896, while engaged in field work in stratigraphical geology, I encountered many dikes of diabase rich in olivine, and others of the same microscopical appearance as the typical camptonite in the Pemigewassett Valley, N. H.

"By diligent investigation it was my good fortune last August to discover in the locality of these ramifying dikes and the famous Corinth copper mines an extraordinary dike of limburgite, from 6 to 10 feet in width, and penetrating the calciferous mica schist toward the west for more than half a mile.

"This limburgite bears individual crystals of olivine two to three inches in length and one to two inches in breadth. A single specimen has been placed in the museum of Dartmouth

College containing a crystal of olivine two and one-half inches by one and three-fourths.

"Some of the smaller crystals by the oxidation of the iron have become converted into limonite or hematite; others have gone over into serpentine, while a bit of calcite derived from the contiguous orthorhombic pyroxene or the basic plagioclase feldspar is occasionally seen in the cavities once filled by the original olivine crystals.

"As the locality is to the northward in the exact direction of the moving ice, and at a distance of only about twenty miles from the famous Thetford boulders, it seems evident that Corinth, Vt., was their original habitat."

PALAEONTOLOGY.

When the Washington limestone was formed by successive sedimentary depositions it was unquestionably replete with fossils, but when granitic eruptions burst through it with that intense heat and powerful crystallizing agency by which the limestone has become so highly metamorphosed, almost the last relic of its organic life was obliterated.

In fact we are compelled to look to a contemporaneous area in Canada for our palaeontological evidence. Dr. C. H. Hitchcock has reported an area of limestone in Derby, Vt., full of crinoidal fragments about one-fourth of an inch in diameter.

A microscopical slide of the Waits River marble has afforded evidence of the same fossils, but the strongest testimony yet in favor of a few existing fossils is the discovery of a crinoidal stem one-half inch in diameter in the Waits River marble December 28, 1897. It was exhumed from ten feet below the surface of bed rock.

The stem was slightly distorted with an elongation in the direction of the lamination. A large sum was refused for this crinoidal stem because the block was wanted for a definite monument. This locality has been most thoroughly examined many times during the past six years, and always with an increasing amount of evidence of a positive nature. I believe

that here, as the quarries are worked to a much greater depth, we shall soon find our richest palaeontological evidence in the Washington limestone.

The Canadian territory is at Willard's Mills, Castle Brook, Magog, Quebec, about three miles to the west of the head of Lake Memphremagog. The slates are lithologically homogeneous with the roofing slates of Montpelier and Northfield, and are, doubtless, the most productive of graptolites of any rock yet discovered, either in Canada or the United States.

The coveted bonanza is situated on the western bank of the brook, directly opposite the mill, where the decomposing terrane has been in part carried away by the rapid washings of the overflowing dam.

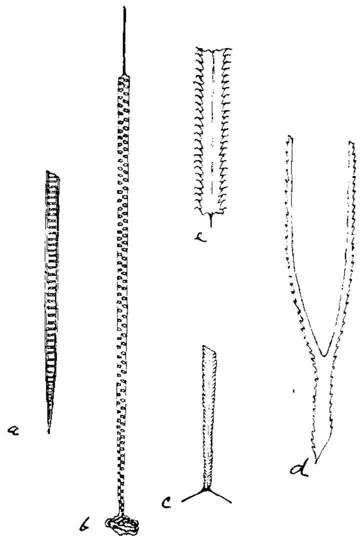
Large collections of these graptolites have been made both by the Geological Survey of Canada and by Dr. C. D. Wolcott of the United States Geological Survey.

October 9, 1897, I visited the locality with Dr. C. H. Hitchcock, and we made extensive collections for the museum of Dartmouth College. In this most fortunate contribution I have identified fifteen species, a full list of which is given below:

Dicranograptus ramosus, Hall.
Dicranograptus furcatus.
Dicranograptus sextans.
Diplograptus angustifolius.
Diplograptus foliaceus-pristis.
Diplograptus mucronatus.
Graptolithus laevis.
Graptolithus sagittarius.
Graptolithus scalaris.
Graptolithus tenuis.
Climacograptus bicornis, Hall.
Climacograptus normalis.
Caenograptus gracilis.
Corynoides calicularis.
Monograptus clingani. ?

The last species was accidentally broken, but it showed a curved virgula with proximal and distal ends distinct, and a few celules near the center of the convex side.

The accompanying figure represents four species of these graptolites, one-half natural size.



a, Graptolithus scalaris, showing a smooth margin.

b, G. scalaris, showing a chitinous mass at the base of the radical termination.

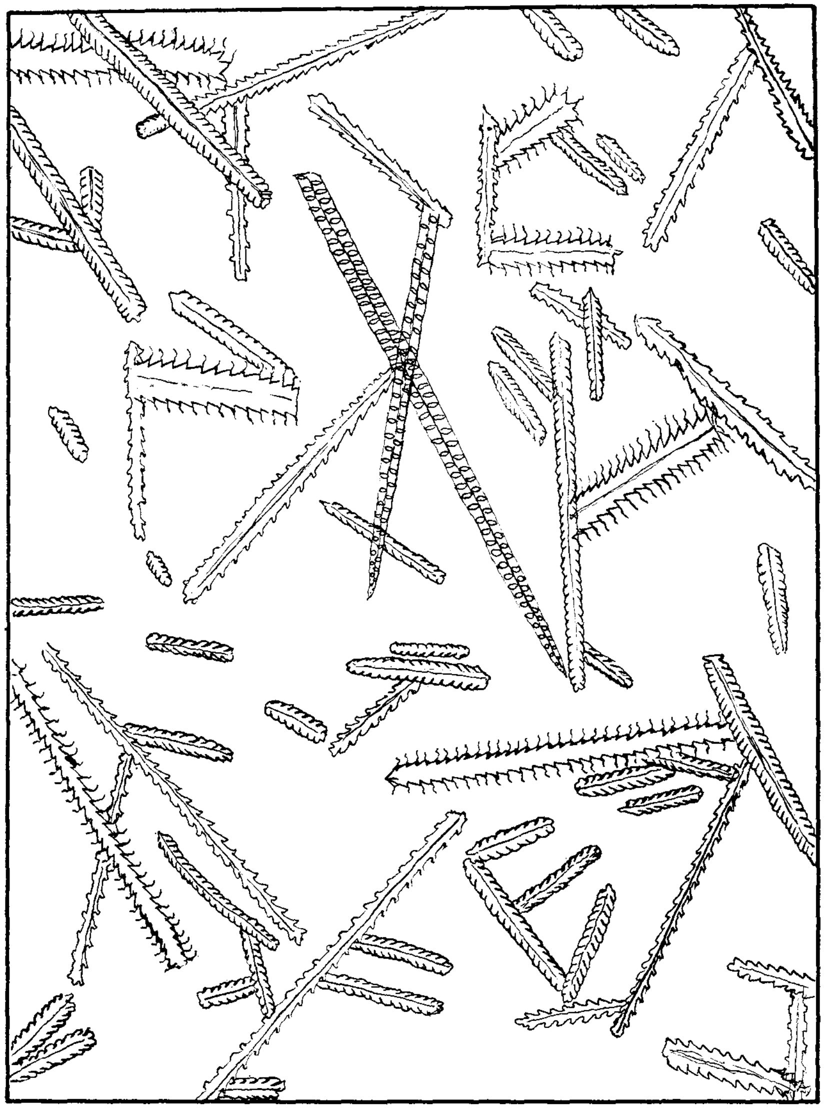
c, Climacograptus bicornis, showing obtuse teeth and a strong bifurcation which is thickened at the point of separation.

d, Dicranograptus ramosus, showing the diverging and elongated bifurcations.

e, Diplograptus mucronatus, with the mucronate teeth extremely well preserved. From Castle Brook, Magog, Quebec.

Plate XXIV represents a section of slate with a few of the best preserved forms of the graptolites. Many broken and incomplete forms present on the same fragment of slate were not sketched. As the illustration is natural size it will furnish some idea of the abundant distribution of these fossils.

PLATE XXIII.



Graptolites.

Slab of Lower Trenton Slate, Castle Brook, Magog, P. Q. Twice natural size.

Dr. George M. Dawson, in his Annual Report of the Geological Survey of Canada, Vol. VII, 1894, Appendix 133 J., enumerates the following species from the collections made by Dr. R. W. Ells and W. E. Deeks, 1890, and by H. M. Ami and H. B. Cushing, 1894:

Leptograptus, species indeterminate.
Dicellograptus, probably new species.
Dicranograptus ramosus, Hall.
Climacograptus bicornis, Hall.
Climacograptus bicornis, variety scalaris.
Climacograptus, new species.
Diplograptus foliaceus, Murchison.
Diplograptus angustifolius, Lapworth.
Glassograptus ciliatus, Emmons.
Corynoides calicularis.

The comparative absence of fossiliferous terranes in eastern Vermont has made doubtful from the biological standpoint the stratigraphical position of the slates, Bradford schist and Washington limestone. It has been left to physical, stratigraphical and lithological similarity; therefore its pronounced age has oscillated from the Primitive of Zadoc Thompson to the Niagara of Dr. Dana.

If we attempt to define the general stratigraphical succession in accordance with some great cycle of orogenic development in eastern Vermont, we find the slate resting unconformably upon the great Huronian terranes on the east and the west.

The eastern slate is the oldest and marks the beginning of the Lower Trenton series; the western is the youngest and marks the culmination of the period. The succession is continuous from east to west, and records no unconformity in Orange county.

If ever such relations are found between the Lower and Upper Silurian terranes of eastern Vermont, I am confident that it will be in the vicinity of Lake Memphremagog.

Although the uncertainty increases as we approach the more and more ancient deposits, nevertheless it is not extremely difficult to give a true stratigraphical position to these Palaeozoic terranes.

When we study the records of the Canadian graptolites, when we consider the lithological homogeneity of these slates, when we accept the evidence of crinoidal stems in the Washington limestone, when we know the true stratigraphical position of these terranes, we are compelled to locate the clay slates, the Bradford schist and the Washington limestone as Lower Silurian, and more specifically Lower Trenton.

BIBLIOGRAPHY.

1841 Final Report on the Geology of Massachusetts; Mica Schist with Beds of Limestone.—Dr. Edward Hitchcock.

1842 History of Vermont, Natural, Civil, Statistical, with Appendix upon the Geology of Vermont, pp. 222, 223. Limestone with Argillaceous Slate.—Zadoc Thompson.

1845 First Annual Report of the Geology of Vermont, p. 62. Calcareo-mica Slate Belonging to the Primary System.—Professor C. B. Adams.

1846 A Manuscript Map; Calcareo-mica Slate.—Professor C. B. Adams.

American Journal of Science, II Edition, Vol. I, p. 435. Calcareo-mica Slate.—Professor C. B. Adams.

1847 Third Annual Report of the Geology of Vermont, p. 24. Calcareo-mica Slate.—Professor C. B. Adams.

Geological Survey of Canada. A Geological and Mineralogical Description of the Eastern Townships. Gaspé Slate.—Sir W. E. Logan.

1848 Geography and Geology of Vermont, 44, 45, 188, 189. Calcareo-mica Slate.—Zadoc Thompson.

1855 Esquisse Géologique of Canada, accompanied by a geological map of British North America to illustrate the extensive collection of rocks and minerals at the Paris Exposition. Niagara Limestone.—T. S. Hunt.

1856 Preliminary Report of the Natural History of Vermont, Appendix, p. 76. Calcareo-mica Slate.—Augustus Young.

1858 Proceedings of the Boston Society of Natural History. Calcareo-mica Slate.—C. H. Hitchcock.

Second Annual Report of the Geological Survey of Vermont, p. 10. Calciferous Mica Schist.—Dr. Edward Hitchcock.

1859 Geological Map of A. D. Hagar, published in connection with H. F. Walling's topographical map of Vermont. Mica-slate Schist.

1861 Geology of Vermont. Calciferous Mica Schist.—Dr. E. and C. H. Hitchcock.

Map of Final Report. Calciferous Mica Schist.—C. H. Hitchcock.

1862 Letter to Mr. Joachim Barronde on the Taconic Rocks of Vermont and Canada. Lower Taconic (Cambrian).—Jules Marcou.

Proceedings of the Boston Society of Natural History, Vol. VII, pp. 327, 369; Vol. VIII, p. 239. Calciferous Mica Schist.—C. H. Hitchcock.

1863 Geological Survey of Canada, with Atlas, pp. 431, 432. Gaspé Slates and Limestones (Upper Silurian).—Sir W. E. Logan.

1865 Monograph of the Graptolitidae of the Quebec Group. Decade II, Niagara.—Dr. James Hall.

1866 Geological Map of Canada. Gaspé Slates and Limestones.—Sir W. E. Logan.

1867 Geology of Vermont. Papers before the A. A. A. S. Calciferous Mica Schist.—C. H. Hitchcock.

Manual of Geology. Third Edition, p. 221. Niagara.—Dr. James D. Dana.

1869 First Annual Report on the Geology and Mineralogy of New Hampshire, p. 21. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

1870 Second Annual Report on the Geology and Mineralogy of New Hampshire, p. 17. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

The Geology of Northern New England. Paragraph 12 under Geology of Vermont. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

1871 Walling's Official Atlas of Massachusetts. Geological sketch, p. 20. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

1872 Report on the Geology and Mineralogy of New Hampshire, p. 7. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

Paper before the A. A. A. S. Explanations of a New Geological Map of New Hampshire. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

1873 Proceedings of the Boston Society of Natural History, p. 4. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

Relations of Geology and Agriculture. Report of the Board of Agriculture of New Hampshire. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

1874 American Journal of Science. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

Twenty-seventh Annual Report on New York State Museum of Natural History, by Regents of the University. Distribution of Niagara Group. Niagara.—Dr. James Hall.

1877 Topography and Geology of New Hampshire. State Atlas of Comstock and Kline. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

Geology of New Hampshire, Vol. II, p. 395. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

1879 Geology of New England. McFarland's American Geological Railway Guide. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

1881 Geological Map of the United States. Calciferous Mica Schist (Lower Silurian).—Dr. C. H. Hitchcock.

1884 Geological Sections Across Vermont and New Hampshire, with map showing lines of the sections. Bulletin of the American Museum of Natural History. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

Geological Sections Across Vermont and New Hampshire, in New Hampshire Agriculture. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

1886 Geological Survey of Canada, Vol. II, p. 29 A. Niagara (Upper Silurian).—Dr. A. R. C. Selwyn.

1887 Geological Survey of Canada, 47 K. Lower Trenton, Lower Silurian.—Professor Lapworth.

1890 Revised Edition of McFarland's American Geological Guide. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

1892 Geology of the Green Mountain Area in Massachusetts. Hawley Sheet. Privately printed. Goshen and Conway Schists (Upper Silurian).—Dr. B. K. Emerson.

1894 Annual Report of the Geological Survey of Canada, Vol. VII. Lower Trenton (Lower Silurian).—Dr. George M. Dawson.

1895 Paleozoic Terranes in the Connecticut Valley. Calciferous Mica Schist.—Dr. C. H. Hitchcock.

Manual of Geology. Fourth Edition. Niagara.—Dr. James D. Dana.

A Mineralogical Lexicon. Published as a bulletin of the United States Geological Survey, No. 126. Goshen and Conway Schists.—Dr. B. K. Emerson.

1898 The Calciferous Mica Schist and Its Associated Terranes. A thesis of 177 pages, 44 photographs, 6 drawings and 3 maps, in the library of Dartmouth College.—Dr. C. H. Richardson.

The Washington Limestone in Vermont. Proceedings of the American Association for the Advancement of Science. Boston meeting. XLVII.—Dr. C. H. Richardson.

Report on the Marble, Slate and Granite Industries of Vermont.—Professor G. H. Perkins.

Analysis of Washington Marble, with notes upon Distribution and Age in the last mentioned report.—Dr. C. H. Richardson.

REPORT

OF THE

STATE GEOLOGIST

ON THE

Mineral Industries and Geology of Certain Areas

OF

VERMONT.

THIRD OF THIS SERIES, 1901-1902.

GEORGE H. PERKINS, Ph. D.,

State Geologist and Professor of Geology, University of Vermont.

J. B. LYON COMPANY, PRINTERS,
ALBANY, NEW YORK.
1902.

CONTENTS.

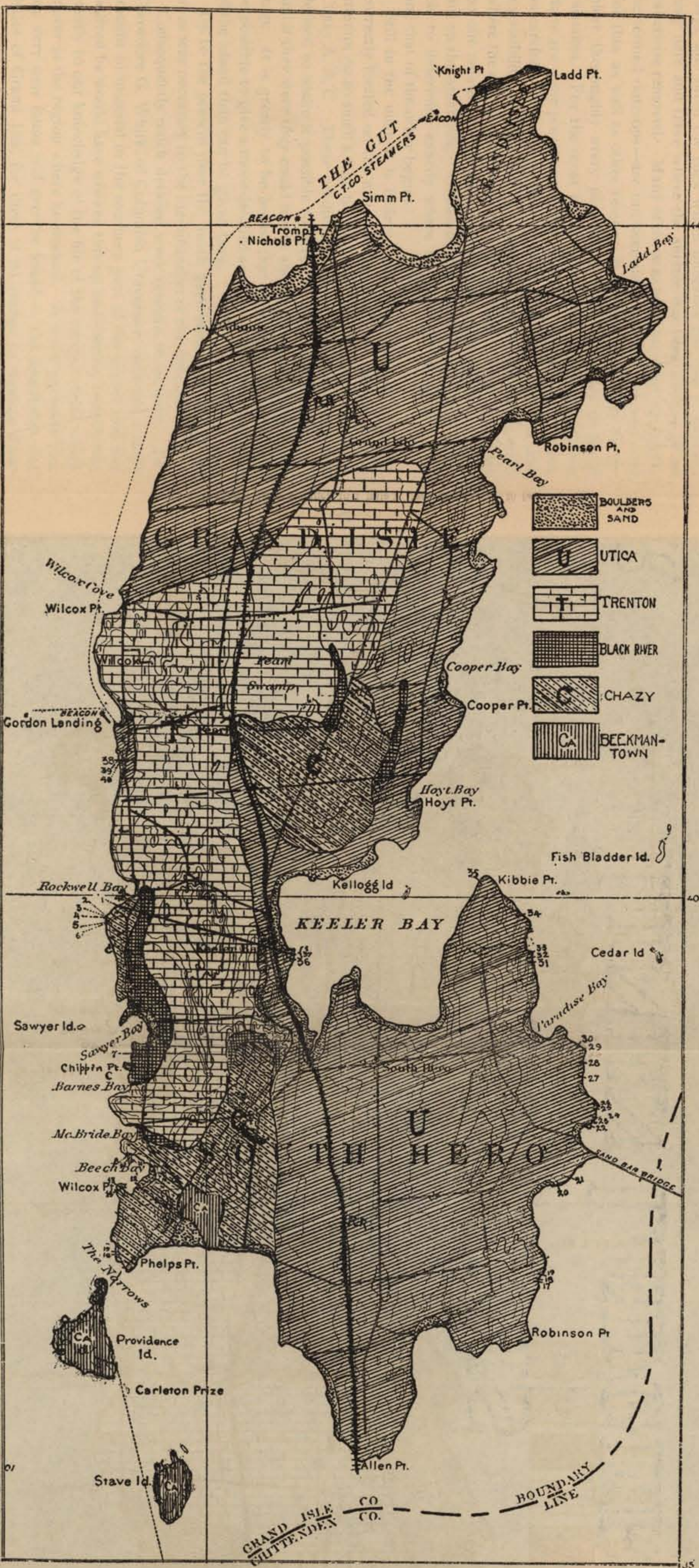
The Geology of Grand Isle.

The following pages contain a summary of the results of work done on Grand Isle, or South Hero, at intervals during the summers of 1901 and 1902. The writer does not wish anyone to suppose that he has attempted to give a complete report upon the geological formations of the island, for this cannot be done without much detailed study of the beds, which are there exposed. Rather is it the design of the following pages to furnish a general account of those features of the island geology which are most obvious and which any geologist who wished to explore the region would most need to know. More full study of the limits of the different beds and especially of the fossils contained in them will, it is hoped, follow in due time.

The writer is glad to acknowledge the very important assistance rendered in the work by Professor H. M. Seely, of Middlebury.

Professor Seely accompanied the writer in his investigation of most of the strata of the western part of the island, and his familiarity with similar strata in other parts of the Champlain Valley, as well as his knowledge of general geology, rendered his counsel and advice of the greatest value. Professor Seely has also read the manuscript of this part of the report, and its value is much increased by the adoption of many suggestions which he was able to make.

The reader will find frequent reference to the accompanying map of Grand Isle helpful to an understanding of the following account. It should be said of this map that it is designed to show as accurately as possible the areas occupied by the rocks of different geological age. As will be seen in the following pages, much of the surface of the island is covered by glacial



Geological Map of Grand Isle.

Scale, 1=62.500. (About 1 inch to 1 mile.) Contour interval, 20 feet.

clays, and often the rock which underlies the clay is exposed only here and there where the surface has been washed off or otherwise removed. Many of these exposures—they can hardly be termed outcrops—are not seen until one is quite near, and for this, as well as other reasons, it has been necessary to explore thoroughly every part of the island in order to avoid mistakes. For the most part this has been accomplished, but there are some portions which I have not been able to examine as carefully as I should have been glad to do. There is also a possibility of some lack of exactness in defining certain areas where the outcrops are not very near, and one formation appears on one side of the concealed area while a different one comes out on the other side. Obviously, it is not in such a case possible to determine exactly where the rock of one period ends and that of the other begins.

Still in the main it is believed that the areas will be found correctly limited on the map. It has not been deemed wise to attempt on so small a map to subdivide the areas, as for example Chazy A, B, C. These subdivisions are not yet sufficiently well defined to make it possible to give them for the whole island, and if they were they could not be shown plainly on the present map. It is greatly to be hoped that in a future report it will be possible to give a more detailed account of the palaeontology of the island than can be given here.

Up to the present time the fossils have been studied only so far as was necessary to the identification of the different beds.

Consequently much detailed work remains to be done. Dr. Theordore G. White, of Columbia University, collected a large amount of material in the southern part of the island, and had he lived he would have worked this up and thereby contributed greatly to our knowledge of the life of the various strata which appear in the region where he worked. It is not probable that any very new fauna will ever be found in the limestones and shales of Grand Isle, for there is no reason to suppose them very unlike the same beds which occur a few miles to the west in New York or south in other parts of the Champlain Valley.

Grand Isle, or as it is often called, South Hero, is the largest island in Lake Champlain. It is a rather long, narrow island, its long axis being nearly north and south. From Allen Point on the southern end to Ladds on the north its length is about thirteen miles. The greatest width just south of the village of South Hero is rather more than four miles, and the width south of Adams is about the same. The exact average width is not easily calculated, but it is not far from three miles. The shore is in many places indented by bays of greater or less area, usually, as shown in Plate XXIX,* of a semicircular outline, and often with the adjacent shores presenting landscapes of charming beauty. It is probable that all of these numerous bays are of glacial origin, the ice having carried out the limestone or shale which once filled the area now occupied by water, leaving only easily moved material which has since been washed out by the lake waves. And this process is still going forward, so that here and there, if not in all, the lake is constantly working inland and deepening the bays. The total area of Grand Isle is not far from nineteen thousand acres, or about thirty square miles. Most of this can be utilized for agricultural purposes. Various crops are raised, but the most important is that of apples. No less than twenty-two thousand barrels of apples have been sold from Grand Isle in a single year, and though ordinarily the crop is less than this, it is always very large. The surface of the island is for the most part quite level. There is a ridge, mainly of Trenton limestone, which extends partly through the island from south to north which constitutes the highest land, but this is nowhere more than 160 feet above the lake, and rarely more than 100, while most of it is not over 60.

Swamps, indicating a level below that of the lake, occasionally occur, but occupy only a small part of the surface of the island. The largest of these is Pearl Swamp, which covers something like a square mile, and another smaller one which extends south

* For the photographs of which most of the plates of Grand Isle scenery are reproductions, I am indebted to Rev. G. W. Perry.

from Keelers Bay to the west of Allens Point marks what is probably an old lake channel by which the present island was divided into an eastern and a larger western island. Other swampy tracts of no great area are seen near some of the numerous bays which indent the shore.

While rock masses of greater or less size crop out in many parts of the island and in many places the covered ledges are only a few inches below the surface, yet as one looks over it the greater part of the island is covered by Champlain clays. These mostly came from the ground material which resulted from the movement of the great ice sheets over the country by which the mountains and ledges were often ground to powder, and this fine material was then distributed and deposited by water. On the island these clays were deposited when the lake covered the whole surface, and in the still water the material was deposited and somewhat compacted. Immediately after the melting of the great ice masses Lake Champlain was much larger than at present, and therefore covered much that now is dry land.

At this time, the islands being submerged in the glacial lake, the clay which now forms so large a part of the soil of Grand Isle was deposited. In some few places there is boulder drift, and here and there the surface is strewn with local drift, some of it from near ledges. In the northern part of the island the soil is often mixed with another clay which has come from the decomposition of the underlying Utica shale.

Sand is not commonly found, but between Allens Point and Phelps Point there is an extensive ridge of yellow sand which is perhaps a mile long and ten to fifteen feet high.

This is piled up by lake winds and waves and is being blown inland in some places over cultivated fields. This sand undoubtedly has come from the Lamoille River, which empties into Lake Champlain not far south of the island. Other though small areas of pure sand occur on the shores of the bays.

Before speaking further of the geological formations which are found on Grand Isle, it will be well to call attention to the names which are used to designate the different subdivisions. The term Champlainian is used instead of Ordovician, or the more common Lower Silurian, because the first given term appears to have priority and to be more appropriate. Beekmantown is adopted in place of Calciferous, while the familiar names Chazy, Black River, Trenton and Utica Shale are retained.

As has just been indicated, the rocks of Grand Isle, i. e., the limestones and shales, are all of the Champlainian (Ordovician) age. The rocks on the mainland east of the island are Cambrian, and therefore older, while those of the New York shore to the west are of the same age. Only a few quite small areas of the Beekmantown beds are found on the island, all near the south end. All, or nearly all, of the members of the Chazy appear. There is only a part of the Black River and a part of the Trenton and probably the whole of the Utica.

It is probable that originally Grand Isle, North Hero, Isle la Motte and the Alburgh peninsula were, after the elevation which came at the close of the Utica, one body of land which has been since divided into the separate islands which they now are by erosion. Still the whole of this land does not appear to have been formed at the same time, for the southern part of Grand Isle and the whole of Isle la Motte are older than North Hero and Alburgh.

Probably the islands were raised out of the ancient sea before the Green Mountains were completed, that is, before or soon after the close of the Champlainian. The limestone and shale so common on the islands was formed in deep, quiet water. Hence we may believe that the Champlain sea, which was an arm of the larger ocean, was for a long time undisturbed by upheaval or other geologic activity. Before this there was only a narrow river-like body of water which connected the present Champlain Valley with that of the Hudson and which wore out the deeper parts of the present lake. By the later uprising of the land between Whitehall and Troy this connection was broken.

After the great ice sheet melted and thus retreated northward the land was depressed and the glacial lake became an arm of the St. Lawrence Gulf. It was during this time, as well as in the preceding, that the clays mentioned before were deposited. Finally the land again rose to its present height, which is less than that in the early part of the ice age and the present lake basin was outlined.*

Returning to the development of the island, we may notice that its first foundations seem to have been laid down in the upper Beekmantown, though at this time only a small area was made. Then during the Chazy considerable additions were made along the western shore and also on the eastern, north of Keelers Bay. Later, Black River beds were deposited, mostly in rather narrow strips and not covering large areas, though the beds are thick and massive. Then came the laying down of the Trenton strata, which, after some upheaval, were to form the higher portion of the island. In the still muddy waters of the Utica most of the eastern and northern parts of the island were formed.

During the whole of this very long period, that is, through the whole of the Champlainian, there was not much change in the position of the strata, but after the close of the Utica when the whole region was greatly disturbed and the main mass of the Green Mountains was raised up and metamorphosed, the beds on the island felt the commotion. For the most part the strata below the Utica are not greatly disturbed, the dip in most cases being only a few degrees, as will appear later on, though in exceptional cases as in some parts of the Trenton uplift which forms what may be called the back bone of the island, there is strong tilting, and in a few cases also some of the Chazy beds have been much tilted. When we come to the Utica, however, we frequently find far greater evidence of up-

*According to Baldwin, "The fresh water lake was at first fifty feet or more higher than now, but the Richelieu has lowered its channel to its present level since. The present lake lies mostly well above the preglacial channel, but the southern end seems to occupy that part of the old channel, and is now little broader than a river."

heaval and its attendant phenomena. Many of the Chazy, Black River and Trenton beds are nearly horizontal, as shown in the latter beds in Plate XXVIII and the Black River in Plate XXXIV. In Plate XXVI we may see Trenton beds somewhat folded, and in Plate XLIX, which is one of the shale headlands near Allen Point, the Utica layers are thrown up until they are nearly vertical, and in Plates LI, LII, LIII, which show the cliff south of Sandbar bridge, we have an example of folding and crushing which can scarcely be surpassed in complexity. Not only in the displacement of the rocks have the forces that were in action after the close of the Champlainian left proof of their activity, but in numerous faults, most of them not very extensive however, which are met with in different parts of the region. It is very likely that some of the bays were started by a fault, that is by a break in the strata and the uplift of the beds on one side thus disturbing the continuity of the beds.

Most commonly, the uplifted beds have since been so completely eroded that no indication of the fault is noticeable on the surface. Dikes, which usually appear as bands of harder and darker rock running through the limestone or shale, have been produced by volcanic action which has broken asunder the beds of stratified rock and through the crevice thus formed forced up a lava stream which cooled into the hard rock now found. In a subsequent section these dikes will be fully treated. It is sufficient for the present to notice their existence and frequent occurrence on some parts of the island. Between Rockwell Bay and Phelps Point, a distance in a straight line of not more than three miles, there are sixteen dikes varying in width from only a few inches to four feet. It is not possible to determine how long these volcanic activities continued, but it must have been long. Finally, however, the disturbances ceased, and for a vastly longer period a new series of conditions prevailed.

At the close of the Utica Grand Isle became dry land, having been elevated from the sea in which the Utica shales were deposited, and it appears to have remained above water through the vast period of time which must have elapsed while elsewhere in North America the great beds of the Silurian, Devonian, Carboniferous, the whole of the Mesozoic and the Tertiary were slowly formed and occupied by varied and ever changing animal and vegetable forms. It is difficult, if not impossible, to comprehend the duration of this vast interval during which we cannot suppose that no change took place in the surface of the island, for the rains, frosts, and all atmospheric agencies must have been active, slowly, but constantly. The waves of what may have been now a sea, now an ocean current, now a river, also did their part in wearing away the land.

The slow weathering and erosion of the rock went on century after century, until the total effect must have been very great. The result of all this was that the surface of the land was more level, that the elevations were reduced and movable materials washed into the hollows, the shore was gradually worn away and, as the rocks were of very unequal hardness, worn away very unevenly, thus giving much irregularity to its outline, the different islands were separated from the mainland and from each other, and there was general reduction of the area of dry land and of surface irregularities. It is scarcely conceivable that during all these ages, millions of years in duration, there should have been no life, either animal or vegetable, on the islands of the Champlain Sea, but whatever living things there were they have left not the faintest trace to tell of their existence. From what we know of the life of other parts of the country during this time, we can judge as to what species may very probably have migrated hither, but knowledge of them we have none so far as Vermont is concerned. Thus from the close of the Champlainian, through Palaeozoic and Mesozoic time, no beds of rock were laid down in this region because no part of it was at any time beneath the surface of the ocean.

At length, however, a new series of conditions and a new set of forces came into action. At the close of the Champlainian the forces in action were mainly igneous; now it is not fire but ice that rules. Far to the north in the region of Hudson Bay there was accumulated an immense mass of snow and ice which became consolidated into an enormous glacier, hundreds of miles in width and thousands of feet in thickness. As is always the way with glaciers, this, like a great river of ice as it was, began to creep slowly southward. Year by year it approached nearer our territory and as it approached the climate, which, up to this time, had probably been much warmer than it is now, grew colder. Whatever life there was, animal or plant, was either destroyed or driven south. In time the vast ice sheet reached our northern border and came on over the land. With a momentum wholly irresistible on it came, crushing, grinding, destroying. The rocks were ground to powder or rubbed smooth over every exposed surface; points and pinnacles were pushed off; here and there, where now are bays, the whole mass of rock was pushed off from the surface and carried on in the path of the glacier. Always moving from the north to the south the vast mass crept on as if all was to be annihilated. To-day in the smooth and polished surfaces of many ledges, in the groovings, scratchings, and rounded surfaces of many of the exposed rock masses we find the story of the great ice sheet plainly written. Where the rock on the island is shale the softness of the material has made it impossible that the record long withstand the effects of the weather, but where, as for example, at Sawyer Bay, the rock is hard and compact, there most beautiful proof of the former presence of the great glacier may be seen. The marks of the ice on the ledges is especially distinct when the surface soil, which has protected the rock from the weather, has been recently washed off or been otherwise removed.

For a considerable time the present surface of the island was thus covered by this great mass of slowly moving ice, and was continually reduced by its erosion towards the level of the surrounding sea. But the region was not destined to be always arctic and in due time the cold climate, which had prevailed throughout the northern United States during glacial times,

PLATE XXIV.

Bank of Glacial Clay, Balls Bay.

By courtesy of *The Vermonter*.

began to moderate. As a necessary consequence of this moderation of the cold the ice of the great glacier began to melt and the ice mass itself began to retreat northward. A second consequence of the milder climate was that through the melting of the ice great volumes of water were poured over the land. These floods, of course, washed off and transported to other localities all movable material of which, as the result of the crushing, grinding glacier, there was enormous quantity. It should have been stated before speaking of the great ice sheet that all through the northern part of the continent the land had been slowly rising for a long time before the formation of the ice mass so that in the Champlain Valley the elevation finally reached not less than five hundred feet. This elevation of the continent was greatest in the north and decreased toward the south. After the greatest elevation had been reached the land began to subside until finally it was some hundreds of feet below the present level and the ice began to retreat. The period of greatest subsidence immediately preceded the melting of the ice, and at this time Grand Isle was under the waters of what I have called the Champlain Sea. It is not likely that the present surface of this island was ever covered very deeply, but it certainly was well covered, and in the waters of this sea were deposited the clays which now cover the surface. While as ocean depths go, the depth of water here may not have been very great, still it must have been considerable, for we find deposits of clay of twenty or even twenty-five feet in thickness.

Plate XXIV shows one of these deposits of clay and many similar occur on the island.

After the subsidence which followed the Glacial period had given place to reelevation, the surface of the island in wholly changed character once more appeared above the water to remain dry land as it is now.

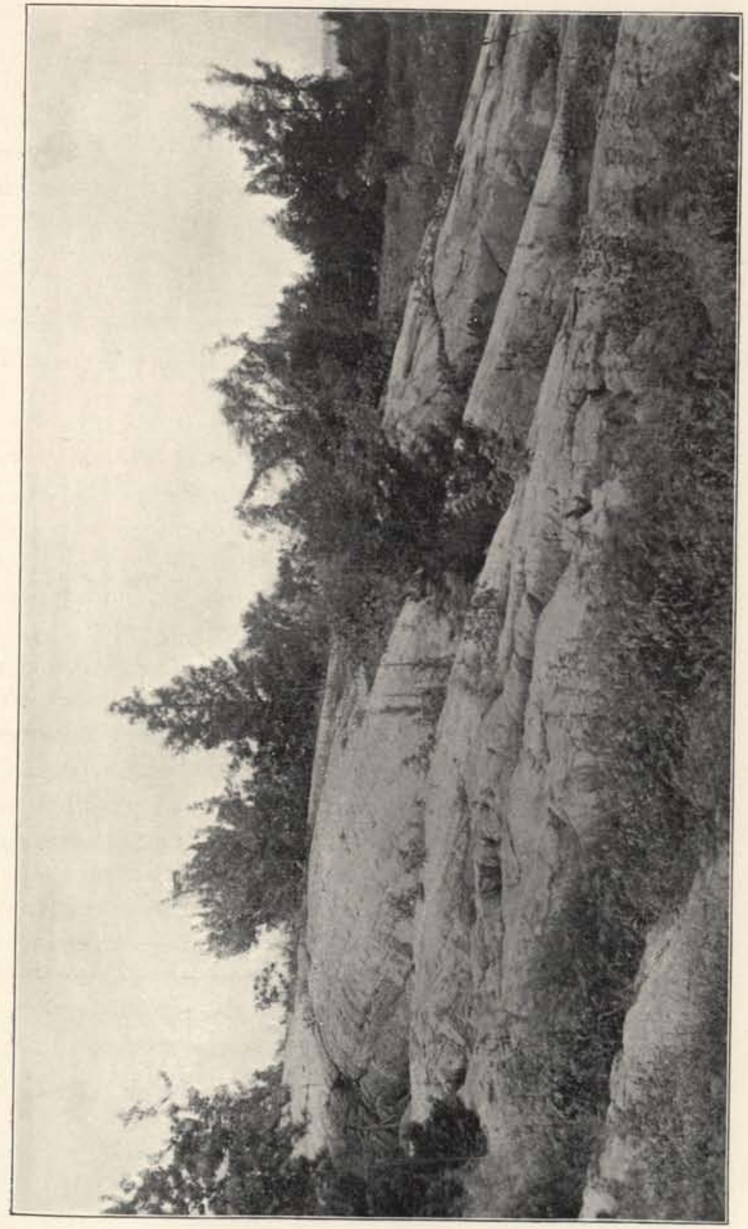
The scarcity of boulder drift from the island is easily understood from what has been said. Whatever was left by the great ice sheet was of course washed away during the subsequent subsidence. The presence of local drift, that is, angular fragments of neighboring rock to which I have alluded, shows that local glaciers may have existed even after the reelevation of the land and have broken the exposed ledges and transported the fragments short distances and then melted away, leaving their burdens where we now find them. There is nowhere, so far as I have discovered, evidence that after the final raising of the island its surface was disturbed to any great extent. The effect of the ice sheet is seen in many rock masses now found, as in the outcrop of Black River, shown in Plate XXV. It may be noticed, in passing, that while boulders rarely occur on the island, there are places on the shore where very fine groups of them may be found. Most of these are of Canadian rock, syenite, hornblende, gneiss, greenstone, etc., with an occasional representative of Vermont. Especially on the north end of the island do these boulders occur in profusion, some of them several tons in weight. As has been stated, the shores of the island are mostly rocky. By far the greater part of the shore line is made up of the Utica shale. Probably not less than five-sixths of the entire shore is Utica. It is the only rock which I have seen on the eastern, northern and a part of the western shore; that is, from Allen Point eastward and northward around the northern end of the island and down the west shore to Wilcox Cove only Utica shale is exposed on the shore. As will be noticed later, from Wilcox Cove south, with the exception of a small amount of shale near Gordons Landing, the rock, as far as Phelps Point, is limestone. Some of it, however, is shale-like. This portion of the shore is therefore most interesting to the geologist, and the following pages are chiefly occupied with an account of the beds of this portion of the island shore.

As has already been noticed, no part of the island is greatly elevated above the lake. With an occasional exception, the cliffs along the shore are only from 10 to 20 feet high.

The geological map will show better than any mere description the distribution of the different beds.

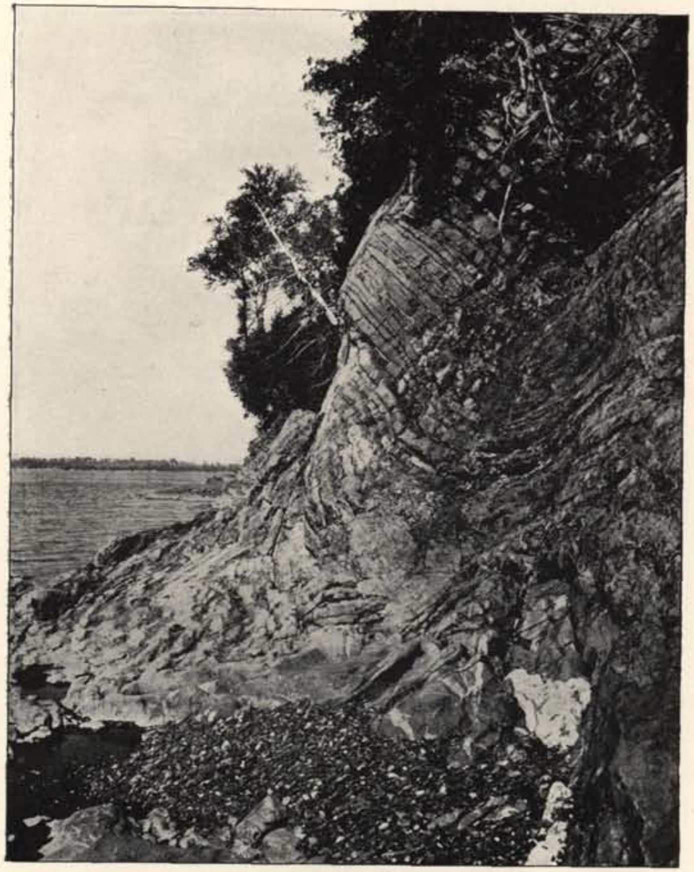
In the following pages it is my intention to give a running account of the different formations as they are found along the

PLATE XXV.



Black River Limestone, Showing Glaciation. East of Road Near Table Bay.

PLATE XXVI.



Synclinal Fold, North of Gordons; Trenton Limestone.

western shore, beginning on the north at Wilcox Cove and going on south to and including Phelps Point, a distance of about ten miles, following the irregularities of the shore. In a straight line it is five and three-quarters. So far as the lake shore is concerned, all the exposures which are not sand or Utica are included within this part of the shore. Many of the same and also other beds are found to a limited extent inland, as will be shown later.

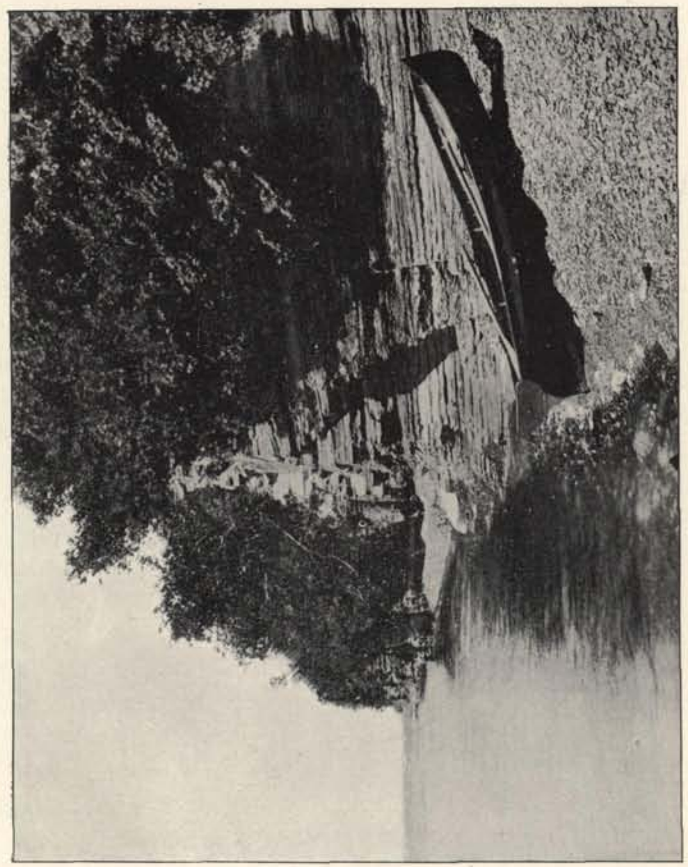
Commencing at Wilcox Cove and going along the shore at low water toward the south we find first the thin-bedded black shale characteristic of the Utica and containing *Diplograptus pristis, Triarthrus beckii, Orthoceras coralliferum.* North of the cove and around it there is evidence of much disturbance and the shale is strongly tilted and in places even vertical. The bedding is also very irregular. Some of the layers are less shaly and small faults occur in several parts of the cliff. The dip is at first southwest, but as we go south, northeast. Here the black shale, or shaly limestone, is frequently veined with pure white, or sometimes clouded, calcite. In places the rock is typical Utica shale, elsewhere more like Trenton limestone, and *Asaphus gigas* and *Diplograptus pristis* sometimes occur in the same block. For a considerable distance between Wilcox Cove and Gordons the beds are neither purely Utica nor Trenton but a mixture of both; that is, they form a transition series by which the Trenton passes imperceptibly into the Utica, so that it is not in any way possible to set a boundary between them. The same condition has been observed elsewhere, and it would seem that what has been called Utica and regarded as a distinct group should be placed as Upper Trenton, both because of lithological and palaeontological evidence. South of Wilcox Cove the strata are for a short distance horizontal or nearly so, and are in all about 12 feet thick. Ere long, however, there is a dip of 30° to 40° southwest.

Somewhat farther south, nearly west of the house of E. Gordon, the high, shaly cliffs have been greatly eroded by the lake waves and overhang the narrow beach. South of this, cliffs of

Utica shale 15 to 16 feet high appear. Still farther south similar beds appear. Throughout this part of the shore the confusion between the Utica and the Trenton is seen. A part of the cliffs seem to be undoubtedly Utica, then come those that are quite suggestive of the Trenton, then again typical Utica and so on. Finally not a long distance north of Gordons, or, as now called, Centers, true Trenton is met. This is a dark gray limestone which extends in low cliffs for some rods along the water's edge, sometimes—even at low water—coming quite to the edge of the lake. The bedding is quite irregular and in some places curiously concretionary or lenticular, the lenses being of various sizes from four or five inches in diameter to those of much greater size. This lenticular bed is from six to eight feet thick. There has apparently never been any great disturbance of these Trenton beds, as nowhere do they dip strongly. At the northern end the dip is 10° to 15° southeast, but near the little quarry north of Gordons it changes to northeast. At this quarry there is an uplift so that the strata are in a low anticline. Not far away, as seen in Plate XXVI, there are synclinal beds. At the northern end of this uplift the dip is northeast 10° to 15°, then for several rods the beds are horizontal, then at the south of the quarry the dip is southeast 20° to 30°. At Gordons dock and for some distance south the cliffs are clearly Utica. Plate XXVII shows a typical shale cliff. Then again the transition beds recur, so that one cannot decide whether the compact layers are Utica or Trenton.

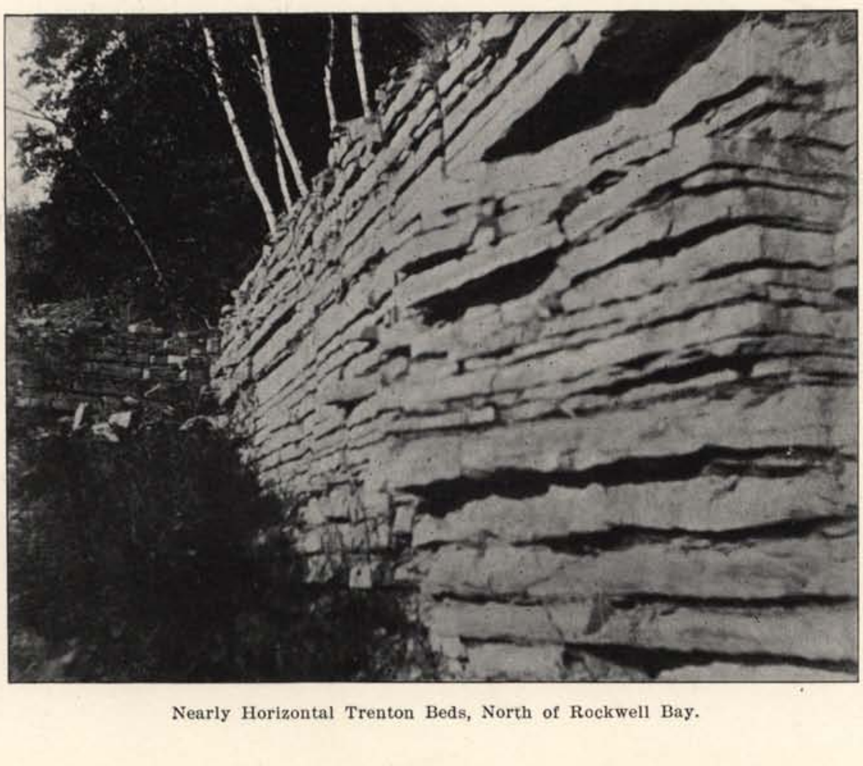
Here and there, as one proceeds south, the rock has been carried out by glacial action, in some cases aided by faults. The space left vacant by this removal is usually filled, not by drift, but by Champlain clay of light-brown color. When cliffs which are unquestionably Trenton are reached, they are quite different in character from any that have been found north of them. The compact rather thin-bedded limestone layers are separated by thin layers of shale, and as they are regular the cliffs appear as if built up by masons, as shown in Plate XXVIII. As may be seen, the strata are here much thinner and more regular than

PLATE XXVII.



Utica Shale, Corbin Beach, West Shore, Grand Isle. A Characteristic Shale Bluff.

PLATE XXVIII.

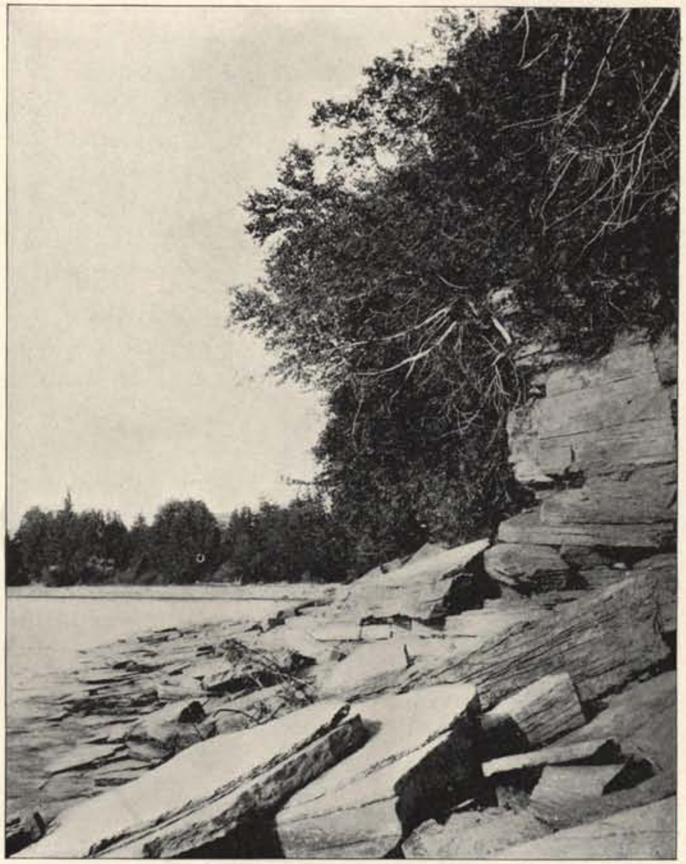


Nearly Horizontal Trenton Beds, North of Rockwell Bay.

PLATE XXIX.

Rockwell Bay from the North. A Typical Grand Isle Bay.

PLATE XXX.



Chazy Cliffs, Rockwell Bay. The Beginning of the Chazy on the West Shore.

those between Wilcox Cove and Gordons. The layers are from four to twenty inches thick, though most vary between four and ten inches. These Trenton beds dip only very slightly and form wall-like cliffs twenty to twenty-five feet high. The limestone is everywhere compact but of varying composition, as appears especially where weathered surfaces are seen, for some of the layers weather to a much lighter color than others; but all when freshly broken are black or very dark. Taken as a whole, the mass is not highly fossiliferous, but some of the layers are crowded with fragmentary fossils and now and then entire forms occur. The number of species is not large. The more common are *Asaphus gigas*, Hall, *Calymene callicephala*, Gr., which are abundant in certain thin layers, *Orthoceras strigatum*, Hall, *Endoceras proteiforme*, *Strophomena alternata*, Con., *Orthis occidentalis*, Hall, *O. lynx*, Eich., *Monticulipora lycoperdon*, *Stictopora*, *Crinoids*, etc. The trilobites are much more widely distributed through the different layers than are the other species named. In some places the rock is very evenly and sharply jointed and occasionally it contains cracks filled with white calcite.

Three dikes, Nos. 38, 39, 40, come through the shale near Corbins, about half a mile south of Gordons Landing.

At one point, just north of Rockwell Bay, a large mass of white calcite has filled a crevice in the limestone. This mass of calcite is eight feet wide at the top, from which it narrows to the bottom. So far as seen, from the top to the base of the cliff it is ten feet high. In general this crystallized mass is white, but parts are shaded with black, and some are quite black. These Trenton cliffs begin about three thousand feet or more than a half a mile north of Rockwell Bay and reach south to the north side of this bay.

ROCKWELL BAY.

Plate XXIX shows the general form of this and of most of the island bays; the details vary, but nearly all exhibit the regular semicircular form seen in this. For about fifty rods the shore is formed by Champlain clay. Most probably there has been faulting here between the Trenton and the Black River, and the latter has been carried out by the ice. There is a shoulder of the Black River which appears a short distance east of the shore, just across the road which runs along the lake, and this, apparently, formerly came to the shore. We leave the Trenton as has been seen on the north side of this bay, and after passing over the sandy beach strewn with boulder we come on the south side to the Chazy.

This first appears in a low shelving outcrop, seen, though not very plainly, in Plate XXX. The beds soon grow higher and form low cliffs along the shore, often so near that except when the water is at the lowest there is no beach between the rock and the water. Between Rockwell Bay and Table Bay the rock is all Upper Chazy, though the beds are often not at all homogeneous, but present much diversity in fossils, lithological characters and color.

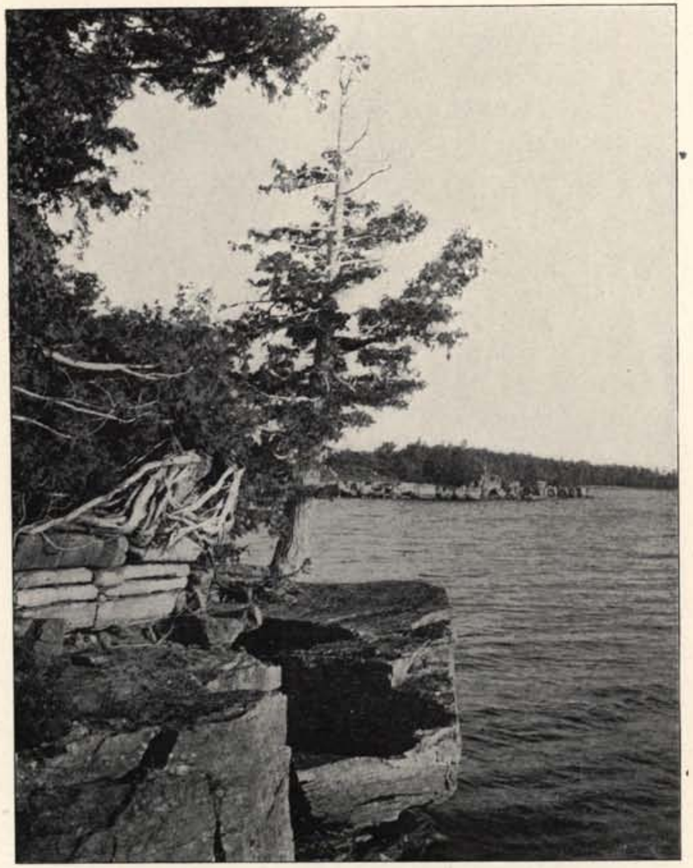
In the Chazy cliffs just south of Rockwell Bay there are two dikes which run through Eagle Camp. The first of these is very compact. No. 41 of the series described in Mr. Shimer's paper is from ten to fifteen inches wide. About 70 feet south of this is dike 42, which is peculiar in that it includes four narrow bands of limestone which alternate with an equal number of bands of dike rock. This dike is thirty-five inches wide and is much decomposed and nearly concealed by débris. Eighty rods south is dike No. 1 of Shimer's list. This crosses the island and enters Keelers Bay on the east side a little south of the site of the old Catholic Church. Like most of the dikes its course is nearly due east and west. There is a narrow vein of whitish calcite, seen in Plate XXXI, running through the western end of the dike or rather what is seen of it as it goes under the water of the lake. The whole dike is four feet wide, the calcite vein being from two to six inches, as its width varies. About 700 feet south of this dike is a second, No. 2 of the list. This is 27 inches wide. A hundred feet south of No. 2 is No. 3, a

PLATE XXXI.

Dike on the Shore, Number 1 of the List, Showing Vein of Calcite in Chazy Limestone.

Dike.

PLATE XXXII.

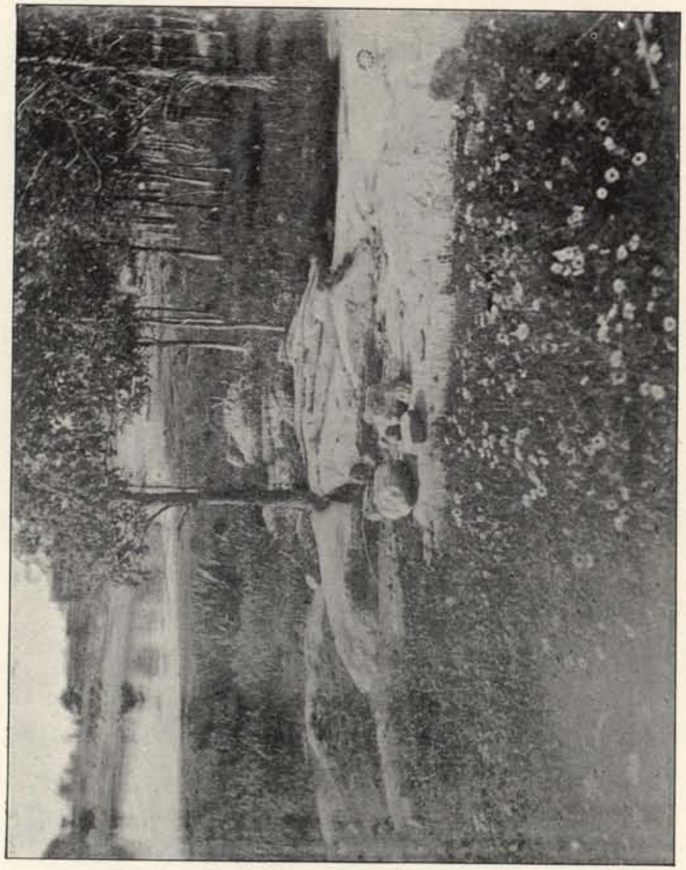


Black River.

Chazy.

Chazy.—Table Bay, from the North.
Chazy in the Foreground, Black River at Sawyer Point in the Distance.

Plate XXXIII.



Glaciated Black River Limestone, Table Bay, from the South.

little dike only seven inches wide. About thirty inches beyond this is No. 4, which is unlike most of these dikes in that its course is quite irregular and crooked, though it maintains the same general direction, east and west, as do the others. This irregular dike is twelve inches wide. No. 5 is not far south of No. 4. It is only six or seven inches wide, and near it is No. 6, which is nearly thirty inches wide.

A few rods before reaching Table Bay the cliffs recede fifty to a hundred feet from the shore, and here the typical Rhynchonella beds first appear and are finely exposed. The beds above these are very full of small branched corals. Farther east in the field there are exposed surfaces of Upper Chazy quite like those that appear in Hills pasture on Isle la Motte and which have become famous for the great abundance of cephalopods which they contain.

The total thickness of the Chazy at this point is not great, perhaps twenty-five or thirty feet.

TABLE BAY.

This is a small bay unnamed on the coast survey charts and not even very well marked. Nevertheless, it is very well defined (Plate XXXII) and is interesting because, on its southern side, the Black River limestone first appears on the shore, though it crops out, as we have noticed, east of Rockwells Bay, and from that point it may be followed as a rather narrow strip south, always approaching the shore, which it finally reaches, as indicated. Plate XXXIII shows Table Bay, and in the foreground is the finely glaciated Black River.

Between the gradual disappearance of the Upper Chazy on the north of this bay and the appearance of the Black River on the south for a distance of three hundred feet the shore is of a compact bed of Champlain clay, which is what is seen as one looks across the bay in the plate. There seems to be a fault and uplift of the rocks here. Continuing on around Sawyers Point the Black River beds grow rapidly thicker and more massive.

Plate XXXII is taken from the north, looking across a part of Table Bay and on to Sawyers Point. The thick-bedded rock in the foreground are the Rynchonella beds of the Chazy, while, as we have seen, the point is Black River, and the most distant shore is also mostly of this formation. Plates XXXIV and XXXV show admirably the peculiar characters of the Black River.

Everywhere on the island it is a very compact, black or dark gray stone breaking with a peculiarly smooth and even fracture, and usually the beds are beautifully jointed so that in more than one instance the stone has been used for building into house wall with no other dressing than was necessary to break out the blocks from the mass. Plate XXXVIII, which was taken at Chippen Bay somewhat farther south, shows this same regular jointing; especially is this seen in Plate LX.

SAWYER BAY.

Following the shore from Table Bay around south into Sawyer Bay we find the Black River greatly glaciated and forming the shore in broad, smooth sheets, which are soon covered by clay deposits. The unusually fine glaciation seen here is undoubtedly due to the recent removal of the surface clay which has hitherto protected the surface of the limestone.

According to the statements of the residents this bay is eating its way inland. There is good evidence corroborating these statements, for the road has evidently been moved away from the shore within a few years, as parts of the old road have become impassable because washed away. From its appearance on Table Bay to its disappearance on the north of Sawyer Bay the Black River extends about a fourth of a mile. Then after crossing the sandy beach, back of which is a solid bank of Champlain clay, to the south side of this bay we again find the limestone appearing. The point on the south, however, is not Black River, but the top of the Chazy. These Chazy beds are very low, forming no cliffs, but only shelving shores. They closely resemble the Lowest Chazy or Upper Beekmantown beds, the

PLATE XXXIV.

Thick-bedded, Regularly Jointed, Black River Limestone, Sawyer Point.

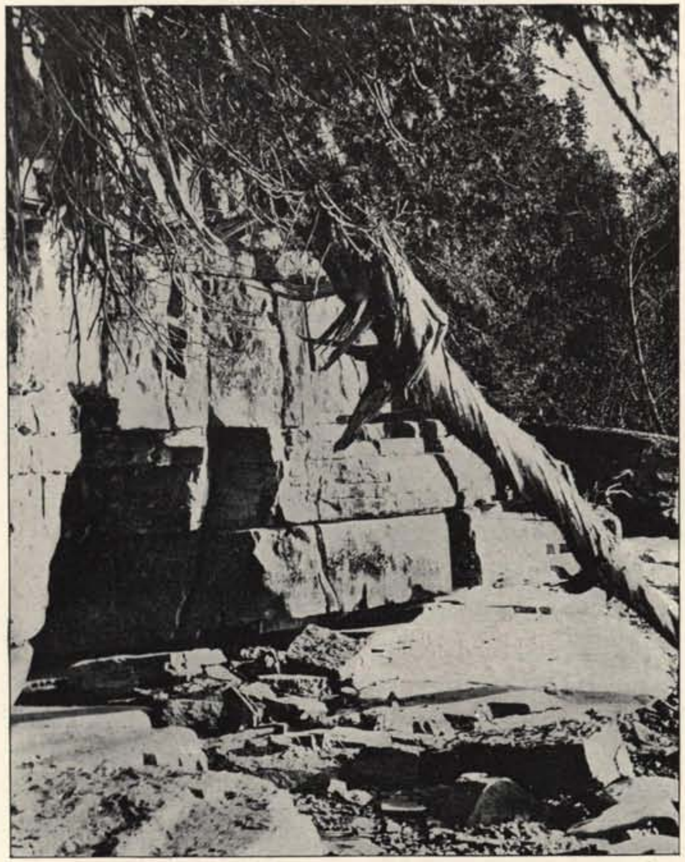
PLATE XXXV.

Black River Limestone, Showing Regular Jointing, Sawyer Bay.

PLATE XXXVI.

Chippen Bay, Looking North. Black River Limestone.

PLATE XXXVII.



Double Cave, Chippen Bay. Black River Limestone.

limestone being strongly siliceous with much yellow sandy material formed in comparatively shallow, muddy water. The limestone contains few fossils for the most part, but in places sponges and other fossils may be found, enough to clearly settle the position of the strata. This does not extend far along the lake, and the very different Black River beds reappear as we come around into the next bay south, Chippen Bay. Nowhere on the island is the Black River so fully exhibited as here.

CHIPPEN BAY.

At first the limestone appears in the same broad, smoothly, glaciated surfaces as we found north at Sawyer Bay. There is little disturbance of the strata, the dip being not over six inches and often less. Ere long the beds are thicker and more massive and form a most regular and solid wall along the water, which is deep enough at the cliffs to allow boats to land against them, using them as a dock. The dip here is for some distance 5° north. Here is a dike forty-eight inches wide, which is different from most in the region, in that it has weathered out from the limestone, leaving a channel some sixteen feet deep. Plate XXXVI gives a general view of Chippen Bay looking north. All the cliffs seen are Black River, and are much higher than at first appears, as they are partly hidden by the trees, Arbor Vitae or White Cedar, which so commonly fringe the rocky island shores and add greatly to the beauty and picturesqueness of the scenery. In the cliffs at this bay the limestone has been in two places so eroded as to form caves (Plate XXXVII). These are side by side and indeed are united for a part of their extent; and the entrance is common, as may be not very distinctly seen in the plate. They are long, narrow, funnel shaped. The northern and smaller is only about three feet wide and high at the entrance and some twenty-five feet deep. The other is five feet wide and six high at the opening and thirty-five feet deep. They really form a double cave, separated by a thin wall of rock. Both become very narrow as they extend into the cliff. Caves are not usual in such rock as the Black River. These are explained by the presence in the cliff near the water of thin layers of shaly material, which readily washes out when attacked by the lake waves. In consequence of this, the more compact upper layers are undermined and fall out to be pulverized and removed by the waves which rush in. The cliffs here are some twelve feet high. Plate LX shows a part of this cliff looking north, and Plate XXXVIII shows the opposite side of the bay looking south towards McBride Bay. This latter presents a different rock. As one passes south around the rockless shore of the middle part of Chippen Bay, crossing 140 feet of sandy beach, he, as has occurred several times before in our progress along the lake shore, comes upon a wholly different sort of rock from that which he left. Here on the south part of Chippen Bay, instead of the clear, smoothly breaking Black River rock, there comes a mottled dark gray and yellow gritty limestone which weathers in curiously rounded cubical blocks, which often present a most singular appearance. It seems to be the "striped rock" of Wing, which he studied at Fort Frederic, 50 miles south. It is this rock which is shown in Plate XXXVIII, though the peculiar weathering does not show in the illustration. The beds of this rock dip only slightly 5° to 8° northeast. Some portions of these beds are curiously jointed, checked and cracked. A dike (No. 7) rather more than four feet wide crosses the low point on the south side of the bay.

The sponges and other fossils of these singular beds define them as Upper Chazy. Following the shelving shore south we soon come to

BARNES BAY.

Here we find the Black River once more, and lying directly on the Upper Chazy (Plate XXXIX). The Black River here dips 4° to 5° southeast, and the whole mass is twenty-five feet thick. The Chazy only appears near the water and not much more than a foot of it is exposed. The Black River is, however, finely seen here, and a short distance from the lake, back in the cedar forest, there is a quarry from which in former times considerable rock has been taken. The lower rock seen in figure

PLATE XXXVIII.

Chippen Point, South Side, Looking South.

PLATE XXXIX.

Contact of Chazy and Black River, Barnes Bay.

40 has all the characters already noted which are found in the Upper Chazy wherever it occurs. The bed of the Black River, which rests immediately upon the Chazy, resembles that limestone more than do the upper beds of that formation. They are less compact, lighter gray, and break with less metallic ring and less smooth fracture. Of this chazy-like Black River there is about five feet. All the rest of the cliff above is of the usual compact Black River. There is a slight uplift in the Chazy from Chippen Bay around into Barnes Bay, with an elevation of ten feet. The whole Chazy exposure here is nearly a thousand feet long from north to south. The strange jointing and weathering of some portions of the Chazy here has already been alluded to. In places the effect is quite unique and striking. The stone turns to much the color of iron rust as it is completely weathered and the layers, which are filled with the rounded masses, which often project to some extent beyond the general surface, appear like boulder conglomerate at a distance. These boulder-like masses, which do not become evident before the mass has considerably weathered, vary in size from those that are only four inches to five inches to those that are as many feet. In all the Black River is about 35 feet thick at Barnes Bay. The dip is for the most part slight, not over 4° or 5°, but at the south end it is more and finally reaches 20°. The general direction of the dip is south by a little east. This place is a good one for the collection of Black River fossils, some of the thinner layers being quite full of them. Besides other species, there are here some fine masses of Columnaria.

A small point extends a short distance into the lake at about the middle of Barnes Bay, formed by a small upthrust of limestone, the beds dipping on each side 10° to 15°.

Following the Black River about this bay southward we finally come to the Trenton, which soon forms cliffs. The layers near the water are much more friable than those near the top, so that these under layers are eroded more rapidly and the upper layer projects over them and over the water; though a more striking instance of this will be found later at Beach

Bay. The Trenton cliffs are here 13 feet high, and dip 3° to 4° northeast. At first thick, limestone layers grow thinner towards the south, and as we reach McBride Bay they resemble the same beds north of Rockwell Bay, but they are not as regular. Plate XL shows the beginning of the Trenton beds on the north of McBride Bay, and Plate XLI shows Trenton Cliffs at this point and the evenly bedded layers.

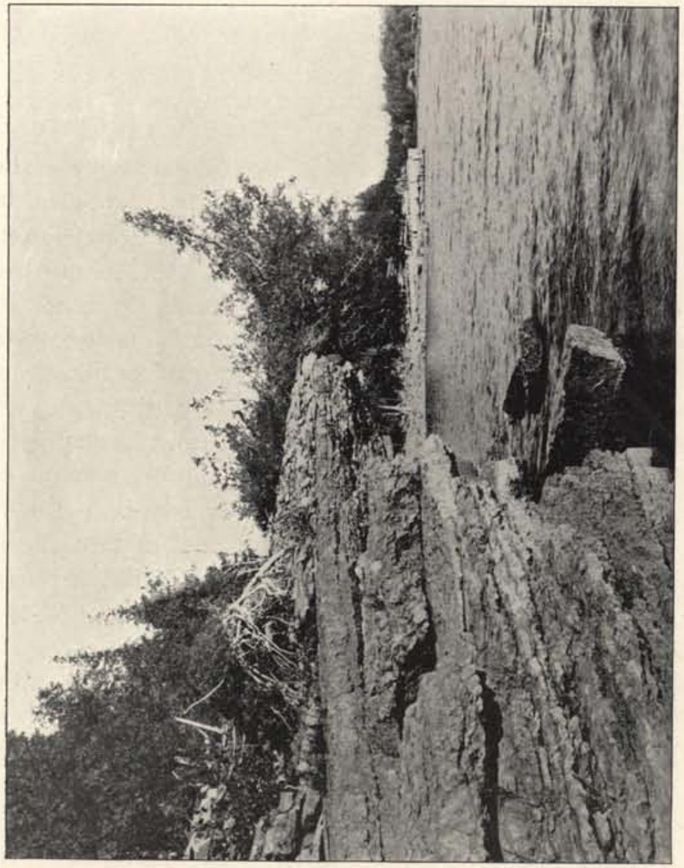
M'BRIDE BAY.

As is the case elsewhere, the thin layers of limestone shown in Plate XLI are separated from each other by much thinner layers of soft shale. There is at McBride Bay in all not far from 75 feet of the Trenton, which dips 5° to 10° northwest. Not far from the northern side of McBride Bay the Black River comes out underlying the Trenton. The contact is very distinct, as the thick, solid beds of the former contrast noticeably with the thinner and lighter colored layers of the latter. Plate XLII shows this, though it can not be shown as distinctly in any plate as it is in the rocks. From its beginning at the point shown in Plate XLII, the Black River increases in thickness toward the south, and a portion of it runs out into the lake, dividing the bay into a smaller southern and a larger northern portion. There are seventeen feet of the Black River here, and the cliff rises as an almost vertical wall from the water.

The layer of Black River seen in Plate XLII at the bottom of the cliff is two feet thick. Its surface where exposed is very rough, and appears as if formed in shallow water. In places here these Black River beds are unusually fossiliferous, and contain Columnaria, Maclurea Grandis, Stromatocerium, etc. Splendid Columnaria alveolata, gold, some of the heads eighteen inches in diameter, occur here, and opercula of Maclurea abound in places. At this point the Black River ends, and does not occur on the shore at any other points than those mentioned.

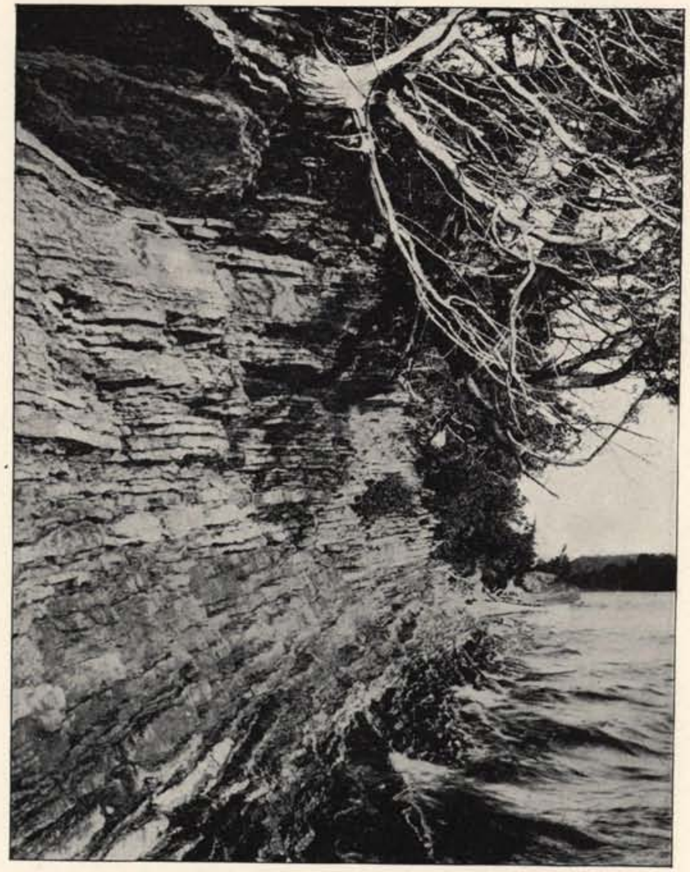
After crossing a stretch of sandy shore the Chazy layers are found. There is, I think, a fault between the two formations.

PLATE XL.



North End of McBride Bay. Beginning of Trenton.

PLATE XLI.



Horizontal Trenton Beds, North of McBride Bay.

PLATE XLII.

Contact of Black River and Trenton, McBride Bay.

The same or similar curious weathering already mentioned in the Chazy at Barnes Bay again appears here. The same blocks of rust colored limestone are seen. When freshly broken the stone is steel-gray, but the iron it contains soon oxidizes and the brownish yellow comes out. From the south side of McBride Bay the Upper Chazy extends with little interruption along the shore and inland until it ends at Phelps Point, where it finally disappears. In a straight line the distance is about two miles; much more if the irregularities of the shore are followed. Short interruptions such as are caused by dikes, faults and this carrying out of rock by ice occur frequently, but on the whole the formation may be regarded as continuous from McBride Bay to beyond Phelps Point.

When first appearing on the south side of McBride Bay the Chazy is found forming low shelving shores, but a little farther south it rises to form a low but massive wall eight feet thick, which follows the shore, or rather forms it, around to and beyond Wilcox Point. The lower beds are full of brachiopods, the upper are more magnesian and abound in sponges and corals. Nearly seven feet are made up almost wholly of Rhynchonella plena. Above this is a siliceous bed containing in its lower part Asaphus, Rhynchonella, etc., while the upper part is nonfossiliferous. Toward the south the beds increase in thickness, and in places are remarkably jointed, the strata breaking evenly into extraordinarily long, slender blocks. One of these which I measured was eight feet long, while its largest end was only five inches or six inches. Toward the south the Rhynchonella beds appear below the siliceous limestone, and soon form the greater part of the cliff. These Rhynchonella beds are for the most part compact, solid, of a bright gray color. Sometimes the rock is softer and decomposes more readily, and the fossils are set free in great numbers. In all, between McBride Bay and Beach Bay there are not less than seventy feet of Chazy, mostly upper.

From Chippen Bay to the north side of Beach Bay there are no dikes, but not far south of McBride Bay towards Beach

Bay there is a very small one, No. 8, only three inches wide. Just beyond this is one of the most interesting dikes on the island. It is No. 9, about thirty inches wide, and is conspicuous by reason of a strip of the Rhynchonella limestone which it has torn out and brought up with it. The strip in places is double, of gray limestone almost wholly composed of the shells and wholly unaltered, at least to all appearance, as it stands out very prominently in a clear light.

BEACH BAY.

On Beach Bay, near Professor Thorp's cottage, is dike No. 10, 2 feet 8 inches wide, and a little farther south is No. 11, which is about the same in width. Somewhat farther south on the extreme southern portion of Beach Bay is dike No. 12, which is 8 inches wide.

North of this bay there is one of the best examples of erosion of softer underlying strata, by which the upper layers are undermined and overhang the water. Plate XLIII shows this so well that description is unnecessary.

We find about Beach Bay a series of outcrops, each separated from that north of it by a small area of drift. One of these beds is of remarkable appearance. It is mainly composed of rounded masses of what appears to be a Stromatocerium.* The stone itself is dark, but these masses weather out nearly white. All the strata at Beach Bay show signs of greater disturbance than do most of those on this side of the island. Yet even here the dip is not more than 30° to 40°

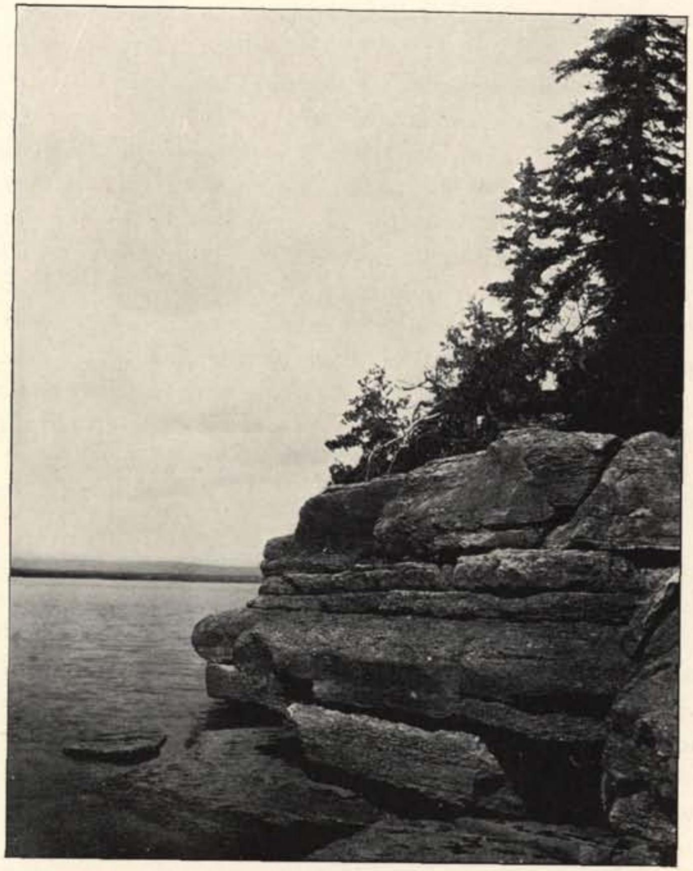
* The following note from Professor Seely is of interest in this connection:

"Appears to be a Stromatocerium" is a good description. Years ago I found this form inland in a field perhaps Northwest of South Hero, and was greatly delighted with the newly discovered Stromatocerium. But on sectionizing I found I was not dealing with a Stromatocerium but something like a coral. It corresponded to nothing I had seen or known, but appeared more like a Chetetes, so for a provisional name I gave it as I think the appellation *Chetetes insularis*. But the signification of Chetetes has become much restricted and it can hardly remain there. Monticulipora, or Prasopora, would more nearly fit. I sent examples to Ulrich, but so far as I know he has not passed on it. It seems much like the Monticulipora or Prasopora lycoperdon, but it grows in interrupted layers or stories. I think it may be a type of an undescribed genus. It may perhaps for the present go under the provisional name *Monticulipora insulara*.

PLATE XLIII.

Overhanging Chazy Cliffs. North of Beach Bay.

PLATE XLIV.



Chazy Cliffs, Wilcox Point.

northwest. These beds continue along the north side of the bay for some distance, and then the rock has gone out for some space and then peculiar, irregular layers appear on the east shore. These beds are only slightly inclined, but what inclination there is is opposite to that of the previously mentioned beds. Several slight faults occur here. Farther south the beds grow thicker, and presently form a wall-like mass along the shores some 8 to 10 feet high. There are also 5 to 6 feet of additional strata back a little from the shore. After extending along the shore for a few rods these beds disappear, and for 100 feet drift and clay form the shore. Perhaps nowhere on the island are the Rhynchonella beds so well exhibited as at Beach Bay. Layer after layer of the limestone is wholly made up of this fossil, and there is hardly anything else in the upper beds, though in the lower ones there is an admixture of other species. The *Rhynchonella plena* is not of equal size in the different layers. In some they are much larger and better developed than in others. These Rhynchonella beds are compact, hard and silver gray in color, and yet in places they crumble more easily than less fossiliferous layers, as is seen in Plate XLIII, where the under and much eroded beds are these while the thicker and harder beds above are less fossiliferous. The Rhynchonella beds were evidently not all formed under the same conditions, as has been already indicated by the difference in size of the individual shells in different beds. Some of these beds were formed in clear and probably rather deep water, others in shallower and muddy water. South of the Rhynchonella beds and below them are layers filled with Stromatopora, sponges, etc. These, at first only three or four inches thick, become soon thicker. Below these come the Stromatocerium layers mentioned, and below these are layers full of sponges and corals.

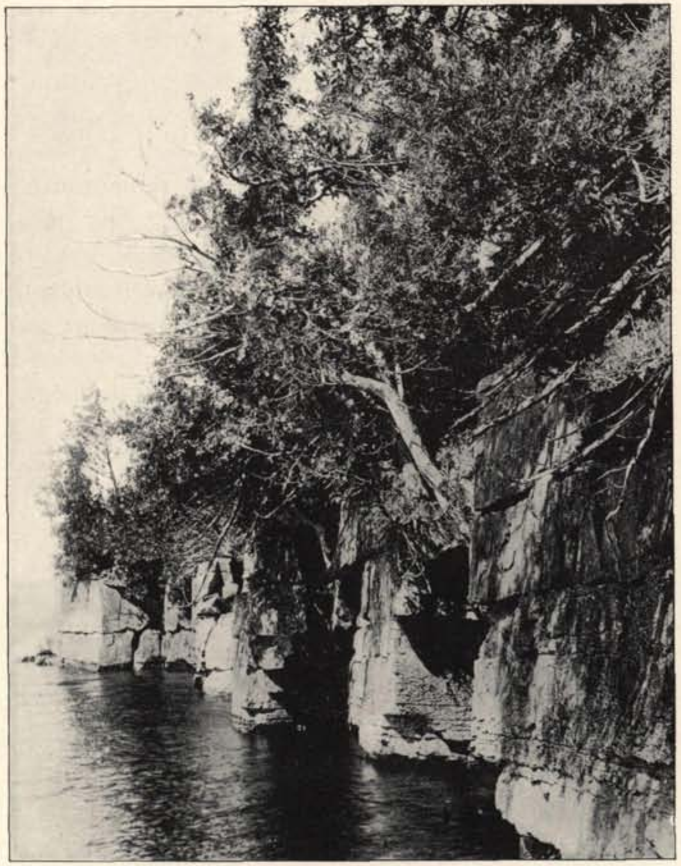
In all there are here forty-five feet of upper Chazy. On the south side of the bay there is a sort of limestone conglomerate composed of numerous fragments of limestone cemented by a paste of yellowish sandy calcareous material. This weathers much as that described at McBride Bay into yellowish, boulder-like masses, so that the whole bed presents a very rough irregular surface when seen in vertical section. The contrast between the smooth wall-like cliffs of the Rhynchonella beds and this latter rock is very noticeable. Between the end of the Rhynchonella beds and the following there are evidences of a fault.

The shore is clay for about 450 feet south of the bed already mentioned at Beach Bay, then come more regular and typical Chazy beds dipping 4° to 5° north. On the south side of the bay the rocks dip 4° to 6° north, then they are horizontal and then dip south about 4° to 6°. Along the extreme south side of Beach Bay the limestone forms a wall 8 to 12 feet high, which continues on to form Wilcox Point, Plate XLIV. As the illustration shows, the layers have little or no dip, though they apparently overlie the more northern beds. There are two dikes across Wilcox Point (or Hero). The first and smaller, No. 13, is but three or four inches wide, and disappears under the water of the lake. The second, No. 14, is thirty inches wide and crosses the point from side to side, though at the north end it rapidly narrows and stops just before it reaches the lake. On the south side it enters the lake, and is about thirty inches wide. The limestone at Wilcox Point is compact, not highly fossiliferous, except that it contains numerous sponges, *Eospongia varians*, *Orthoceras*, *Maclurea*, etc. (Middle Chazy).

The general dip is northeast, but is nowhere great. Near Phelps Point is a dike, No. 15, twenty inches wide, which, unlike most of the dikes which are worn off even with the adjacent limestone or very rarely worn out from it leaving a channel, but as occurs in one or two other cases to be noted, this dike has withstood erosion better than the limestone, and therefore projects from the cliff some two feet or more. A few rods further south there is another dike, No. 16, six inches wide, which also projects from the limstone.

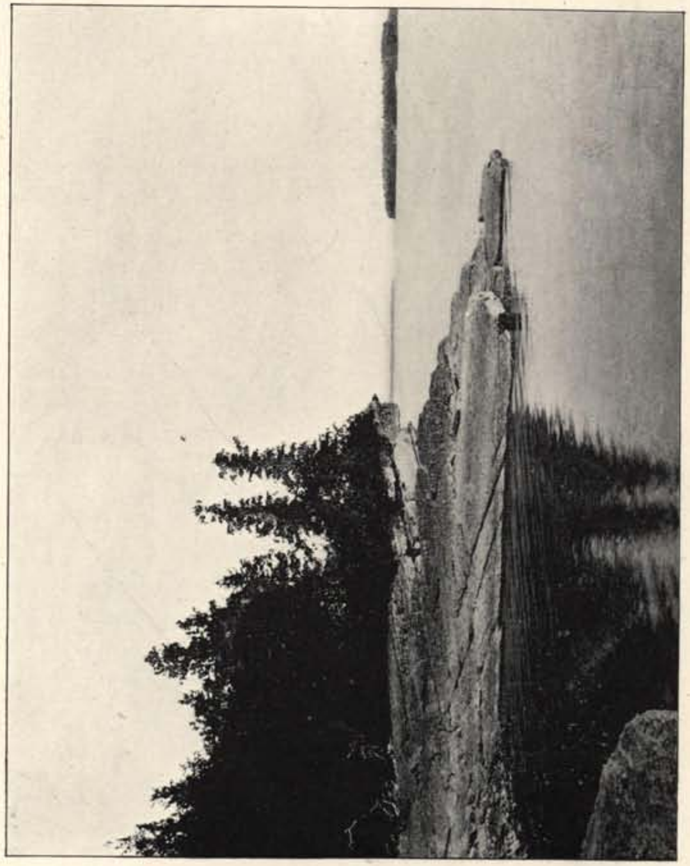
Opposite the north end of Providence Island there has been opened a small quarry in the limestone seen in Plate XLV, from which some rock has been taken out, but it is not now worked. The rock here contains Maclurea, Strephochetus, Stromatocer-

PLATE XLV.



North of Phelps Point, Chazy Cliff. Since Quarried.

PLATE XLVI.



Phelps Point, Chazy Limestone.

ium and is Chazy B, Middle Chazy, of Seely and Brainerd. Some of the beds are very full of fossils, though most contain few. In some quite thick beds the mass is largely composed of Strephochetus occelatus, Seely. South of this quarry the beds dip 10° to 12° northeast. A short distance beyond this quarry another has been opened by the railroad company, and stone for use in construction taken out. Eighty rods farther and a little distance from the shore the railroad company has opened and worked a large quarry in the Chazy and taken out a large amount of the very compact stone. A branch track has been laid to this quarry, leaving the main line a short distance north of Allen Point. Not far southeast of Phelps Point (Plate XLVI), the Chazy finally ends in a bluff ten feet high made up of thick, nearly horizontal beds.

From Wilcox Point south about three-fourths of a mile the Middle Chazy beds continue in cliffs near the shore. They are ordinarily 6 to 10 feet, but at Phelps Point the thickness increases to twenty feet (Plate XLVI), and are very massive.

Where the large quarry just mentioned has been opened there is a most remarkable exposure of the Middle Chazy. The rock is covered by not more than a few inches of earth in some places and nowhere very deeply.

In all not far from fifty feet of strata are exposed by the quarrying. The topmost bed is four or five feet thick, then comes a very hard compact bed which measured where best seen a few inches over twenty feet in thickness, and it is opened for 450 feet along the quarry. So large and compact were the blocks which were blown down by the dynamite charges from this wonderful layer that they were reblasted in order that they might be handled. Beneath this magnificent bed was another much like it twelve feet thick. Nowhere in this quarry are fossils abundant, and it was only after considerable search that its horizon could be determined. At last, however, a few Maclureas and other fossils were found which fix its position as Chazy B. This enormous layer of Chazy is shown in Plate XLVII.

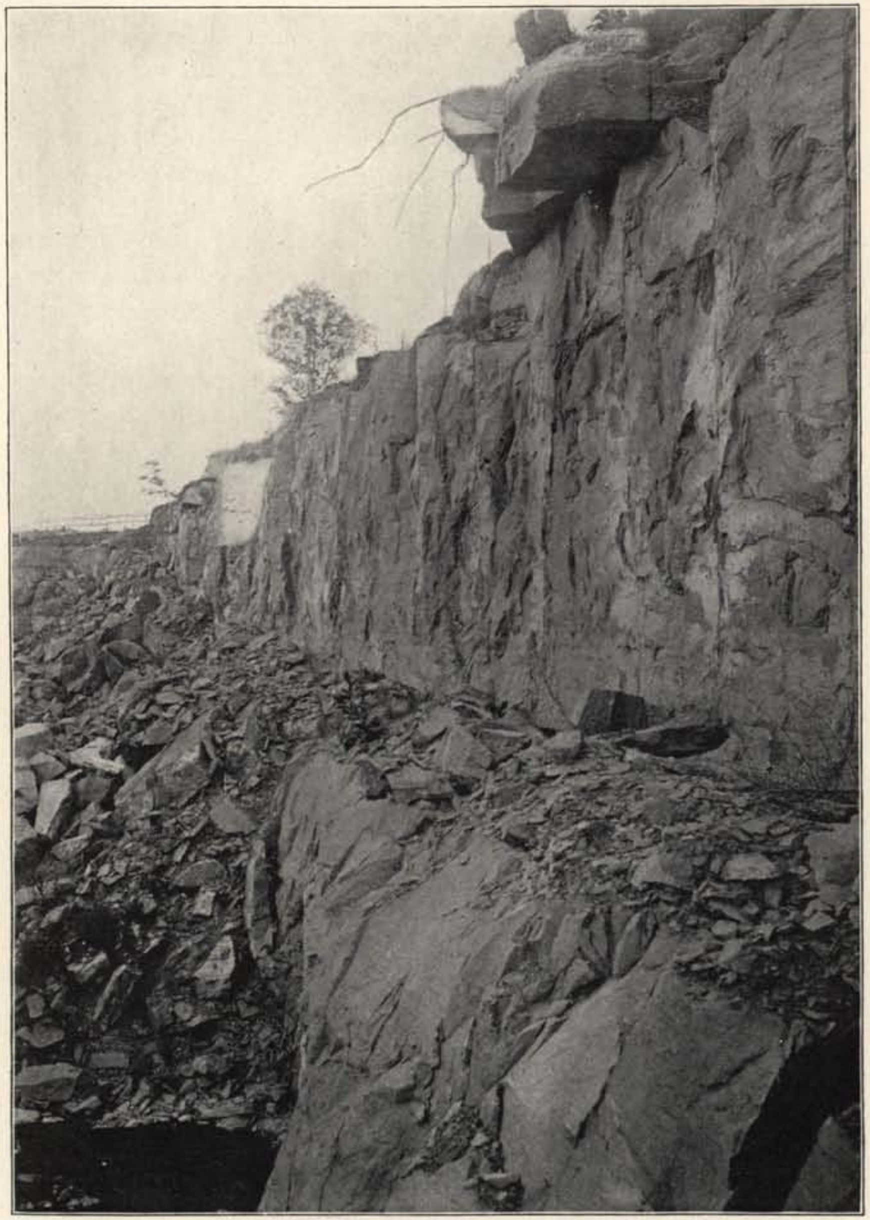
From Phelps Point the shore runs almost directly eastward for over a mile. For the most part the shore here is pure sand washed north from the Lamoille River as has been noticed. This sand beach is, however, interrupted by a small exposure of upper Beekmantown (Calciferous), which appears just south of Mr. Phelps's house for 200 feet along the shore. This is, undoubtedly, a continuation of the same formation on Providence Island, where it is more extensively exposed. As will be shown in the discussion of the Beekmantown, the beds reach inland from the shore and across the wagon road.

The spur track which has been built from the main line to the quarry has necessitated a cut some seventy feet long through the layers of Beekmantown. This area is shown on Brainerd and Seely's map, Plate XLVIII.

Beyond this sand shore, as the map shows, the shore line turns south towards Allen Point, and here the Utica shale begins to continue with the interruption of only a few rods of clay shore, or less commonly, sand beach, entirely around the eastern, northern and western shore of the island until Wilcox Cove, nearly half way down the west side, is reached. As will be seen, the shale is usually far more strongly disturbed, tilted and uplifted than the limestone.

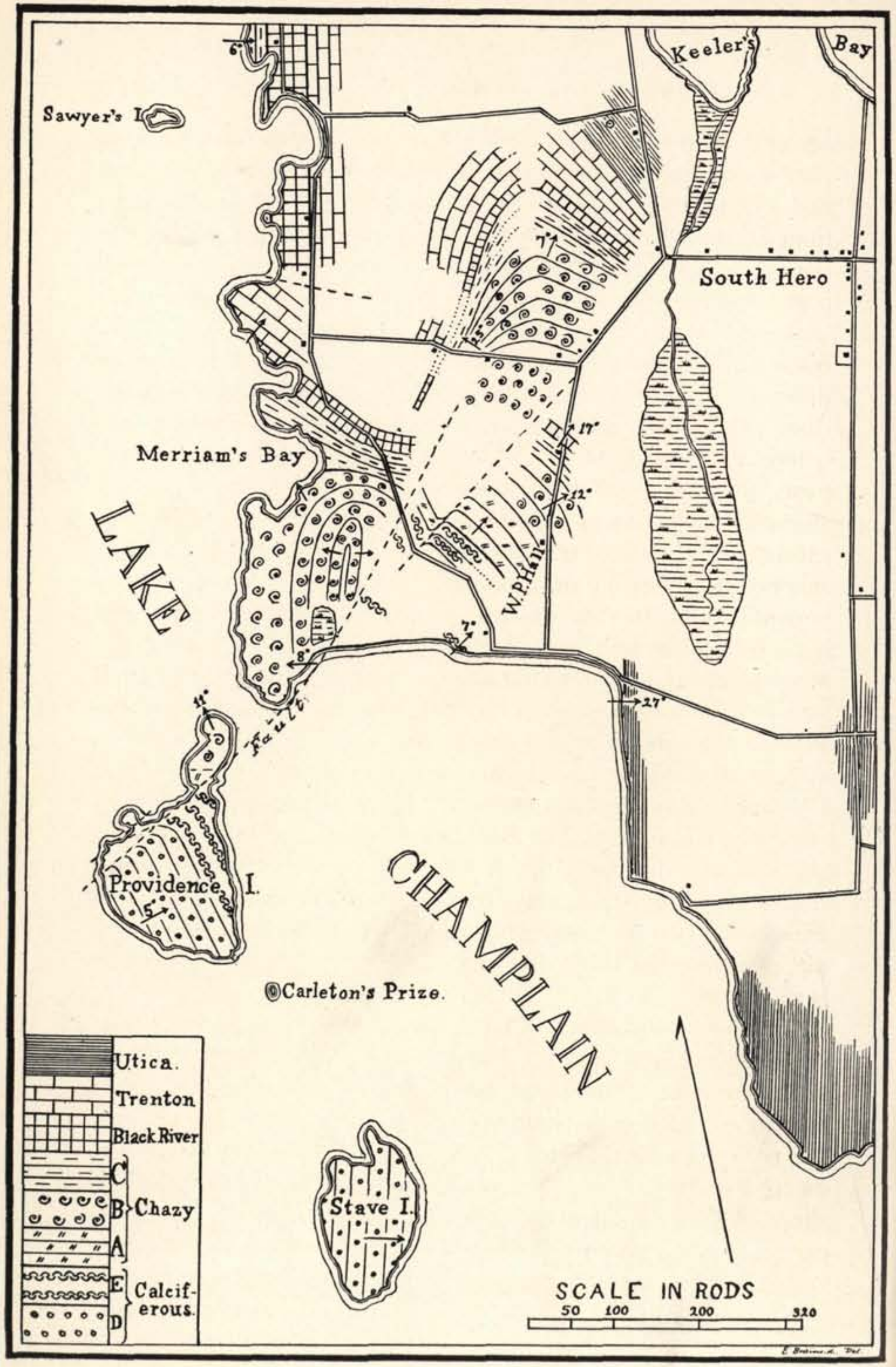
At Allen Point, Plate XLIX, this is well shown. All the cliffs here bear abundant testimony to the disturbing agencies which have at some time been in action here. In this not only is the upturned shale shown, but the effect of the lake waves upon this easily eroded rock, and also the characteristic growth of arbor vitae or white cedar, which is very fond of growing on the shale and flourishes wherever it can get the least foothold, as is also shown in Plates XLV and XLVI. The shale here as elsewhere throughout the island, with few exceptions, is thin bedded, brittle, with few fossils, except in certain thin layers, which afford the characteristic Utica *Diplograptus pristis, Triarthrus beckii, Orthoceras coraliferum, Schizocrania filosa,* etc.

As has been noticed, only Utica occurs on the shore of the east and north portions of the island, and hence no such detailed



Thick Bedding of Chazy at Quarry on Phelps Point. (The upper layer is over twenty feet in thickness.)

PLATE XLVIII.



Map of the Southwestern Part of Grand Isle. Drawn by E. Brainerd.

account of the different bays and points is necessary for this part as has been given of that which lies between Wilcox Cove and Phelps Point. A few localities should, however, be mentioned. Disturbances have been noticed at different points, but the culmination of these seems to have been in the southeastern part of the island. Everywhere, from Allen Point north, the shale beds show the same tilting and folding as that seen at the point. The shale, though not very different in appearance at different places, is evidently not always of identical composition. In some places the weathering is very little, while elsewhere it is considerable. Where the beds most readily decompose, there may often be seen, especially if the rock can be studied in a section as in some of the railroad cuts, a very interesting and gradual transition from hard shale that breaks sharply at the stroke of a hammer, up through that which has become softer, to that which is little else than clay, and which is to be broken and moved only with shovel and plough. In some places the clay so long as undisturbed retains the original stratification of the shale, even when so soft that it is not possible to remove a block of any large size.

This decomposed shale mingled with more or less of the Champlain clay constitutes the soil of by far the greater part of not only Grand Isle, but also North Hero and Alburgh. In some places the covering of Champlain clay is very thin, so that most of the soil is clay from the decomposed shale. Elsewhere the two are somewhat equally mingled, and there are places where the thick deposits of glacial clay form the entire surface soil.

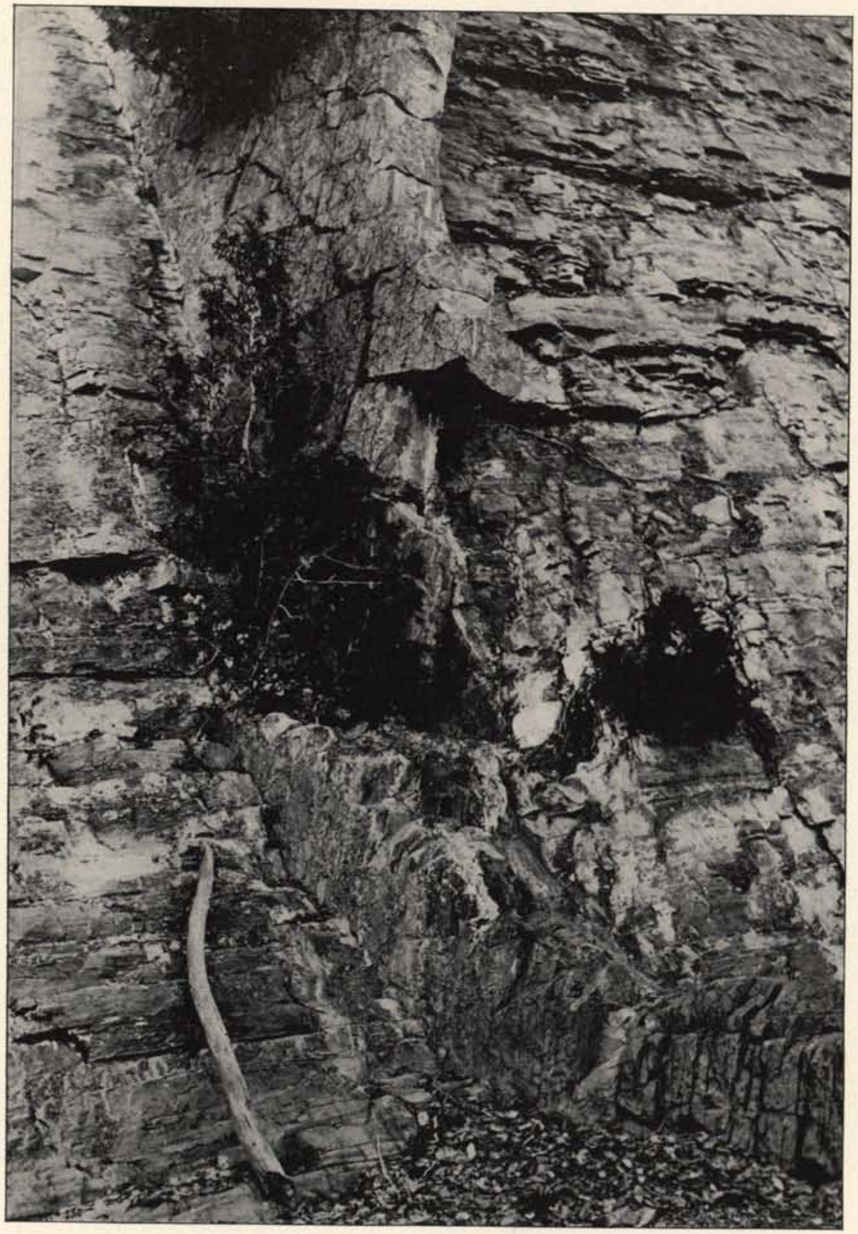
At Allen Point, Plate XLIX, the shaly layers are thin, uniformly black and brittle. Farther north, this is the extreme southern point of the island, the beds are not only highly tilted, but the inclination constantly changes, as does the character of the rock to a less degree. North and east from Allen Point on to Robinson Point we find stretches of shale coming to the shore in bluffs interrupted by bays where the rock has been carried out and partly replaced by the clays containing *Macoma,* *Saxicava*, etc. The bluffs, whether of clay or shale, are not often more than thirty feet high, and often less.

Not far beyond Robinson Point there is a small dike about twelve inches wide. This has yielded to weathering to such an extent that it has disappeared from its place in the shale for a distance of thirty-two feet, leaving a singularly deep, narrow channel in the cliff. A little north of this is a second dike of about the same size, and it too has been weathered out from the shale, though not so deeply as the first one. About eighty feet farther north is a much larger dike. This presents a very striking appearance as it projects from the cliff. It is shown in Plate L, but is much less distinct in the illustration than as actually seen, since the plate does not show the marked contrast between the yellowish, weathered surface of the igneous rock and the black shale on each side of it. As Plate L shows, the dike not only extends from top to bottom of the cliff, which is here 40 feet high, but runs like a low wall out across the beach into the water. In average width this dike is twenty inches, and it projects beyond the shale from two to eight feet on the south side, while on the north it is only three feet beyond the cliff because the rock has not weathered away so fast on that side.

Passing on northward around a small bay to within about a quarter of a mile of Sandbar bridge, one comes to one of the most interesting cliffs on the island. It exhibits to a superlative degree the crumbling and crushing of the shaly layers. Plates LI, LII, LIII show the general features of this remarkable bluff better than could any description. The bluff forms a not prominent point at its southern end, which is that shown in the plates. From the right side of Plate LIII it extends north toward the bridge for a distance of about 1,700 feet. It is not of uniform height, nor entirely of like character throughout, but is nowhere so thoroughly crumpled as at the point shown in the illustrations. In some parts the rock is uniformly black, thin bedded and not strongly folded, but at the part shown, especially in that seen in Plate LI, it is not all black, but conspicuously banded

PLATE XLIX.

Utica Shale, much tilted, Allen Point.



Dike Near Robinsons Point. (The Dike rock is twenty inches wide, and projects from two to eight feet beyond the shale.)

with layers of a gray or drab color. These light layers are often very even, and add much to the distinctness of the folding. They are of different width, some being not more than 2 inches or 3 inches, while others are 6 inches or 8 inches. This banding is only partially shown in the plates, and is therefore much more conspicuous in the actual cliff.

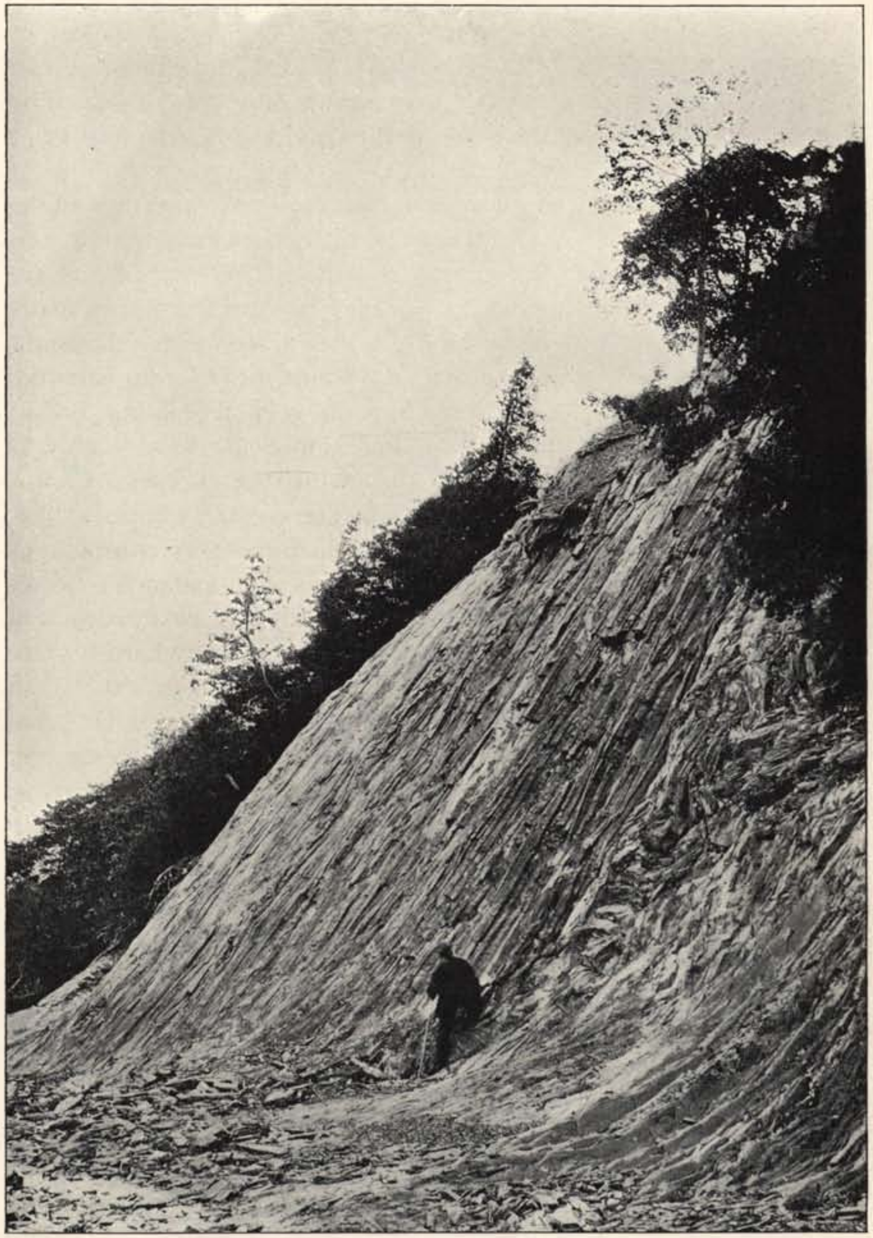
At the time of our visit to this place we had no boat, and without one it is not possible to get far enough from the cliff to bring it all into one view. If the reader will understand that the three plates are to be taken together in order to get the whole, and that only the lower half of the central portion is shown, a better idea of the whole mass will be obtained. Plate LI shows the western portion, and as will be noticed, the layers of shale are here pretty regularly arranged and are nearly vertical. The height is approximately forty feet. Towards the right of the picture the crumpling begins, and in Plate LII the culmination of disturbance is reached. It is difficult to imagine a more complete example of superlative folding and crushing than this cliff affords.

The same distorted condition of the layers is seen in the shale which forms the narrow shore only exposed at very low water and out into the lake as far as it can be seen. Plate LIII shows the eastern part of the point formed by this cliff. From here the mass continues north, forming the shore.

There are two dikes which have broken through the shale at not distant points. One of these, the most southerly, No. 20, runs northwest, and the other only a few rods north, No. 21, runs nearly west. As will be shown in the account of these dikes quoted later on, they are quite unlike in composition as well as in direction. Crossing Sandbar bridge and continuing north, we find shale not only along the shore, but projecting into the lake in quite a reef opposite the Phelps House. Along shore the uplifted and more or less crumpled shale, often with white calcite veins, continues except where interrupted by bays.

Dikes also abound in this part of the shore. Between Sandbar bridge and Paradise Bay there are nine, and five more before the end of Kibbe Point is passed. Most of these run nearly east and west, though a few take a different course. The cliffs between Sandbar bridge and Paradise Bay are often 15 to 20 feet high and very steep.

As we have seen, the shale is generally tilted at a high angle, but in places it is more horizontal. The general dip, however, along the eastern shore is 40° to 60°. Usually the cliffs are back from the water's edge, except at high water, but in many places for a short distance they reach the water even in midsummer. On the north side of Kibbe Point, near Camp Idlewild, the shale presents wonderfully fine and regular jointing, breaking away in great sheets six feet or more square as evenly as if sawn. Just west of a little bay which lies between Camps Englewood and Idlewild the shale is intersected by curious dike-like bands of highly siliceous rock, which are very conspicuous because the iron which the rock contains in abundance oxidizes on weathering, and thus the exposed surface is rust brown and thus is in contrast with the black shale. The very hard texture of the siliceous bands is also in strong contrast with the often soft and friable shale, though some of the latter is far from brittle. The hard bands are, however, often very evenly and thinly laminated, in this resembling the shale. These bands or layers in the shale vary in thickness from a fraction of an inch to twenty inches. In all there are between twenty and thirty of these siliceous layers at Kibbe Point. I did not find any others on the island. On the western shore of this point there is a stretch of several rods where the shale does not come near the water, and the low shore is thickly strewn with large boulders. A mile south of the end of Kibbe Point the shale ends, and for nearly a mile and a half around the south of Keelers Bay the shore is low and sandy, and this continues entirely around this the largest bay on the island with one or two exceptions. These are the point, which does not appear to be named, that projects north into the bay, where the shale appears for 500 feet along the water's edge; a few rods on the western side of the bay ending in several small points just south



Cliff, Utica Shale, Western Portion. South of Sandbar Bridge.

PLATE LII.

Cliff, Utica. Central Portion Showing Great Disturbance. South of Sandbar Bridge.

PLATE LIII.

Cliff, Utica Shale. South of Sandbar Bridge. Eastern Portion.

of the site of the old Catholic church, and a more extensive mass at Hoyt Point, where really the continuous shale cliffs begin again, though for some distance north of Hoyt Point there is sandy shore. Towards Cooper Point the broken and tilted shale forms high cliffs, and on north of here the breaks in the cliffs are few and short. As one passes from Sandbar bridge to and around Ladd Point the character of the shale varies from place to place as to inclination, solidity and bedding. The dip is sometimes nearly vertical, but rarely more than 60° and usually less. It is also rarely horizontal or nearly so. Kibbe Point is perhaps the sharpest upthrust, reaching at the greatest an elevation of eighty feet above the lake. Near the northern part of this point the shale dips 60°, while at Ladd Point the dip is nowhere more than 35° and much of the rock dips only 5° to 10°. Along the extreme north end of the island, between Ladd Point and Knight Point, the low shore is covered with boulders of large size and great variety. South of Knight Point, near the carriage bridge to North Hero, there is an old quarry from which stone was taken for constructing the bridge. Here is a fine exposure of the shale. The section seen in the side of the quarry is twenty-two feet high. The dip is 10° north 10° east. The upper eight feet are thin bedded, but all below this is solid and compact. South of the bridge the shale soon disappears, and from here on around the bay to Simm Point and on around Tromp Point there are only occasional low outcroppings of shale. Not until after passing south beyond Long Point do shale cliffs appear. From here south to Wilcox Cove these continue with little interruption. The cliffs along this part of the western shore of the island are from 10 to 20 and often 30 feet high. The dip is quite uniformly 5° to 10° northeast. Plate XXVII shows a typical shale cliff of the west shore.

Although most of the surface of Grand Isle is as we have repeatedly noticed largely covered by clay deposit and the underlying rock is thereby concealed, yet in most parts of the area there are outcrops, often very little or not at all raised above the surface, which enables us to form a pretty accurate idea of the rock formation, especially as there is so fine an opportunity along the shore. As an aid to our knowledge of the structure of the island we have numerous railroad cuts made by the Rutland-Canadian road as it traverses the island from end to end. And yet these cuts, as it chances, give less information than at first would be expected, because, with one exception, they all are in the shale. As these cuts give an excellent idea of the surface of the island, I have thought that a somewhat detailed statement concerning them would be useful. As will be noticed, if the map of the region is examined, the railroad extends through the island from south to north in an approximately straight line. The level of the road bed is considerably above that of the lake, especially towards the north. The heights given in the following list of cuts are above the road bed. For all measurements I am indebted to Mr. I. S. Lloyd, assistant engineer of the road.

Commencing at Allen Point we have a cut 2,050 feet long through Champlain clay and Utica shale, and on the average about 10 feet deep. In this cut the shale appears for a distance of 830 feet, and is from 4 to 8 feet thick. The rest of the excavation is in the clay. North of Allen Point there is a shallow cut, mostly in clay, 2,600 feet long. The next is what is called Squier cut, opposite the Iodine Springs House and near the shore of Keeler Bay. This is deeper than other cuts. This cut is 2,300 feet long in all, but that part in which shale is seen is 694 feet long, and the rock is from 7 to 30 feet thick, averaging not far from 15 feet. A short distance north of the Squier cut is another, still near the shore of Keeler Bay, which is 1,350 feet long and 17 feet in greatest depth. Of the total length 330 feet are shale with a thickness of from 4 to 8 feet.

North of this last cut there are two earth cuts with no solid rock.

The first is 600 feet long and about 3 feet deep, the other is 575 feet long and 2 feet deep. Some distance north of these latter cuts is one known as the Corbin cut. This is the most

interesting of the series, as it is the only one on the island which exposes limestone. It is a long cut, 4,000 feet in all. Much of the excavation is in clay, but there are 700 feet of Upper Chazy limestone, a hard, compact, gray stone, varying in thickness from 2 feet to 9 feet, averaging about 4 feet.

After leaving the Chazy on the west shore at Rockwells Bay as the island is crossed towards the east, no Chazy beds appear until within a few rods of this cut. From this point eastward to within a short distance of the eastern shore there are numerous outcroppings of Upper Chazy, and also on the southern border a little Middle Chazy. In the cut the strata are somewhat tilted, dipping 15° northwest. In all about 70 feet are exposed.

The next cut north, Pearl cut, is in earth, and gives a fine exposure of clays and sands in which are bands of Champlain shells, *Macoma* and *Saxicava*. The whole depth of the deposits as seen is over twenty feet. Farther north, not far south of Grand Isle station, there is a cut in shale 350 feet long and on the average 3 feet deep. Just north of the station is a small cut only 46 feet long, and then comes the great Kinney cut, which is in all 8,300 feet long, though nowhere very deep—2 feet to 6 feet.

There are four exposures of Utica in this cut, which are in length, respectively, 125 feet, 310 feet, 3,000 feet, 500 feet.

From these statements it will be readily seen that most of the island, at least where the railroad runs, is underlaid by Utica shale.

Although the various formations which occur on Grand Isle have been noticed on previous pages, yet it may be well to add somewhat to what has been given. Beginning at the lowest beds found and proceeding upward we have the following, adopting the groups proposed by Brainerd and Seely:

Upper Beekmantown (Calciferous).
Chazy A (Lower Chazy).
Chazy B (Middle Chazy).
Chazy C (Upper Chazy).

Black River.
Trenton.
Utica.
Champlain Clays.

In passing over the rocks from the south end of the island between Phelps Point and Allen Point, where the Beekmantown crops out, to the north all these groups are met with and in the order given.

This is well shown in Plates XLVIII and LIV, for which I am indebted to President Brainerd, of Middlebury, who drew the maps to illustrate a paper by himself, and Professor Seely on the *Calciferous Formation in the Champlain Valley.**

A comparison of Plate XLVIII with the foregoing account of the series of beds met as one passes from Sawyer Bay south, will aid the reader to a better understanding of the subject.

As Dr. T. G. White, of Columbia University, who spent some weeks on the island not long before his untimely death, has noticed, there are at the southern end of the island, the upper Beekmantown (Calciferous), the whole of the Chazy, thickness of 315 feet, 35 feet of the Black River and 23 feet of the Trenton. To the north there are many feet of the Utica.

The following notes made by Dr. White have been kindly obtained for me by Professor J. F. Kemp:

STATION 135—SOUTH HERO AND GRAND ISLE SECTION.

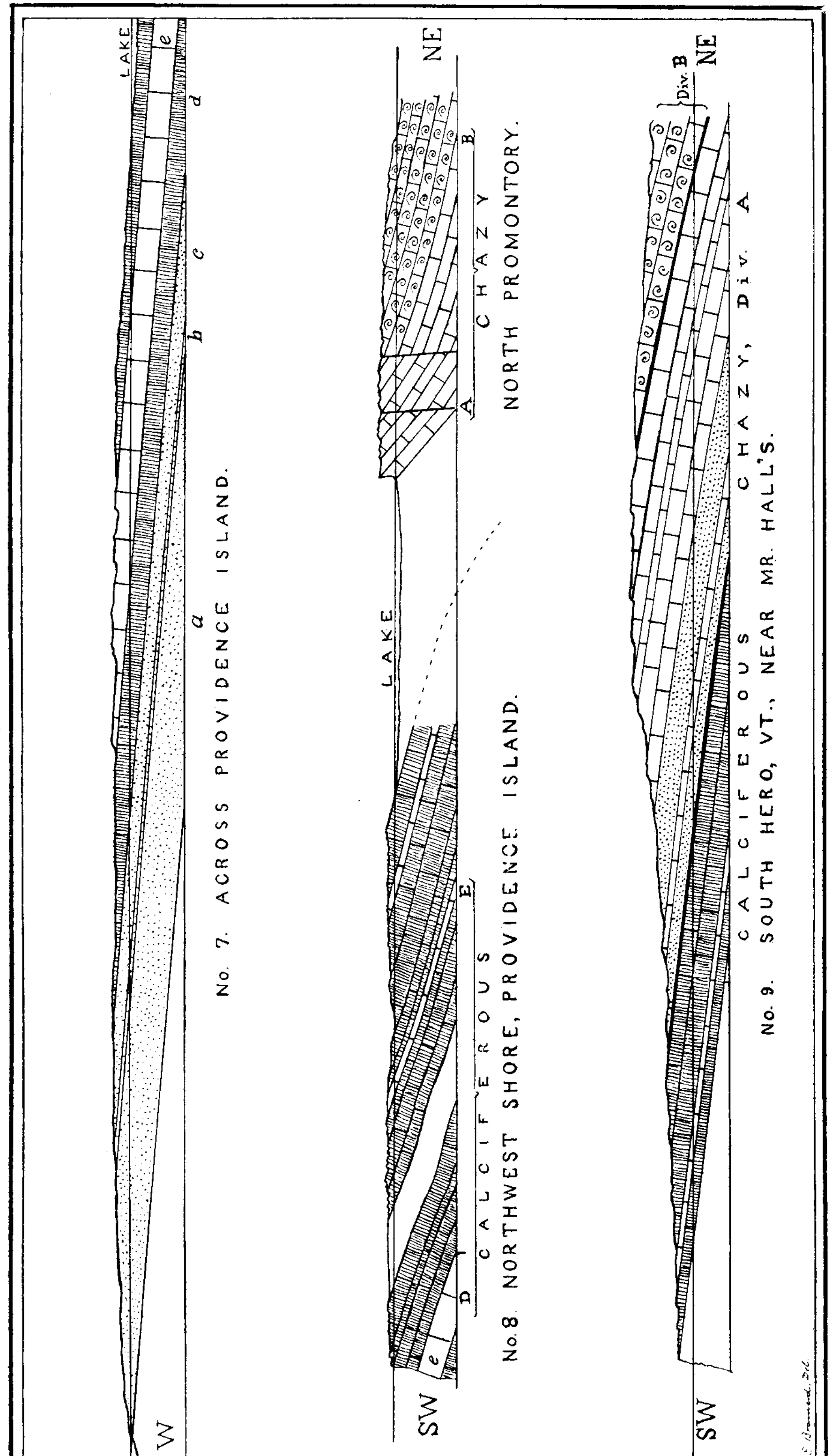
(See Brainerd and Seely, 1891; Bull. Amer. Mus. Nat. Hist. III, map No. 4.)

A 1. Ridge in the swamp on the eastern side of the head of the western arm of Keeler bay, north of the road from the Iodine Springs Hotel to South Hero village. Friable black Trenton. No fossils. Dip 20° N. 85° W.

	Thickness.	Total.
C 1. South of the farmhouse of W. P. Hall, on the road from South Hero village to Phelps Point (see B. & S. map). Dip 4° N. 35° E. (Calcif. of B. & S.?).	.5′	.5′
2. Chazy. Orthis and trilobites	11′	11.5′
3. Chazy. Sandy, friable. No fossils	2′	13′
4. Chazy.	7′	20′
5. Chazy. Limestone with red streaks, due to decomposed pyrite. Orthis	10′	30′

* Bulletin American Museum of Natural History, Vol. III, No. 1.

PLATE LIV.



SECTIONS ILLUSTRATING THE CALCIFEROUS OF THE CHAMPLAIN VALLEY.
Vertical & horizontal scale in feet

		Thickness.	Total.
C 6.	"Red spot" layer, with many fossils. Large Orthoceras. Dip 8° N. 35° E.	6′	36′
7.	Trilobites, Orthis and Orthoceras	27′	63′
8.	Looks similar to an artificial wall. Some layers apparently siliceous. Very fossiliferous	16′	79′
9.	Chazy. Trilobites like C 8, but weathered	8′	87′
10.	(Top of knoll.) Surface rather decomposed. Strophomena and large Orthoceras	58′	145′
11.	Similar to the material at Bluff Point. Trilobites and Orthis	11′	156′
12.	(Presumably the line of fault, figured by B. & S., crosses here.) Character of rock changes. Dip normal. No fossils. Rock specimen only	7′	163′
13.	On the opposite side of the fault. On the easterly ridge, east of C 12. Dip 3° N. 50° E. White crystalline limestone	25	188′
14.	Somewhat crystalline, like C 12. On same side of the fault as C 12. Few fossils. Trilobite	12′	200′
15.	Fossils similar to C 11	21′	221′
16.	Very hard, compact limestone. Dip 4° N. 5° E. Ostracods	18′	239′
17.	Exactly the same as C 16. No specimen	55′	294′
18.	Maclurea limestone. Dip 14° N. 35° E.	21′	315′

C 18 is 147 feet distant from C 19.

C 17 is 390 feet distant from C 18.

A dike 4 inches wide follows C 18, the dip being 6° S., bearing N. 67° W. The distance from C 18 to the dike is 127 feet. Either this dike or the fault shown by Brainerd and Seely conspicuously alters the direction of the dip, so that at C 19 the dip is N. 80° to 90° E.

C 19 and C 20. Portions of a ridge running toward the schoolhouse, the dip of which, as above noted, changes so that C 18 is carried east of the road.

C 20. Near the point marked on B. & S. map, on the roadside, east of C 20, is a "red-spot" (Chazy) limestone similar to C 6. The outcrop extends for some distance south, on the east side of the road. The dip at the top of the knoll is 9° N. 45° E.

North of C 21 on the road is a continuous overlapping section in a small quarry. All the beds dip 15° N. 50° E.

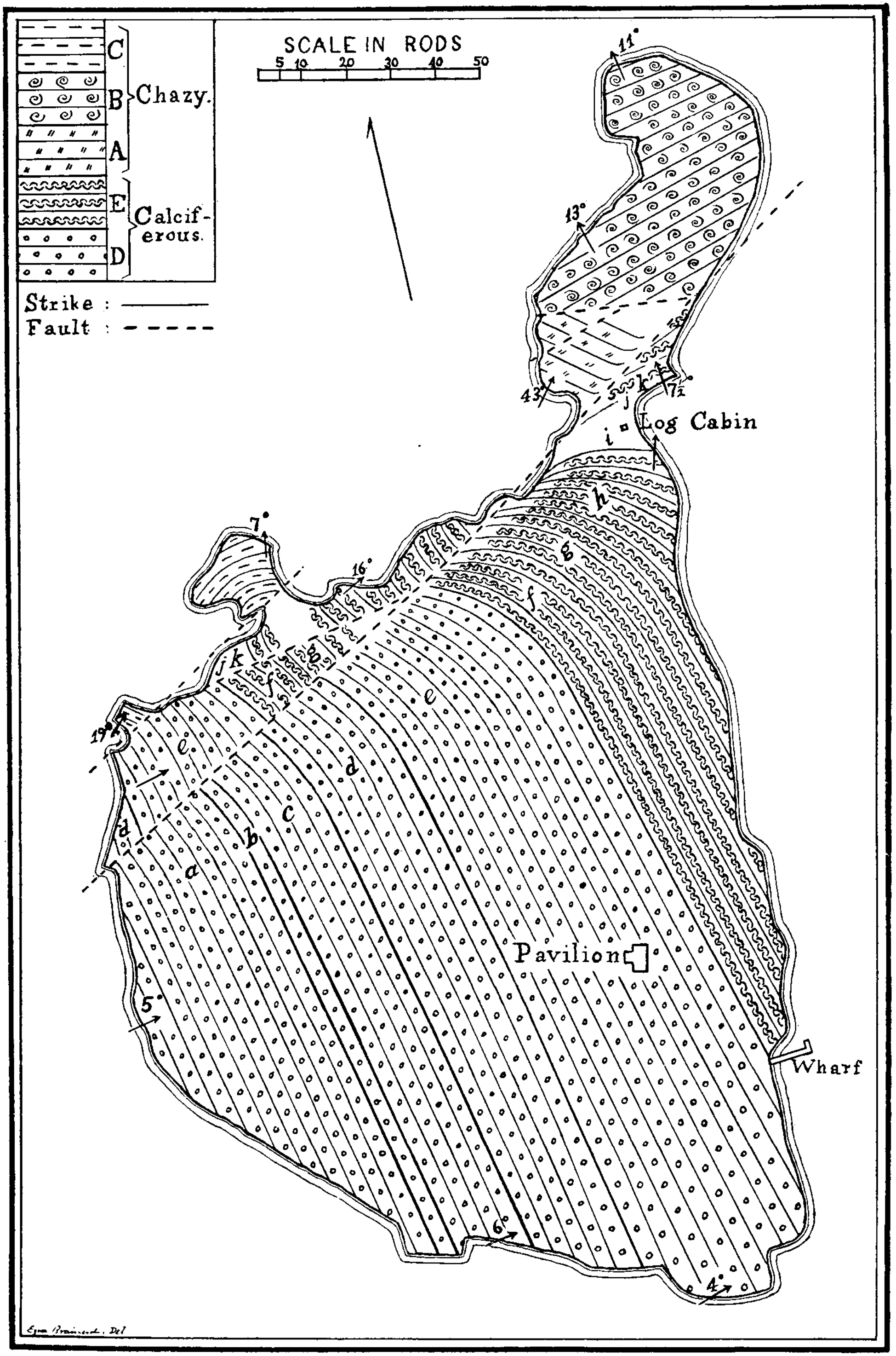
		Thickness.	Total.
C 21.	Full of Rhynchonella plena	1′ 6″	1′ 6″
C 22.	Same, not quite so fossiliferous	2′ 8″	4′ 2″
C 23.	" with trilobites	2′ 6″	6′ 8″
C 24.	Weathers red	8″	7′ 4″
C 25.	Gray, nearly barren limestone	1′ 6″	8′ 10″

		Thickness.	Total.
C 26.	Gray limestone with trilobites and orthis	2′	10′ 10″
C 27.	Rhynchonella plena bed	2′ 3″	12′
	Horizontal distance 21 ft. from top of C 27 to bottom of C 28.		
C 28.	Dove colored limestone, barren	2′	14′
	Layers not exposed	7′	21′
C 29.	Barren, darker dove-colored limestone	1′ 6″	22′ 6″
C 30.	Same; fossiliferous; Leperditia	1′ 3″	23′ 9″
	The surfaces show glacial striations, running about 43° N. 15° E.		
C 31.	Strophomena filitexta and Illaenus, similar to Bluff Point	1′	24′ 9″
C 32.	Sandy limestone with trilobites (Button Bay Dalmanites)	1′ 6″	26′ 3″
C 33	Sandy limestone, barren	1′ 6″	27′ 9″
C 34.	Gray limestone, with imperfect Strophomena	1′	28′ 9″
C 35.	Illaenus (scarce)	1′	29′ 9″
	Horizontal distance from top of C 35 to bottom of C 36 on dip 20° N. 10° E. is 16 feet.		
C 36.	Compact black limestone, considerably sheared in the upper portion; scarce fossils, large crinoid stems. Maclureas possibly indicated on surface	5′	34′ 9″
C 37.	Similar to C 36. Fragments being sectioned for possible microscopic remains.		
C 38.	Nearly barren	2′	
	Followed over small anticline in quarry as shown to road, tracing continuity by bed 38. Dip at C 38°, 20° N. 20° E.; at C 39°, 25° N. 40° E.		
C 39.	No obtainable fossils. H. d 12 ft.	1′	
C 40.	Nearly barren	7′	
C 41.	Frequent shaly "nodules." Asaphus. (5 ft. plus h. d. 18 ft.)		
C 42.	h. d. from 41-140 ft. along road N. 15″ E. Trilobites. Orthis testudinaria. Plectambonites sericea, form of	6′	
C 43.	h. d. 41 to 43, including 42. 207 ft. along road. Ceraurus. Rafinesquina. Platystrophia biforata. Plectambonites sericea. Calymene senaria. Lingula	2′	
C 44.	h. d. 43 to 44. 26 ft. along road. (43?) 44 and 45 1000 ft. N. 15° E. on road. 300 ft. N. of C 21 measured N. 25° E. Dip 13° N. 35° E	2′	
C 45.	(44?) Overlying C 44	3′	
	Corner of the hill to the west	10′	

Section 135 H. Around the northern shores of Grand Isle.

135 H 1. Gray, rather hard, irregularly fracturing limestone, flinty in portions like the "Birdseye." No fossils except Orthis cf. costalis (c).

PLATE LV.



PROVIDENCE ISLAND, LAKE CHAMPLAIN.

Drawn by Ezra Brainerd

Section 135 H 2. Irregularly fracturing, black, rather soft limestone, resembling zone 130 A 7 at Trenton Falls. Contains quite perfect fossils. weathered specimen. Crinoidal columns (a) Bumastus trentonensis (Emmons) (a). Rhynchotrema inaequivalve Castelnau (c). Ceraurus pleurexanthemus Green (i). Strophomena incurvata (Shepard) (i). Conolichas (i). Clionychia ap. (i). Ostracoda (o).

135 H 2a. Separated from H 2 in the laboratory as the rock is essentially different. Rather hard, irregularly fracturing, light gray limestone, looking rather like the "dove limestone"—in fact, probably is high dove, with 135 H 2 lying directly above it. Contains no fossils.

135 H 3.

135 H 4.

135 H 6.

135 H 7.

135 H 8. Dense, compact, black limestone, breaking readily with conchoidal fracture (strain ?). Barren.

135 H 9. Thin-bedded soft black shale (Utica ?).

135 H 10.

135 H 11.

135 H 12. Peculiar strains. Rock specimen only, also associated carbonaceous layer. Considerably fractured.

135 H 13.

135 H 14. Similar to 135 H 12.

135 H 15.

135 H 16. Sheared, soft, black shale. (Utica?).

135 H 17.

135 H 18.

135 H 19. Same rock as 135 H 23.

135 H 20.

135 H 21.

135 H 22.

135 H 23. Badly sheared limestone, evidently was once like 135 H 6 and 135 H 8. Trinucleus.

135 H 24.

135 H 25. Very similar to 135 H 23.

135 H 26. Trenton limestone, like 135 H 6 and 135 H 8.

PROVIDENCE ISLAND.

This island is, as Plate LV shows, closely adjacent to the southwest point of Grand Isle. It obviously once formed a part of the larger island, and its geological structure is one with that of its neighbor.

The map shown in Plate LV is the result of very careful investigations by Messrs. Brainerd and Seely. As the map clearly shows, the major part of this island is Beekmantown, the Chazy being found only at the northern end and on a small projection on the northwest. Some portions of this Chazy rock are wonderfully filled with corals, and especially sponges, probably many of them as yet undescribed. Much of the Beekmantown of Providence Island is the same as that which at Fort Cassin formerly yielded such rich returns to the fossil hunter. The Providence Island layers, though affording many of the same fossils, *Lituites, Maclurea, Murchisonia, Asaphus,* etc., do not appear to be nearly so rich in fossils as the more southern beds. Some species, however, as *Calaurops lituiformis,* occur much more abundantly at Providence Island. *Isochilina,* several species, are plentiful in places.

Professor Seely has kindly furnished a few notes of his work on this island from which I quote the following: "Found on the neck a great mass of Chazy A upturned at a steep angle. Took some remarkable fossils, *Spongia, Orthoceras,* enormous *Nautilus,* small *Lituites, Blastids,* etc. Going south reached the Beekmantown, where there were *Maclurea sordida* and trilobite bed. Sponges of different families were well represented. On the west and south part of the island found great display of *Maclurea sordida.* Found also *Euomphalus,* etc."

"The Beekmantown of this horizon seems characterized by Murchisonia of many forms. It is one of the most interesting regions for fossils."

In Bulletin of American Museum of Natural History, Vol. III, p. 17, where Messrs. Brainerd and Seely published an account of their investigations, we find the following concerning Providence Island: "At Providence Island there is an interesting exposure of the upper part of Division D, and the lowest part of Division E. (The two highest of the Beekmantown.) See maps 56 and 57. On the main body of the island the dip is north 75° east, at an angle of 5°, and the following strata occur in ascending order:

	FEET.
a. Calciferous sandrock in layers 6 to 10 inches in thickness, containing Maclurea affinis, B. and Asaphus canalis, Con.	71
b. Tough magnesian limestone weathering yellow in layers 1 foot in thickness	5
c. Sandy limestone, weathering on the edges in ridges one to two inches apart, holding in a layer 14 feet from the top Calaurops lituiformis, Whitf. in abundance	28
d. Magnesian limestone, more or less siliceous, thin-bedded at first, then in massive beds, holding Asaphus canalis, C.	31
e. Blue or dove colored limestone, in beds 4 to 8 feet in thickness, separated by thinner layers of magnesian limestone, containing Lituites seelyi Whit., L. eatoni Whit., Nautilus kelloggi Whit., Maclurea affinis Bil., Orthoceras sp., Holopea cassina Whit.	44
f. Magnesian limestone, in beds 2 to 3 feet thick, holding at top abundant masses of scoriaceous black chert	10
g. Magnesian limestone holding small nodules of white chert	3
h. Magnesian limestone without chert, weathering yellow	12
i. Concealed	20
j. Tough magnesian limestone, weathering yellow, with numerous fine black lines appearing on the fracture surface	7
k. Very tough, dark-colored limestone, with lenticular masses of compact black chert, in two layers, parallel to the bedding, and two feet apart	5
	238

"Along the northwestern shore of the island is a fault which, on the west, divides into three branches, revealing in succession, higher and higher strata in the northwest side of each branch. The two small peninsulas belong to the summit of the Chazy formation and are filled with *Rhynchonella plena*.

"The western wedge-like mass consists of some of the strata already described. The eastern wedge-like mass, beginning with the peculiar strata marked j. and k. above, contains over 280 feet of still higher strata. (See section No. 8.) The dip fluctuates between 14° and 22° northeast, the average of twelve measurements being 16° to 25°. The rocks are tough magnesian limestones, weathering drab or buff, in beds 1 to 3 feet in thickness; but in three or four places there are intercalated beds of blue limestone 2 to 4 feet thick, one containing *Murchisonia confusa* Whit., *Isochilina seelyi* Whit., *Bucania tripla* Whit. and *Lituites*.

"The strata above this exposure are for 35 rods concealed by the waters of the lake, after which appear on the north headland about 230 feet of the Lower and Middle Chazy, with abundant fossils. The strata here are concealed, but may be seen on South Hero a mile and a quarter northeast, lying southeast of the fault which extends over two miles in this direction. (See Plate LIV, Section 9.) They consist of magnesian limestone similar to those of Section 8, with at least one more bed of blue limestone, containing *Isochilina* and of about 70 feet of the sandstone interstratified with impure limestone at the base of the Chazy. We regard all the magnesian rock above the 44 feet of dove-colored limestone as equivalent to Division E of the Calciferous in Shoreham and Charlotte. The total thickness at Providence Island—450 to 500 feet—agrees well with the thickness observed at the south."

SUMMARY OF THE FORMATIONS.

THE BEEKMANTOWN (CALCIFEROUS).

The only exposure of this formation on the island is the small area already noticed northeast of Phelps Point. The rock is found on the shore where it breaks out in the long sand beach between Phelps Point and Allen* Point. Here it extends for two hundred feet along the waters edge in a low flat mass. About six feet in thickness appear at this point, the layers dipping 7° N. 40° E., the strike being N. 20° W.

A short distance back from the lake a heavy deposit of glacial clay wholly conceals the underlying rock, but still farther inland there are numerous small outcrops so that in all we have over forty feet in thickness. The beds are all Upper Beekmantown.

In appearance, both when freshly broken and when weathered, the rock is much of it of peculiar appearance, quite unlike the other beds on the island. Most of it is very hard, siliceous, black or steel gray when freshly broken. It is, however, in a few layers, shaly and softer. The composition of adjacent layers is often quite variable, as is shown in diverse weathering. One layer, after long exposure, presents a series of more or less regular, cubical blocks with rounded edges and light rust brown color. Another layer weathers light yellow or buff. Some, in which there is less iron, or at least in which what iron there is does not oxidize, remain steel or silver gray, the surface often having the appearance of watered silk, the "watering" being in different shades of gray and the effect very pretty. The different beds appear on a somewhat steep hillside north of the road which passes the Phelps farm, in a succession of narrow strips, each separated from that above it by the overlying clay. These, with one or two exposures between the road and the lake, and that mentioned on the shore, are all that can be seen.

* The geographical names used are those of the topographical maps of the U. S. Geol. Survey.

For the most part the rock is very barren in fossils, but there are certain thin layers which are more prolific.

In these there are *Bathyurus, Isochilina, Asaphus, Euomphalus* and other characteristic forms.

Several species of *Isochilina* are described and figured by Professor Whitfield in *Bulletin Am. Mus. Nat. Hist., Vol. II, pp. 58-60, Pl. XIII*, as *Primitia*. As to these fossils, which are more common than any others in the beds of this group on the island, Professor Seely writes: " These ostracods are pretty abundant in the E. (Upper) Beekmantown, and in going down geologically they may be the first certain indications of the true Beekmantown. The forms I have seen distributed seem much like *I. gregaria*, Whitf., but so far as I know, they are not gregarious but wanderers. They will stand at present as *Isochilina* sp. ? "

The Beekmantown beds can be traced back from the lake nearly to the Lower Chazy which appears here, but actual contact could not be found.

THE CHAZY.

Grand Isle is a very favorable locality for studying the Chazy since all the members of the group are found here. The upper beds are especially well developed, but the middle is not wanting and, though not widely distributed over the island, a small area of the lower beds also occurs and furnishes the characteristic fossils.

As has been shown with some detail on preceding pages, the Chazy rocks are found in a rather narrow belt along the western shore from Rockwell Bay south to Table Bay, and then they come in again at McBride Bay, continuing from there to Phelps Point.

From Phelps Point, as the map shows, there is a considerable Chazy area extending northeastward towards and nearly to Keeler Bay, a distance of more than two miles.

North of Keeler Bay, reaching to Pearl Swamp, is another area of mostly Upper, but also to some extent, Middle, Chazy.

On the eastern side of this area, as the map shows, there is a northern projection of this formation. In many parts of this northern area the Upper Chazy is full of *Eospongia, Solenopora, Rhynchonella*, etc., and appears in numerous low outcrops.

The layers have not anywhere been greatly disturbed, rarely dipping more than 10°-15° and often much less. As we have noticed, the Chazy first appears on the western shore, at the south of Rockwell Bay, shown in Plate XXX. Here the rock extends a few rods inland, but is nowhere very wide. From here to the north side of Table Bay, where it stops (Plate XXXII), the rock is wholly Upper Chazy. South from Table Bay this formation next appears in a curious little outcrop of hard, siliceous beds of Upper Chazy at Chippen Point, as previously described. No other Chazy beds appear till we reach the south side of Chippen Bay, when the upper beds again come to the surface and then continue on to Barnes Bay, where, as shown in Plate XXXIX, there is a finely marked contact with the Black River. Farther on, the Chazy appears on the south side of McBride Bay and continues on around Wilcox Point (Plate XLIV), and on to Phelps Point (Plate XLV), where the Middle Chazy is finely seen.

As one proceeds inland from Phelps Point he meets some of the finest Chazy outcrops on the island. The magnificent beds at the large quarry near the point (Plate XLVII) have been noticed.

A mile northeast from Phelps Point is a hill 150 feet above the lake at its highest point, and one of the highest on the island, where the lower beds are well shown. Before reaching this hill, not far east of the wagon road, there is a small outcrop of the very lowest beds of the Chazy. These beds are very hard, yellow where weathered, but dark gray when freshly broken. There are here in all not over four feet of rock. Most of it is not fossiliferous, but a few thin layers contain an abundance of a large and probably undescribed Lingula. Professor Seely has named this provisionally *L. limitaris*.

East of Wilcox Point there is another sharp uplift of Middle Chazy which has been thrust up to a height of a hundred feet.

Some of the Chazy beds are thicker and more massive than any others on the island. Others are thinner and easily crumbled. Not infrequently a thick and compact bed is followed by one that is thin and friable.

This variety in these beds is well shown by the following section taken between Rockwell Bay and Table Bay:

	Feet.	Inches.
1. Shaly and very friable layer full of Solenopora and sponges	4	6
2. Layer similar to 1, but more compact	1	
3. Dark gray, compact layer, jointed, made up chiefly of fragment of brachiopods and other fossils	5	6
4. Thin-bedded, muddy layer containing numerous globular sponges, Rhynchonella, Solenopora, etc	5	8
5. Compact layer, sponges and corals	2	
6. Shaly layer with many corals and sponges	5	
7. Shaly layer full of corals		6
8. Similar to 7		10
9. Compact limestone	1	8
10. Shaly layer		3
11. Compact limestone	2	9
12. Compact sandy layer, surface very irregular	2	
13 Compact layer, irregular bedding, full of small, fragmentary fossils	3	
14. Compact layer, numerous streaks of yellow sandy material	2	6
15. Compact, irregular bedding, many sponges	5	6
16. Similar to the above	1	4
17. Compact, regular	2	
18. Irregular, botryoidal surface, jointed, weathering in irregular cubical blocks of rust color	2	3
19. Compact calcareous layer, many sponges		4
20. Shaly layer	3	
21. Compact limestone	6	
22. Irregular shaly layer	2	
23. Irregular shaly beds full of Solenopora, Rhynchonella, streaked with yellow sandy material	1	4
24. Compact layer, much like 23	5	
25. Compact, like 24	2	6
26. Shaly, irregular layer	3	4
27. Shaly, irregular; in places compact	2	4
28. Compact limestone	2	4
29. Compact limestone, full of fragmentary fossils, finely jointed	3	8
30. Thin-bedded sponge layer	1	3
31. Similar to 30	1	8
32. Massive limestone	6	
33. Thin-bedded limestone	3	4

	Feet.	Inches.
34. Compact layer, corals and sponges	1	1
35. Thin-bedded layer, corals, sponges		3
36. Similar to 35		3
37. " "		5
38. Rhynchonella layer	2	
39. Coral and sponge layer		9
40. Compact layer with Brachiopods and other small fossils	1	8
41. Compact layer with trilobites, corals, brachiopods, and in general a greater variety of species than the preceding		4
42. Very solid layer, many species, dip very little. Dikes No. 3, 4, 5, are located here	1	9
43. Compact layer composed almost wholly of Rhynchonella plena		5
44. " " " "	1	
45. " " " "	1	
46. " " " "		6
47. " " " "		3
48. " " " "	1	2
49. " " " "		10
50. " " " "		4
Beds 43 to 50 inclusive form the "Rhynchonella Beds" of Brainerd and Seely.		
51. Compact layer		4
52. Layer full of small, fragmentary fossils		10
53. " " "		7
54. " " "		3
55. Compact layer full of Rhynchonella plena		8
56. " " "	1	1
57. " " "		9
58. Shaly and somewhat sandy layer with numerous Rhynchonella	2	10
59. Layer with fragmentary fossils		3
60. " " "		5
61. " " "		1
62. " " "		6
63. " " "	2	8
64. " " "		8
65. Layer full of sponges	3	8
66. Irregularly bedded layer filled with Rhynchonella, etc., more or less fragmentary	5	5
	124	10

From this point the strata run along with little displacement until near Table Point, and a few rods beyond this the Chazy beds disappear for a considerable distance, except the small area at Chippen Point, as may be seen by consulting the geological map.

I have simply enumerated the different beds as they occur between Rockwell Bay and Table Bay. There are several faults, and though these are not large, it is quite possible that there is some repetition in the above list. More thorough study of the beds and their fossils is necessary to a complete knowledge of their relation to each other and to the whole formation.

As may readily be understood from the foregoing list of beds, the Chazy is far from uniform in its structure. Indeed there is constant variation. Not merely in different localities, but even in the adjacent layers of the same mass there is often great diversity. This diversity is seen not only in the physical character of the rock, but in its color, mode of weathering, etc. As elsewhere, the beds are often filled with numerous small fossils and these are the rule, although in a few layers large Orthocerata occur.

Nevertheless, while the prevalent diversity in structure, composition, color, etc., of the Chazy beds is noticeable, yet there is also very noticeable uniformity. Few of the Chazy beds would be mistaken by an observer of much experience for those of either the Black River or the Trenton. Though very unlike it may be, in many respects, yet they all have in common a Chazy family resemblance.

In the Bulletin of the American Museum of Natural History, Vol. VIII, p. 305, Messrs. Brainerd and Seely give a somewhat detailed account of "The Chazy of Lake Champlain." The studies of these gentlemen were most extensive on Valcour and Providence islands, though, as their map shows, they did not leave Grand Isle unstudied.

They found "By far the best exhibit of the Chazy formation at Valcour Island and on the neighboring mainland from Bluff Point to Port Jackson. It here attained its maximum thickness. The base of the formation is seen resting upon the yellow magnesian limestone at the top of the Calciferous, and may be traced upwards in various exposures through 890 feet of strata till its summit is seen underlying the Black River limestone.

"The strata here measured are as follows in ascending order:

	Feet.
Group A (Lower Chazy).	
1. Gray or drab colored sandstone, interstratified with thin, or sometimes thick, layers of slate and with occasional thin layers of limestone at the base containing *Camerella ? costata* Bill.	56
The slaty sandstone gradually passes into	
2. Massive beds, made up of thin alternating layers of tough slate and nodular limestone, containing undetermined species of *Orthis* and *Orthoceras*	82
3. Dark bluish-gray, somewhat impure limestone, in beds of variable thickness; often packed with *Orthis costalis* Hall, which occurs with more or less frequency through the whole mass. Other fossils are: *Lingula huronensis* Bill., *Harpes antiquatus* Bill., *Harpes ottawaënsis* Bill. (?), *Illænus arcturus* Hall (*I. bayfieldii* Bill.), *Lituites* sp. (?)	110
4. Gray, tolerably pure limestone in beds 8 to 20 inches thick, separated by earthy seams, the bedding being uneven. Many layers consist of crinoidal fragments, largely of *Palæocystites tenuiradiatus* Hall. Near the middle of the mass, for a thickness of 10 feet, some of the fragments and small ovoid masses (*Bolboporites americanus* Bill.) are of a bright red color	90
Making for the total thickness of *A*	338
Group B (Middle Chazy).	
1. Impure, nodular limestone, containing *Maclurea magna* Le Sueur	25
2. Gray, massive, pure limestone, abounding in crinoidal fragments	20
3. Bluish-black, thick-bedded limestone, usually weathering so as to show pure nodular masses enveloped in a somewhat impure, lighter-colored matrix; everywhere characterized by *Maclurea magna.* Near the middle of this mass, for a thickness of about 30 feet, the fossils are silicified and of jet-black color. The more important, besides *Maclurea*, are species of *Strophomena*, *Orthis* and *Orthoceras*	210
4. Dark, compact, fine-grained limestone, with obscure bedding, weathering to a light gray. Fossils are infrequent, but at a single locality there were collected *Orthis perveta* Con., *Orthis platys* Bill., *Leptæna fasciata* Hall, *Asaphus canalis* Con., *Cheirurus polydorus* Bill., *Harpes*, sp. und., *Illænus incertus* Bill., *Lichas minganensis* Bill., *Sphærexochus parvus* Bill., and several undescribed species	20
5. Bluish-black limestone like number 3, but less pure, containing *Maclurea magna* Le Sueur, *Orthis perveta* Con., *Strophomena incrassata* Hall, *Orthis disparilis* Con., or *O. porcia* Bill	75
Total thickness of *B*	350
Group C (Upper Chazy).	
1. Dove-colored compact limestone, in massive beds, containing a large species of *Orthoceras; Placoparia* (*Calymene*) *multicostata* Hall, *Solenopora compacta*, and a large *Bucania*	60

	Feet.
2. Dark impure limestone, in thin beds, abounding in *Rhynchonella plena;* at the base a bed 4 or 5 feet thick is filled with various forms of *Monticulipora* or *Stenopora*	125
3. Tough, arenaceous magnesian limestone, passing into fine-grained sandstone	17
Total thickness of *C.*	202
Aggregate thickness of the Chazy on Valcour Island	890

"Valcour Island, which lies about six miles south of Plattsburg, N. Y., is over two miles in length and one mile in width. Almost the entire shore is rocky, with deep bays and steep promontories, sometimes fifty feet in height. The strata slope for the most part eastward at an angle of from 3° to 7°; but a little north of the centre of the island there is a shallow syncline. Along the northwest shore of Sloop Cove is a minor fault, extending across the promontory north of the Cove. The excavation of the bay is doubtless due to this fault. Across the northern end of the island runs a greater fault, with an upthrow on the south side. The strata north of the fault dip to the northeast, the highest rock on the northeast point being the Black River limestone. Underneath, as we go westward, are seen the strata of *Group C*, Chazy, and the upper part of *Group B*.

"At the south end of the island there is evidence of still greater disturbance. A fault with two branches runs in from the south shore to the northeast, but does not extend to the east shore. The rocks at the southeast are thus tilted to the east at an angle of from 22° to 30°, exposing the sandstone at the very base of the formation. The thickness of Chazy strata seen here is over 600 feet—in fact, the whole of the formation is exposed except the upper 80 feet and about 200 feet covered with soil. This hiatus of the upper part of *Group A* seems to have been caused by the removal by glacial action of the narrow mass of rock between the fault and the shore line. About one hundred rods southeast is a small rocky island, called Grand Island, consisting of the slaty strata of *Group A*, and lying in the strike of the same strata on Valcour Island."

The following account of the sponges of the Chazy has been prepared for this report by Prof. Seely, who has studied these organisms for many years:

SOME SPONGES OF THE CHAZY FORMATION.

H. M. SEELY.

The Chazy formation is essentially one of limestone. Among the notable exceptions of limestone rocks is a fossiliferous sandstone which occurs in many places and which may be regarded as the very bottom of the series; and another sandstone near the top, a very hard one resembling quartzite. The very cap or top of the formation is usually a stratum of varying thickness of very tough non-fossiliferous magnesian limestone. The rocks of the series are more related to those of the Beekmantown below than to the Trenton above.

The rocks of the Chazy are very diverse in their structure as well as in their fossiliferous composition through all the formation, which when fully displayed reaches a thickness of nearly 900 feet. Yet in all this diversity there are peculiarities which, though not easily described in words, show a unity in characteristics which one comes readily to recognize in the field. Through sparsely fossiliferous layers to those almost wholly made up of remains of old-time animals, such as trilobites, cephalopods, brachiopods, corals, sponges and other extinct forms, unities run and most usually reveal the horizon of the rocks.

One of the most peculiar and characteristic rocks of the Chazy, one very frequently met but seldom or never described, is in the main made up of smallish nodular masses imbedded in what apparently originally was a calcareous magnesian and aluminous magma or mud. Its character best appears when weathered. On the projecting wall of a cliff it appears a roughened mass, with sharp irregular projecting lines, the included calcareous nodules having somewhat weathered out leaving the reticulated lines in relief. On the horizontal mass of rock where exposed to sun and frost the mesh breaks away, and the rain carrying away the clayey portion leaves a mass of uncemented nodules.

This stone at its best forms a tough valuable material for buildings or other coarser constructions. The cut faces bear an irregular banded look, the mesh and the nodules giving a characteristic appearance.

The spherical or elongated masses breaking down from a weathering rock appear like rolled fragments or calcareous concretions, and such without doubt they are in many cases. Yet a careful study will disclose the fact that a portion of these nodular forms have definite structure. This structure is sometimes revealed by the natural weathering of the rock, better shown however when the object is cut and polished, and still better when cut in very thin sections and viewed by the help of the microscope. By such means it becomes evident that what at first seemed an accidental concretion is really an individual form, the stony body of an animal that once existed in the sea.

These fossil forms are in the main so unlike anything now living that it is difficult in many cases to refer them to their proper places in classification. Since, however, in numerous respects they approach in structure the existing calcareous sponges, it seems best to class them with these sponges.

This wide field of study, that of the lower calcareous sponges, has been but slightly cultivated. Something, however, has been done. An early recognition of one of these forms was made by Mr. Billings, the paleontologist of the Canadian Survey under Logan, who in describing forms from the Chazy of the Mingan Islands founded a new genus, Eospongia, to include these newly observed forms. One of the most commonly occurring of these he named *Eospongia varians*. It is quite possible that several species were included under the varying species *varians*.

The most usual appearance is like in shape to a small pear stem downward and depressed by pressure upon the blossom end. Sometimes, however, it is in the shape of an elongated pear. A cavity or cup occupied the place of the blossom end of the pear. When weathered across with a small portion of the cup as a center and the radiating tortuous channels reaching out toward the periphery, one is reminded of the crude representations of the sun, a center with streaming irregular rays.

A full description as given by Mr. Billings is found in the Paleozoic Fossils of Canada, Vol. 1, p. 19, as follows:

GENUS EOSPONGIA.

"Generic characters—subglobular, pyriform, or sub-hemispherical sponges not free, with an internal arrangement of pores (sometimes reticulated) radiating irregularly from the central axis; cup of variable depth; *Eospongia varians*, n. sp.

"This species is depressed turbinate, expanding from the obtusely pointed pedicle to a width of from two to three inches, at a height of from one to two and a half inches. The upper margin is obtusely rounded. The width of the cup is about one-third of the whole diameter, and about a half or three-fourths of an inch deep, rounded at the bottom, and with a thick rounded margin. The greatest width of the species is in general near the top, but in those which have grown around the stalk of a crinoid there is a depression below as well as above, so that it is often difficult to say which is the cup and which is the base. The transverse polished section show numerous radiating tortuous canals, often branching from half to one line in diameter and usually distant once or twice their width. The vertical section shows other channels ascending and sloping outwards. The weathered surfaces are irregularly striated with obscure, rounded, often interrupted radiating ridges from one-half to one line wide."

This description, though complete, is without illustration, and so one is liable at first to pass the fossil by without placing it, but when once fully known, new examples are recognized at a glance.

These fossil sponges, beautiful objects, are seen not unfrequently on the polished dies of monumental stones coming from the Chazy quarries of Isle La Motte. They are seen too in place and very noticeable in the rocks on the grounds of the summer cottage of Mr. Thorp on the banks of Champlain, South Hero.

In the original description of the *Eospongia varians* the locality where observed was mentioned as Mingan Islands. The portion of the Chazy, however, from which obtained, the lower, middle or upper, is left problematical. In the study of the rocks of the Chazy it is often very desirable to know at what horizon a given fossil or stratum is found. At Chazy, N. Y., where these rocks were first studied, as well as on Valcour Island, where they are wonderfully developed, it is easy to distinguish them into three divisions, and these have been named from the first three letters of the alphabet, A signifying the lowest division, B the middle and C the upper.

This discrimination will frequently help. The form varians, as subsequent observations have shown, belongs in B, the middle division, particularly to the upper part of B. So also the nodular reticular limestone, mentioned previously, is largely developed in B.

In the American Journal of Science, Vol. XXX, page 355, November, 1885, there is described and figured a definite organism from the Chazy. This approaches in character the sponges and has been classified with them. The weathered surface of the little fossil usually shows concentric folds or ridges, these distinguishing it from a pebble. The internal structure is remarkable, appearing on microscopic examination of thin sections, like threads of tangled yarn, evidently minute canals or tubes running through the organism.

From the character of these minute canals the genus was named *Strephochetus*, twining canals. In worn examples of the inclosing rock these organisms near the size of garden currants appear like little eyes looking from the stone and so have received the specific name *ocellatus*, and the full name of the fossil is *Strephochetus ocellatus*. The little wavy tubes or canals have a diameter of one two-thousandths of an inch in diameter.

Plates LVII and LVIII give a fair indication of the external appearance of the fossil, and also the minute structure of the organism as seen in thin sections, exhibited under in one case one hundred and in the other three hundred and fifty diameters microscopic enlargement.

This form is found in the rocks of the middle B, and often there occurs in connection with it the remains of the great water snail, the typical fossil of the Chazy, the *Maclurea magna*. It appears in many localities, yet keeping pretty well to the horizon B. So it may be used to determine the presence of the Chazy rock as well as the horizon of the same. It is abundant in the B Chazy at Field Bay and Mile Point, near Fort Cassin, and especially is it to be noticed at the second quarry opened at Phelps Point, South Hero, where, in some places, the rocks are almost wholly made up of this little rounded fossil. (Plate LVIII.)

Further observation has shown that *Strephochetus ocellatus* was not the only species inhabiting the ancient seas. The same journal of the following year has descriptions of three other forms. One of these is so notable that a few words ought to be said about it here. It is in a higher horizon of the Chazy division C, and particularly in a magnesium stratum there. Its canals are larger and less tortuous than those of *S. ocellatus*, has greater size, sometimes it is free from support, but more often it incloses or incrusts some object, as a shell. Seen in the original rock, it is very noticeable. Its name is *Strephochetus brainerdi*.

Later than the publication of the above accounts another form of Strephochetus has been found and this in the division A. It approaches *S. brainerdi* in size, and has much the internal structure of *S. ocellatus*; externally, however, the weathered surface does not show the folds or ridges, but has more the appearance of a petrified sponge. The name *Strephochetus primus* has been given to this species.

So various strata of the different divisions of the Chazy appear to have had sown through them forms of the size of the smaller fruits, currants, cherries and plums, these sometimes pressed out of original shape, looking to an unobservant person like pebbles or nodules, but when carefully noted they are found to be the remains of ancient organisms. In most cases they were scattered sparsely through the paste in which they were originally imbedded, in rarer instances they were so massed that they now form the greater portion of the rock.

The following descriptions of various species of this genus are introduced here for the convenience of those interested:

Strephochetus (στρέφω I twine, ὀχετός canal), nov. gen.

A free calcareous sponge showing in structure concentric layers composed of minute twining canals.

Strephochetus ocellatus, n. sp.

Plates LVI (figs. 3, 4), LVII, LIX.

Type of genus. A compact calcareous sponge, spherical or slightly flattened, distinctly concentric in character, usually less than half an inch in diameter, forming when in masses, a tough limestone. When weathered the concentric character is very evident, the fossil then looking like little eyes peering from the stone.

These forms are often gathered in crowded masses, the intermediate spaces being filled with fragments of the fossil mingled with oölitic grains. More rarely they appear here and there in a mass of oölite.

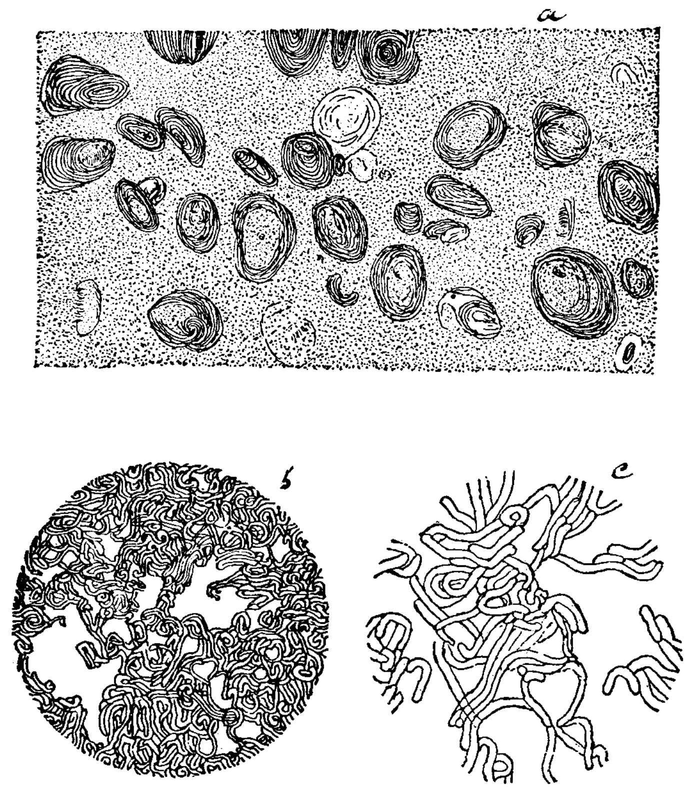
This fossil occurs in connection with well recognized Chazy forms and especially with *Maclurea magna*. It is found in place in the towns of Addison, Bridport, etc., in Addison county, Vermont, and bowlders in those towns as well as at Crown Point, N. Y.

S. brainerdi, n. sp.

Plate LVI, fig. 2; Plate LVII, fig. 8.

A free calcareous sponge having the twining canals peculiar to the genus, which structure may enlarge into furrows and

PLATE LVI



Strephochetus ocellatus, Seely.
a As in rock. *b c* Microscopic structure, much magnified.

ERRATA.

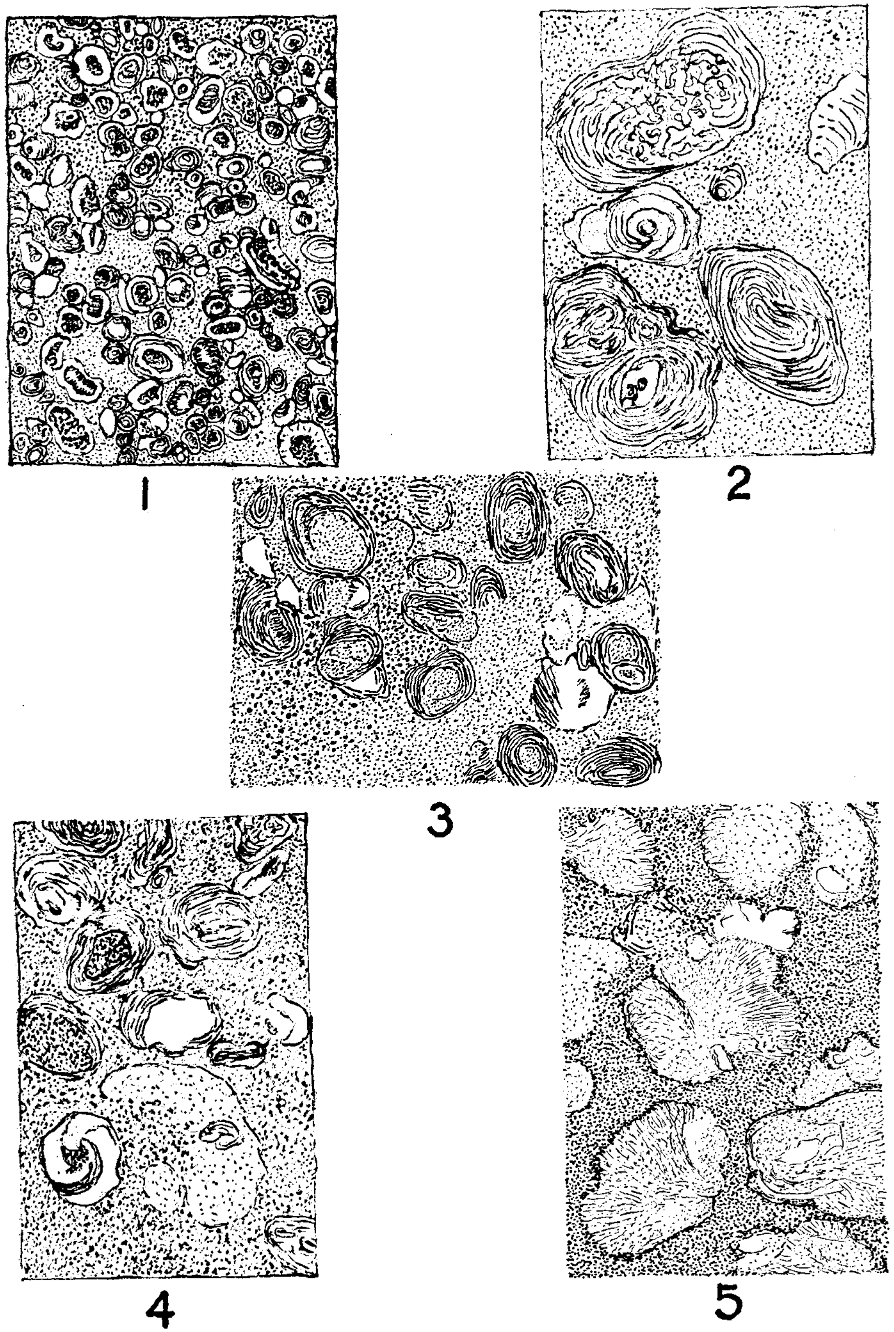
Instead of the references given to the plates of Strephochetus read as follows:

Page 156.—Strephochetus ocellatus, Plates LVI, LVII (figs. 3, 4), LIX.

Page 156.—Strephochetus brainerdi, Plates LVII (fig. 2), LVIII (figs. 7, 8).

Page 157.—S. atratus, Plates LVII (fig. 1), LVIII (fig. 9).

Page 160.—S. prunus, Plates LVII (fig. 5), LVIII (fig. 8).



Sections of Rock Containing Strephochetus.

1 S. atratus, South Hero, Vt., Black River.
2 S. brainerdi, Chazy, N. Y. Upper, or C, Chazy.
3 S. ocellatus, Ferrisburgh, Vt. Middle, or B, Chazy.
4 S. ocellatus, South Hero, Vt. Middle Chazy.
5 S. prunus, Isle La Motte, Vt. Lower, or A, Chazy.

further into well-defined cylindrical canals, and these canals may so increase in number and press upon each other that in sections they appear polygonal. The diameter of the large canals varies from $\frac{1}{500}$ to $\frac{1}{250}$ of an inch. The size of this species is greater than any other of the genus yet observed, being frequently over an inch in length. Its outline is usually oval in section, though in many cases the specimens are irregular or angular as though they had been crushed by pressure.

This form has as yet been observed only in some of the magnesian layers intercalated among the compact and fine-grained layers of the Chazy rocks in the magnificent display of these at the village of Chazy, N. Y. The specific name is given in honor of President Ezra Brainerd, whose careful observations and accurate measurements have added much to our knowledge of the series.

S. atratus, n. sp.

Plate LVI, fig. 1; Plate LVII, fig. 9.

A free calcareous sponge, smallest of the genus yet recognized, having the external appearance of *S. ocellatus,* with the internal structure of *S. brainerdi,* the small canals obscure, the larger ones distinct.

This form was obtained from the Black River limestone at McBride Bay, South Hero, Vt., and in the Black River limestone at the quarry of west lime kiln, Chazy, N. Y. This little fossil appears coated with black and from its covering takes its specific name.

S. richmondensis, S. A. Miller.

A free globular or sub-globular calcareous sponge, varying in size from two-eighths to seven-eighths of an inch in section, consisting of numerous irregularly concentric laminæ, separated by interlaminar spaces, filled in most cases with exceedingly small twining canals, or rarely with minute vertical tubes. These laminæ are more dense than the intervening spaces and in those examples in which the tubular structure chiefly prevails they seem the basis from which the tubes radiate. These tubes are arrested by a laminar covering and this becomes the floor for a new set of tubes. This structure of laminæ and tubes may be many times repeated.

The twining canals have the ordinary diameter of the strephochetal structure, about $\frac{1}{2000}$ of an inch, the radiating tubes vary from $\frac{1}{1000}$ to $\frac{1}{400}$ of an inch; $\frac{1}{500}$ of an inch however is the usual diameter. The irregularly concentric laminæ in cut and weathered specimens give the form the appearance of a Stromatocerium.

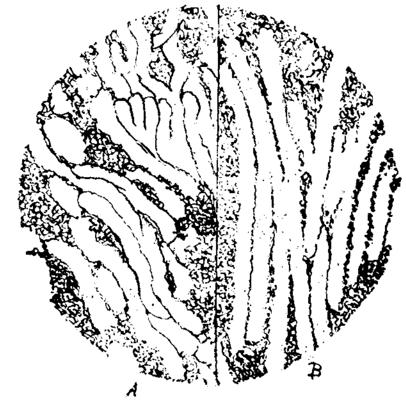
This fossil occurs in the upper Hudson River rocks at Richmond, Ind., Madison, Ind., and at Turners, Ky.

The description of the form, *S. brainerdi*, is hardly complete without further reference to its remarkable structure. While externally it has the stromatoporoid appearance of the other members of the genus, its internal structure may in part vary from the typical form, by the presence of furrows and larger canals, both cylindrical and compressed. One might readily suspect on making a transverse section of some parts of the specimen, that he had in hand a coral, or possibly a coral enveloped by a sponge. But after cutting and carefully examining many sections, and especially as he saw the strephochetal portion at points giving way to furrows, and the gradual introduction of cylindrical canals of large size, and then these, pressing upon each other where the interstitial material became less, until a section was angular, he would reach the conclusion that all these various structures belong really to the same fossil.

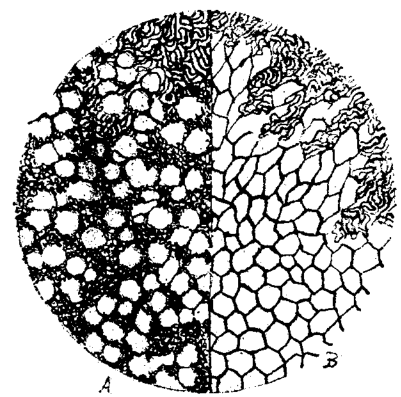
S. atratus so nearly resembles *S. ocellatus* externally that it may be easily mistaken for this latter fossil. Its minute structure, however, differs from it, and is so obscure that it was a question whether it could be placed here. Still its general character so nearly resembles the type species, and its structure so closely repeats that of some specimens of *S. brainerdi* that it is safe to place it here.

In the paper referred to at the beginning of this article, mention was made of the microscopic character of *Stromatocerium richmondense*, Miller. This form was originally referred to

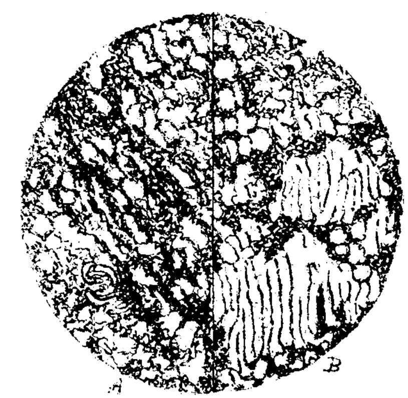
6



7



8



9

Sections of Strephochetus, Seely.

6 S. prunus, showing irregular channels with minute tortuous strephochetal canals.
7 S. brainerdi. Minute canals with enlarged channels. A, channels irregular; B, channels nearly parallel.
8 S. brainerdi. Channels in cross section. A, distributed singly among strephochetal canals; B, compressed upon each other, outlines becoming polygonal.
9 S. atratus. A, most frequent appearance; B, section showing both cross and perpendicular character.

Enlarged, × 100.

PLATE LIX.

Photographed from a Layer almost wholly composed of Strephochetus ocellatus, Seely. Upper Quarry at Phelps Point.

Stromatocerium with hesitation, the choice seeming to lie between that and Stromatopora. After making many sections it becomes evident that it most nearly approaches the genus Strephochetus. Mr. Miller has authorized the specific description above, and it is to be known as *Strephochetus richmondensis*.

This species has several peculiarities of structure. Not unfrequently it occurs as an incrusting body, having for its core a bit of coral, or a fragment of the shell of a brachiopod. It sometimes resembles the structure of *S. brainerdi* in the great enlargement of its canals. In this species, however, the tubes present great uniformity of direction though not of size. They run along nearly parallel with each other for a little distance, and then are cut short by a laminar covering which may be the basis for a similar set of slightly radiating tubes. This may be repeated, as described in the specific characterization of the fossil, ten or fifteen times.

Sections cut in either direction, horizontal or perpendicular, suggest the genus Solenopora, while those of *S. brainerdi*, in like manner that of Chætetes. The discovery of septa or tabulæ, in either of these tubular forms, would lead one at once to place it among the millepore corals. The character of these forms deepens the impression that the line between corals and sponges becomes in some places very narrow and indistinct.

The horizon of these different species is as follows: *S. ocellatus*, near the middle of the Chazy; *S. brainerdi*, in the upper Dove, higher in the Chazy; *S. atratus*, in the Black River; *S. richmondensis*, in the Hudson River.

The appearance of the members of the genus may be represented by the smaller fruits, currants, gooseberries and cherries, distributed through a paste of oölitic, fragamental or subcrystalline material. These in most cases have apparently been subjected to pressure and left in a crushed or torn condition. In weathered specimens they show a concentric structure, more or less regular, which is helpful in distinguishing the genus.

There are intimations that the genus exists in rocks higher than those mentioned, and it is quite probable that forms which have hitherto been regarded as concretionary or as pebbles will on examination be found to belong here. The structure, which for lack of better term we have called Strephochetal, will be decisive on this point.

It would be highly satisfactory if it should be found, as is quite probable, that the strephochetal structure always indicates the presence of a sponge. In that case we might by it hope to settle the question of relationship, now uncertain, of several important genera.

Strephochetus prunus, n. sp.

Plate LVI, fig. 5; Plate LVII, fig. 6.

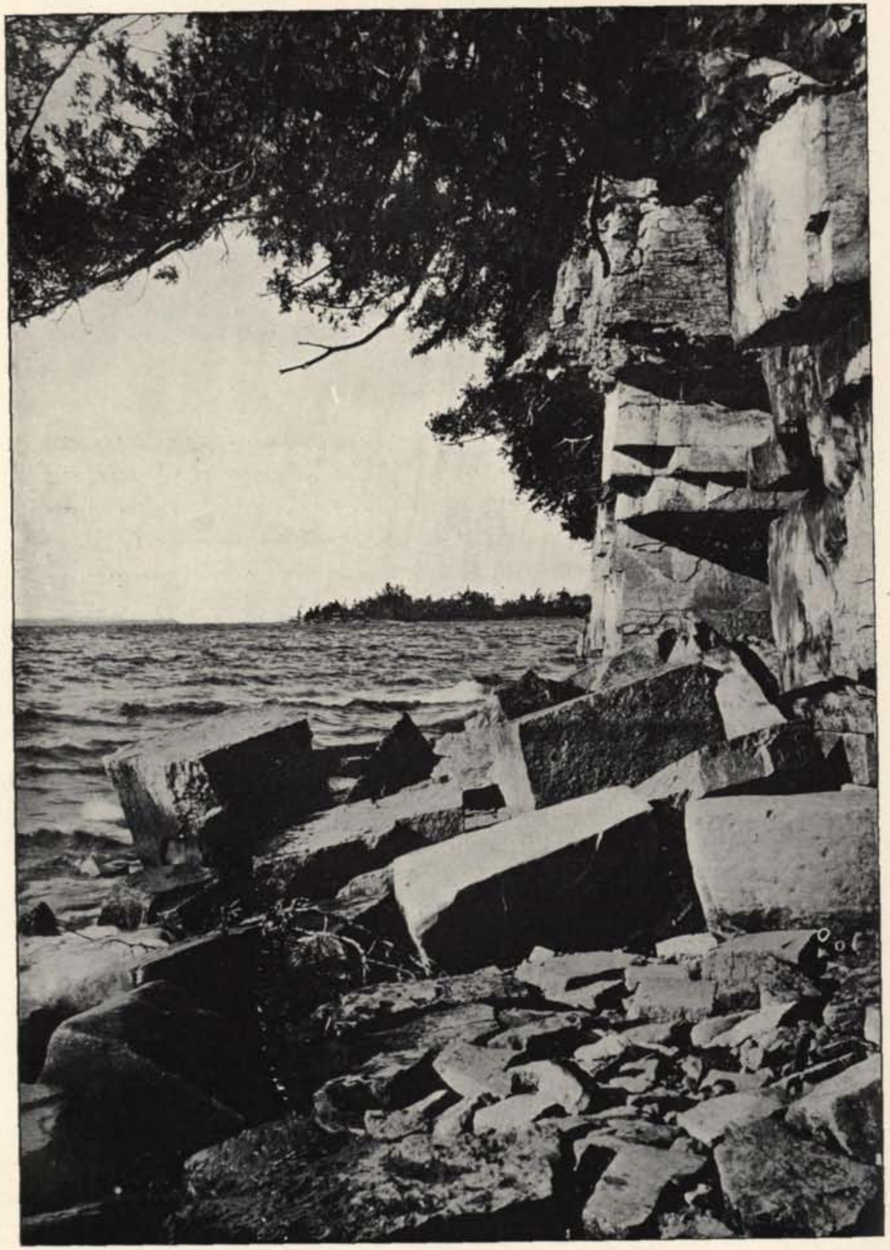
Description.—A free calcareous sponge of the size of a small plum, having the microscopic twining canals of the type of the genus, *S. ocellatus.* On weathered surfaces it has a rough spongy appearance approaching that of *Eospongia varians,* Billings, but without the coarse irregular radiating channels of the latter. Usually imbedded in a stony paste it weathers distinctly within the including mass or at times drops away as a small nodule. Its horizon is the lower or A Chazy.

Discrimination.—From the other members of the genera it is most easily separated by recalling their character and horizon. *S. ocellatus* is mostly of the size of a pea or currant, has on weathered or polished surface the banded structure of a minute *Stromatocerium,* and is found in the middle or B Chazy. *S. brainerdi* has a different mode of growth, it usually inclosing some nuclear object, as a shell, around which it has developed and has for its horizon upper or C Chazy.

Distribution.—*Strephochetus prunus* has been collected from South Hero, Vt., Isle la Motte, Vt., and Chazy, N. Y.

Other pebbly forms occur in the Chazy. One of these occurring in C, is after many namings and renamings now known as *Solenopora compacta.* This may be mistaken for a Strephochetus, but a thin section shows that the tubes are not wavy but parallel, and so is more nearly related to the corals.

PLATE LX.



Chippen Point, Looking North, Black River Limestone.

Other rounded organic remains in the Chazy, as well as in the Trenton above and in the Beekmantown below, are awaiting study. So also others wait, especially the elongated forms, related, in shape at least, to the cup sponges of the present day, found in division A of the Chazy. A start has been made in the study and classification of these old time organisms. It is to be hoped that some one with enthusiasm, time and skill will carry the work on to completion that of the full determination and classification of these stony sponge like forms.

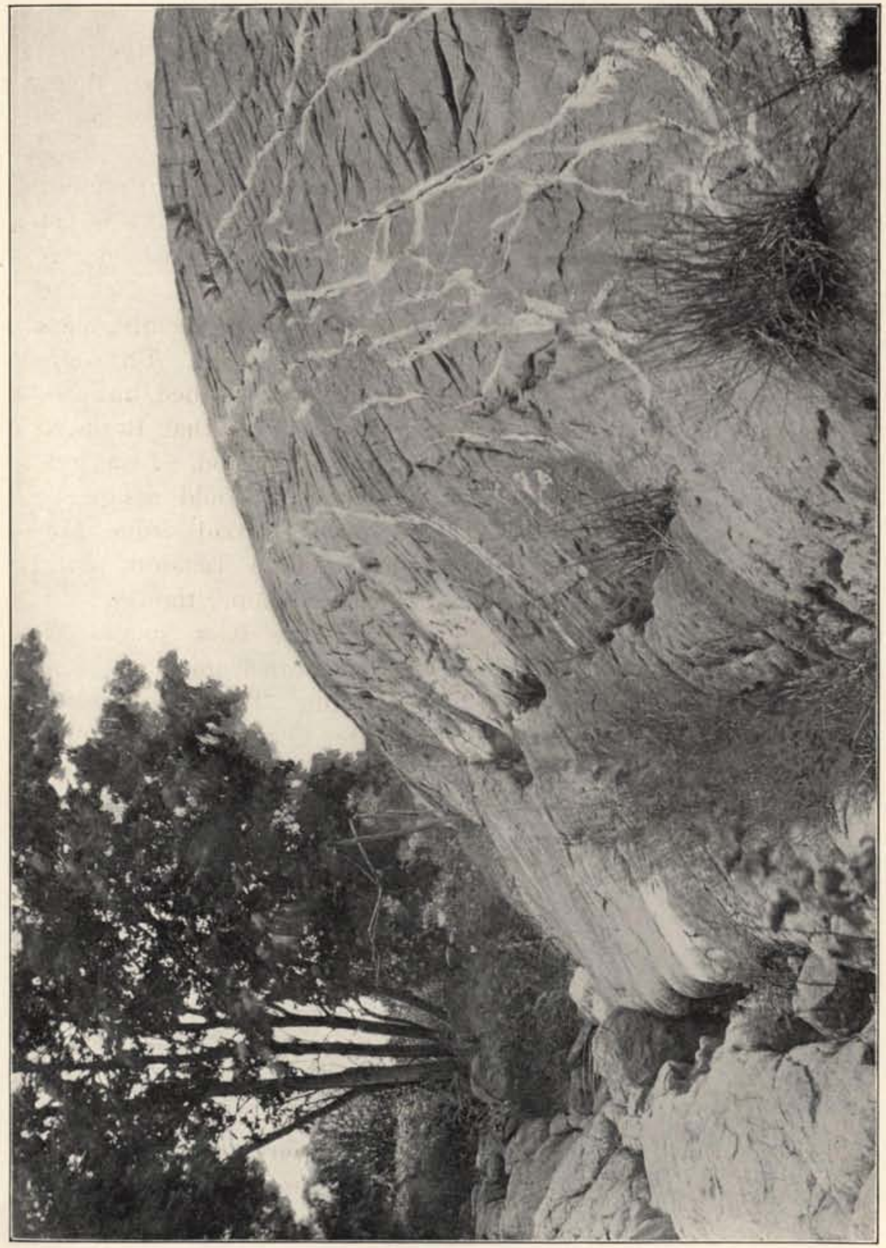
THE BLACK RIVER LIMESTONE.

This group is not largely represented in the rocks of Grand Isle, as a glance at the map shows. The largest area is that on the western shore beginning at Rockwell Bay, where, though it does not reach the water, it is found only a few rods back, and at the middle portion of the bay it seems to have originally been present, but to have been carried out by glacial action. Beginning at this point, just north of the road which runs from Rockwell Bay to Keeler Bay, the Black River extends in a rather narrow strip, increasing as it goes south to Barnes Bay, a distance in a straight line of a mile and three-quarters. As far as Table Bay it has the upper Chazy between it and the lake shore, but at this bay it comes to the water in a low outcrop which soon becomes a cliff, and, with a few interruptions, forms the shore, until, at the northern part of Barnes Bay, it gives place to Trenton beds which occupy Barnes Point. About half a mile south of McBride Bay it again appears in a narrow outcrop which, as the map shows, extends a little south of east between the Trenton and Upper Chazy. This latter is the most southern exposure of this rock.

Plate LX shows well a cliff of Black River at Chippen Bay, a small bay a few rods south of Sawyer Bay, and the peculiar and most regular jointing which is characteristic of this rock is well shown in the picture. The Black River is also shown in Plates XXXIV and XXXV. The contact between the Black River and Trenton at McBride Bay is distinctly shown in Plate XLII.

Between the Upper Chazy and the Trenton north of the road from McBride Bay and the railroad station at South Hero there is a narrow, much broken outcrop of this rock, the position of which may be better understood by reference to the map. This mass, which I think is undoubtedly Black River, as Brainerd and Seely designated it on their map (Plate XLVIII), is yet much less easily recognized than any other on the island. It has evidently been much pressed and broken, is full of calcite veins, which in some places form more than half the entire mass and is, so far as I could ascertain, destitute of fossils. For some time I was in doubt as to the age of this particular bed, but prolonged and careful examination convinced me that Brainerd and Seely were correct in assigning it to this period. I was not, however, able to find any rock which I could assign to this group on the south side of the road from McBrides to South Hero, back of the Buel Landon place, such as is indicated on Brainerd's map, though undoubted Trenton is found there. There is a small outcrop which crosses the road that runs south from that named above by the Hall place to Phelps Point. This little outcrop is shown on the map north of the letter O in the word South, and reaches about fifty feet east of the road and two hundred and fifty feet west of it. There is a small quarry in this outcrop on the west side of the road, and here a fine wall of the rock six to eight feet high is seen. The whole mass is three hundred feet long from east to west, and at the widest is seventy-five feet wide. This is at the west end. At the highest point this upthrust is thirty feet above the road. It ends abruptly at a fault which runs between it and the Chazy west of it. These beds dip 17°-23° N. E. No Black River is seen as we go north from those mentioned until the exposure seen on the map not far west of Hoyt Bay is reached. This, like the remaining outcrop to be noticed, is a long, narrow ridge or series of ridges, much rounded in "roches môutonnées" forms by the ice action. Plate LXI, also Plate XXV, though taken on the west shore

PLATE LXI.



Typical Outcrop of Black River Limestone, Showing Rounded Form Due to Glaciation and Veins of White Calcite. East of Road Near Table Bay.

not far back from Table Bay, is exceedingly characteristic of the usual outcrops of this limestone when seen away from the lake shore. The calcite veins so common in the rock of these upthrusts are also well shown in the plate. The only remaining Black River outcrop which was seen is that shown on the map as beginning just south of the road which runs from Gordon dock to the main road from South Hero village to Grand Isle village, along the south side of Pearl Swamp. This mass, which is almost wholly destitute of fossils, reaches north beyond the middle of the swamp, running at first nearly in the same direction as the road and then turning west along the east border of the swamp. The rock in the large western exposure is more typical than that of the others. Here the regular jointing, black color, compact texture, metallic ring render identification easy, even were no fossils present.

The rock of the smaller outcrops mentioned is more irregularly jointed, lighter in color, often being dove color, often full of white calcite veins and in all respects less typical than that on the western shore of the island. Obviously, this is largely due to the much greater disturbance which the inland beds have undergone. Where fossils occur, they are in all parts of the island much the same. *Columnaria alveolata* is often found and sometimes in masses a foot or more in diameter. A large Maclurea, which I have assumed to be *M. logani*, though a revision of this genus which is much needed might place it elsewhere, is very common in some places. The narrow outcrop which runs southeast from McBride Bay contains this most abundantly. Opercula of this species are also not infrequent. Considerable masses of a large sea weed (*Bythotrephis* ?) are found near Chippen Point. No detailed study of the fossils of this group has been made so far as these particular beds are concerned, but the following species have been recognized, mostly from the layers on the west side of the island: *Leperditia fabulites*. This occurs in great abundance in certain shaly layers, which are between the thicker limestone layers near Sawyer Bay on the south side. *Stromatocerium rugosum* is found now and then with *Columnaria. Tetradium fibratum, Rafenesquina alternata, Rhynchotrema inequivalve, Dalmanella testudinaria, Hormatoma gracilis, Lophospira bicincta, Lingula elongata, Calymene senaria, Ceraurus pleurexanthemus,* etc., etc. Some of the above I have not found in these beds, but give them on the authority of Dr. T. G. White.

THE TRENTON LIMESTONE.

As the map shows, this formation occupies a single large area on the island. It greatly exceeds in extent either the Chazy or Black River, forming an anticline through the midst of the island so that most of the high land is of this age. The Trenton rocks begin on the south at the north side of McBride Bay. From this point it extends north nearly to Grand Isle village, a distance of over six miles, and, as has been noticed, it forms the rock of the lake shore from Rockwell Bay to Wilcox Cove with some interruption where Utica comes to the shore at and south of Gordon Landing. This formation covers the larger part of the island from its southern to its northern limit. The beds appear to be most Lower Trenton, but the fossils have not been studied with sufficient care in all the beds to make this certain.

Dr. White* gives the total thickness of the Trenton at the southern portion of the outcrop, where he worked, as twenty-three feet, but this is only a part of the whole, and when all the beds are correlated the thickness will, I do not doubt, be found to be much more than this. The Trenton cannot be traced continuously over the whole area marked on the map, for, outside of the large uplift which forms a sort of backbone of the island, many of the outcrops are separated by a more or less thick covering of clay and in some cases this covering is of considerable extent. Nevertheless it has seemed quite safe to assume the continuity of the rock under the clay where the out-

* Bulletin Geol. Soc. America, Vol. X, p 458.

PLATE LXII.

Hero.

Trenton Bluff at McBrides Bay, Looking South. The Shore in the Distance is Chazy.

crops on each side were of the same age. There is a curious little outcrop of Trenton, whch is too small to be shown on the map, except by a letter T, which is located just southeast of the junction of the road which runs from McBrides to the railroad station, and that running south from this road to that which goes to Phelps Point.

It may be located on the map north of the letter O and east of C in the Chazy area which forms the southwestern portion of the island. The mass forms a small knoll of somewhat irregular shape, about three hundred feet long, from fifty to a hundred feet wide and ten to fifteen feet high. In this rock there were found *Asaphus gigas, Calymene callicephala, Monticulipora lycoperdon,* etc., which sufficiently fix its age.

The median uplift or anticline consists of mainly Trenton strata, but at the south end Chazy beds and at the north Utica also form parts of it. All these beds are of course greatly disturbed, but where the rock appears on the shore of the lake its strata are not usually greatly disturbed. Indeed they are often nearly horizontal, as shown in Plates XXVIII, XLI and LXII.

Everywhere there is great variety in the character of the different beds which make up the whole mass of rock. Thick and compact layers may be followed or preceded by thin and shaly ones. As has been noticed, some of the layers are full of lenses of various sizes. The variation in color, from light gray to black, is as great as in texture. Some layers have all the characters of the Chazy and would almost certainly be mistaken for them were there no fossils.

The ordinary fossils of the Lower Trenton occur in most of the beds, but some of the outcrops are Upper Trenton. Without attempting to give a complete list of the Trenton fauna of Grand Isle, I may name the following as common species: *Asaphus gigas,* which, though not often found unbroken, is in some layers very abundant in fragments so that it is by far the most common fossil in them and some layers contain little else than larger or smaller pieces of this trilobite. *Calymene callicephala,* also very rarely found entire, is very often present in parts. The figure shows an unusually fine specimen from the Trenton of Chimney Point.

Trinucleus concentricus is also a very conspicuous fossil in some of the layers, the glabellæ appearing on almost every fragment broken by the hammer. *Monticulipora lycoperdon*, while not making up the bulk of some layers as it does at Chimney Point, is yet common and often serves a good purpose as a ready mark by which to identify some of the layers. Huge specimens are now and then found. One in the museum in Montpelier is 18 inches in circumference at the base. This is the only coral that is at all common. Crinoid stems, probably *Schizocrinus*, occur here and there in clusters. Brachiopods

Calymene callicephala.

of the common Trenton species abound in some of the layers and are almost wholly absent from others. *Orthis lynx* is common, but always small. *O. testudinaria, Leptaena sericea, Strophomena alternata*, etc., are common. In some layers Bellerophon is numerous and fine specimens can be easily broken out. Gasteropods are not usually common, and Cephalopods still less abundant, but some species of each are found. Some large specimens of *Endoceras proteiforme* have been obtained.

What Dr. White remarks as to the rocks of the whole Champlain region is entirely true of this portion of it:

"The lowest bed of the Black River * * * is a compact and tough dove gray limestone, having a conchoidal fracture, and in appearance somewhat resembling the true Birdseye, but usually containing no fossils other than ostracods. The capping bed of the underlying Chazy, where well exposed, seems to be a very constant and characteristic layer of fine-grained sandstone or quartzite. * * * The succeeding Black River beds are of heavy bedded black limestone, having thin shaly partings, and ordinarily in the upper portion of each distinct thick layer a fossiliferous zone.

"The change to beds carrying a true Trenton fauna is usually abrupt, the latter formation consisting of much more thinly bedded and usually softer black limestones and slates. * * * The frequent lenticular character of the limestones is a marked characteristic. The lenses consist of a gray, finely crystalline, almost saccharoidal limestone, usually very fossiliferous within layers of black slate. The rich fauna of these granular layers is no doubt due to more numerous currents, and certain species, such as *Zygospira exigua* and *Z. recurvirostris, Tetradium fibratum, Platystrophia biforata, Bucania punctifrons, Conradella compressa, Holopea paludiniformis, Bathyurus spiniger* and *Ceraurus pleurexanthemus*, seem to be wholly confined to deposits of this kind.

"On the other hand, a large assemblage of linguloid species, *Parastrophia hemiplicata*, most of the lamellibranchs, as might be expected, *Protowarthia cancellatus, Isotelus gigas, Trinucleus concentricus*, were almost wholly denizens of the mud, and are found principally in the shaly portions of the rock.

"Toward the upper portions of the series, the changes of the sea bottom evidently became a great deal more rapid and increasingly shaly layers appear with attenuated fine crystalline lenses between."*

The Trenton passes gradually into the Utica so that in many places it is impossible to find a limit between them. Some of the Trenton beds are shaly and in every way like typical Utica except in the fossils, and some of the Utica beds are limestone and exactly like some of those in the Trenton. An illustration of this is found in the small uplift on the south of Keeler Bay, just north of the road from the South Hero railroad station

* Bull. Geol. Society America, Vol. X, pp. 454–455.

to the village. In his manuscipt notes Dr. White calls this Trenton, though he says that he found no fossils. On examination of this locality I was at first inclined to indorse what Dr. White had said, but although the limestone has a very Trenton-like appearance, it does contain well defined *Triarthrus beckii.*

Near Wilcox Cove I found *Asaphus gigas* and *Diplograptus pristis* on the same bit of limestone. From Wilcox Cove for some distance south, these transition beds are found along the shore, beds which might with apparently equal accuracy be called either Trenton or Utica. These are followed by unquestionably Trenton beds down to Gordon Landing, where for a short distance typical Utica make their appearance. Then come more doubtful beds and then undoubted Trenton to Rockwell Bay.

In some comments on Dr. White's paper, to which reference has often been made, Dr. Ami, at a meeting of the Geological Society, made the following statement: "The lacuna existing at the interval of transition from the Trenton to the Utica is unfortunate, as everywhere in the Ottawa and St. Lawrence valleys, in Canada and in Ontario east of Toronto, these two formations pass imperceptibly one into the other. Along the Rideau river at Ottawa, at Rochesterville and at numerous other localities in the vicinity of Ottawa, the pyroschists of the Utica or bituminous shale follow directly upon the Trenton without any discordance of stratification whatever." The lacuna to which Dr. Ami refers does not exist in the Champlain region, though Dr. White thought it did, as he did not chance to come upon the transition beds, but if he could have extended his investigations to the west shore of the island he would have found them.

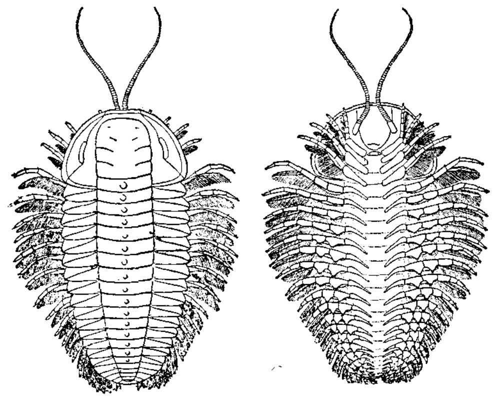
A glance at the map shows how much more extensively the Utica is distributed than any of the other formations.

UTICA.

Over the greater part of the area indicated on the map as occupied by Utica, the rock is of the typical thin-bedded shale

often finely jointed. It is often more or less tilted or even folded and has evidently suffered greater disturbance than have the other formations. The superlative disturbance shown in Plates LI, LII, LIII is not common, though nearly as great crushing and breaking has taken place at one or two other points, but everywhere the shale has been upheaved to some extent.

Fossils are nowhere abundant, though some thin layers yield *Diplograptus pristis* in considerable number. Often *Triarthrus* is the only fossil to be found by most diligent searching. As this fossil is eminently characteristic of the Utica, I insert here a cut of the perfect animal which Prof. Seely has furnished.



Triarthrus beckii.

Showing both upper and lower surfaces of a perfect specimen.

Nowhere have specimens as complete as that figured been found in the Utica of Grand Isle, but entire specimens do sometimes occur, though the usual find is only the glabella or "head." I have considered this trilobite as characteristic of the Utica, and in several instances it has been the only fossil I could find in a mass of rock and therefore my determination of such a mass as Utica has rested wholly upon the presence of Triarthrus.

It has been already noticed that most of the higher land on the island is formed by a Trenton anticlinal uplift, but at the north end the Trenton is replaced by the Utica, and also in the southeastern portion, as the map shows. This is not only true along the lake shore, but in some cases inland. One of the most interesting of these Utica uplifts is situated a short distance north of the road that runs from Sawyer Bay to Keeler Bay on the west of the main north and south island road. Here the layers of shale are nearly vertical and form a hill or knoll some eighty rods long and half as wide, with exceedingly steep sides. It is a hundred feet high above the bay. In many places the bare shale is seen, but much of the elevation, even where very steep, is covered by a tenacious clay which alone could hold its place on such slopes. Kibbe Point is wholly a Utica uplift, with, for the most part, high shores, the shale bluffs often coming quite to the water even in summer.

As has been shown on preceding pages, the shore of the lake is wholly shale, except where the rock has been carried out and clay comes to the water, for a distance of several miles, that is, from where the shale begins east of the sand beach south of the Chazy, between Phelps Point and Allen Point around most of the shore of the island to Wilcox Cove. Throughout this whole distance no other rock comes to the shore. Plate XLIX, Allen Point, gives a very good illustration of the numerous headlands which occur along this long stretch of shore, and Plate XXVII, which is taken on the west side near Corbin's, shows the ordinary shale bluff where not greatly disturbed. As the general character of the shale in different parts of the island has been noticed in foregoing accounts, further details may be omitted.

On the geological map of Vermont, which is published in the report of 1861, a wide strip along the western side of the island is colored as Trenton and the remainder as Hudson River. I am sorry to be obliged to call attention to the error of this, but a very slight comparison with the map given in the present report or a very brief examination of the region itself will suffice to show how far from correct is the older map. In the text of the 1861 report, however, there are a number of Chazy

localities mentioned which are located within the area marked on its map as Trenton.

As for the Hudson River, if the term is used in the sense which it originally had, it does not exist on Grand Isle, nor probably anywhere in the Champlain region. As to this I can heartily endorse Dr. White in saying: "The early reports were inclined to consider the Hudson River group as being largely represented in the region. Most of the strata once referred to this group are now known to be of Cambrian age. The islands in the lake referred to the Hudson River by the Vermont survey (1861) have in several cases proved to belong to the Calciferous. We nowhere found fossils which might be considered typical of the Hudson, such as *Pterinea demissa,* Con., *Modiolopsis curta,* H., *Catazyga erratica,* H., *Dalmanella emacerata,* H., *Cyrtolites ornatus,* Con., nor any of the graptolites referred to that group by Lapworth, while all the fossils found in the upper strata were of well known Utica facies. Professors Brainerd and Seely, at Shoreham, and Mr. Walcott, at Highgate Springs, employed the term Hudson for the upper portion of the slates simply because the thickness represented seemed to be greater than that usually assigned to the Utica alone, and no fossils were found by them. On Cumberland head and Grand Isle, however, we found a thickness of strata probably fully as great, which contained scattered Utica fossils throughout. Erosion and glacial plowing have no doubt removed a great thickness of deposits, but even the elevated "outliers" already referred to give no indication that strata superior to the Utica were deposited in the district."*

THE DIKES.

In our exploration of the shore of Grand Isle all the dikes seen were recorded and are indicated and numbered on the map.

In all forty-two were seen. It is possible that one or two, perhaps more, of these should be considered as opposite ex-

* Bull. Geological Society of America, Vol. XI, p. 456.

posures of dikes which extend across the island from west to east. This is most probable of those on the west side of Keeler Bay, Nos. 36 and 37. I have no doubt that No. 37 is the eastern end of No. 1, and most likely No. 36 is the eastern part of either No. 2 or 6, or one of those in that group, but I have not been able to trace any of them across except No. 1.

Not only the position of the dikes, but the condition of the stratified rocks, shows that much greater disturbance has at some time taken place at the south end of the island than north of this. A glance at the map shows how the dikes are almost wholly confined to the southern half of the island. Indeed, there are only four north of the latitude line which is seen crossing the north part of Keeler Bay.

None of the dikes are large, the widest being forty-eight inches, and most of them much less, some only three or four inches.

By far the larger number are weathered so that they are level with the adjacent limestone or shale. One or two have decomposed so that they have receded from the adjacent rock, leaving a more or less deep channel. One or two, notably that shown in Plate L, have been more resistant than the rock through which they have come, and therefore stand out beyond it.

In most cases the stratified rock does not show any alteration from heat. This is especially remarkable in the case of dike No. 9, which, as has been noticed, not only comes through the Rhynchonella limestone without changing it, but has brought up with it and imbedded in its mass some of the same, and this included stone, which is a mass of the fossils, shows only slight evidence of having been heated.

This mass of perfect shells, conspicuously showing in the midst of the igneous rock, presents a most interesting appearance.

While there is, as would be expected, more or less variation in direction, most of the dikes on the west side of the island extend in general in an easterly direction, that is, towards the middle of the island, and those on the east side in a westerly direction.

The petrography of many of these dikes has been studied at my request by Mr. Hervey W. Shimer, of Columbia University. Mr. Shimer has kindly placed the following report at my disposal, and I am very glad to include it in this account of the island dikes.

As Prof. J. F. Kemp had previously studied the dikes south of Sandbar bridge, numbered 20 and 21, Mr. Shimer did not examine specimens from these, but the description of them given by Prof. Kemp is added to Mr. Shimer's account for the sake of completeness.

Petrographic Description of the Dikes of Grand Isle, Vermont.

HERVEY W. SHIMER, A. M.

Geological Department, Columbia University.

In the preparation of the following brief discussion of the petrography of the dikes of the southern portion of Grand Isle, in northern Lake Champlain, one specimen was investigated from each dike. In the cases where the dike was quite wide and the specimen was taken from the middle of it, accurate determinations could be made on account of the comparatively large size of the minerals present; but where the dike was very narrow, as in No. 8, or where the specimen was taken from the margin of the dike, the determination of the ground mass could not be very definite. But one slide, as a rule, was made from a dike, so that some of the less abundant minerals may not have been noticed.

In all the dikes augite and magnetite are universally present. The magnetite, as is usually the case in eruptive rocks, belongs mostly to the oldest secretion from the magma; but it also occurs here as a secondary product, usually due to the alteration of olivine. The augites are in two generations. Those of the first generation are frequently over 3 mm. in greatest diameter. They often show a zonal structure with from two to four zones. A three-zoned crystal in dike No. 4 had a clear greenish centre, a yellowish rim and an intermediate granular area. The inner and outer zones differed 8° in extinction. Both of the generations are usually automorphic. The augite crystals are usually acicular, greenish to yellowish or colorless. Olivine is present in most of the slides, and when unaltered is

usually in well terminated crystals; but it frequently occurs in small irregular grains. The crystals often have their angular edges corroded. Large ones, with a diameter of 3 mm., have been noticed. Most of the olivine has, however, been partially and often completely altered to serpentine. The alteration proceeds along and at right angle to the length of the irregular fractures, leaving the unaltered olivine between the meshes. Hornblende is not very abundant. It varies from an almost colorless variety, which is non-pleochroic to the normal basaltic brown one. The colorless one has probably been derived from the brown one in alteration. Biotite is much more common and frequently occurs in two generations. The plagioclase feldspar is abundant in very few of the dikes, while in the majority it is entirely wanting. It is often twinned, but shows few lamellæ. No determination as to the kind of feldspar could be made. An isotropic mineral having at times well developed crystal boundaries is present in some of the dikes. This, when heated to redness, presented a cloudy appearance, and is probably analcite.[1] Apatite is quite abundant as an inclusion, especially in augite and biotite. Iron pyrites is abundantly scattered through a few of the dikes.

All of the dikes show more or less weathering. The augite is often changed to chlorite, and the olivine to serpentine. But calcite is the most abundant secondary product. It frequently occurs in globular pits, which strongly suggest amygdalodial cavities, but these we should not expect to find except in the uppermost portion of the dike. Some of the dikes effervesce very freely in cold, dilute acid. Hematite occurs quite abundantly in a few dikes.

These dikes are all closely related to the Camptonites of the Lake Champlain district. As there are no sharp division lines in nature, it must be expected that transition forms between the main types of rocks will occur, and in a strict classification attention must be paid to these transition forms. Also to render discussion easy there must be names applied to them. So that although it may at first thought seem to be an unnecessary multiplication of names and a consequent enhancement of the difficulty of the subject, yet such reasons as these should not cause us to limit our ability to discuss. The names used here have been previously employed in the descriptions of dike rocks from a few other localities. On account of the entire absence of feldspar in most of the dikes, and from the great development of augite and olivine, the majority have been placed under the monchiquites.[2] Those containing well-developed plagioclase crystals, but with augite in excess of and at times to the entire exclusion of the hornblende, have been placed under the augite-camptonites. No true camptonites with their predominant development of plagioclase and hornblende have been noticed among these. Dikes 8, 9, 10, 11 and probably 30 from their very slight development of plagioclase and the corresponding great development of the ferro-magnesian minerals are transition forms between the monchiquites and the augite-camptonites, as will be noted under the individual descriptions. In dikes 7, 24 and 28 phenocrysts of biotite are well developed, and the rocks thus approach the ouachitites;[3] but as the augite is still in excess of the biotite they are placed under the monchiquites. Dike 14, with its well-developed lathe-shaped plagioclase crystals, marks a passage to the diabases; the augite crystals are mostly automorphic so that it is not a true diabase.

MONCHIQUITES.[2]

These in typical development are dike rocks, consisting of olivine, augite, hornblende, biotite (one or all three of the last named) and an isotropic base.[4] In the following ones placed here hornblende is almost entirely absent; while augite, olivine and biotite with much magnetite make up the rock mass.

Dike No. 1; width 48 inches.

This specimen was evidently taken from the edge of the dike for it is very fine-grained. It is composed mostly of augite, olivine and magnetite. The olivine is very fresh, scarcely indicating a change to serpentine. Iron pyrites is also present.

Dike No. 2; width 27 inches. No. 3; width 7 inches. No. 5; width 6 inches.

These rocks are composed mostly of augite, biotite and magnetite, with phenocrysts of augite and olivine. Analcite is also probably present.

Dike No. 4; width 12 inches.

In this rock the most abundant minerals are augite and magnetite. Olivine is present in a subordinate amount. An interesting intergrowth of two kinds of augite, differing chemically, was observed in one large crystal.

Dike No. 6; width 28 inches.

This rock is composed mostly of augite and magnetite, with phenocrysts of olivine and augite. Biotite is present also.

Dike No. 7; width 48 inches.

This rock is quite coarsely crystalline. Many crystals of biotite and augite are visible to the naked eye, also iron pyrites and calcite. As there is much calcite present the rock effervesces very freely in acid. Most of the augite is altered to chlorite, thus furnishing the necessary Ca. for the formation of the great amount of calcite. Olivine is also present.

This rock approaches the ouachitites[3] in its great richness in phenocrysts of biotite. Yet as the augite is in excess and the magnetite is still quite abundant it was thought best to place this under the monchiquites.

Dike No. 8; width 3 inches.

The rock is very fine-grained, as we should expect from the size of the dike. The phenocrysts are mostly olivine. Analcite is probably present.[1] The ground-mass is a mixture of augite, magnetite and plagioclase. The rock is very full of amygdaloidal cavities. These might be expected to occur; since a fragment of the wall rock occurs in the dike, this portion of the dike is probably near the top. These cavities are usually filled entirely with calcite. A few scales of hematite also occur in the rock. From the presence of plagioclase this rock marks a passage to the augite-camptonites.

Dike No. 9; width 30 inches.

This dike rock is made up of phenocrysts of augite, olivine and plagioclase with an exceedingly fine-grained ground-mass composed apparently of augite, magnetite and plagioclase, and hence approaches the augite-camptonites.

In the midst of this dike is a band of the rhynchonella limestone, in which the dike is situated; yet the only effect of metamorphism noticed is the change of the limestone to marble. No garnet was noticed.

Dike No. 10; width 32 inches. No. 11; width 34 inches.

These rocks are composed mostly of augite, biotite and magnetite, with a much smaller amount of plagioclase. Analcite is also probably present. Olivine was not noticed in No. 10. These dikes also represent connecting links between the monchiquites and augite-camptonites.

Dike No. 12; width 8 inches.

The rock is very fine-grained and composed mostly of augite crystals. These are in two generations. The larger ones are often 2 mm. in diameter. The smaller ones and biotite form most of the ground-mass. Olivine, hornblende and magnetite are also present.

Dike No. 24; width 19 inches.

The most abundant minerals present in this rock are biotite and magnetite. The magnetite is often enclosed by the large biotite crystals. Apatite is quite abundant, as is also iron pyrites.

The rock is exceedingly full of amygdaloidal-like cavities; these are usually from an eighth to a quarter of an inch in diameter. These cavities are filled almost entirely with calcite; some zeolites are at times also present.

This rock, in its great development of biotite, approaches the ouachitites; also from the complete absence or very slight development of olivine it marks a passage to the fourchites.[5]

Dike No. 25; width 6 inches.

The most abundant minerals present are augite, magnetite and biotite. The large augite crystals are not abundant, but the small ones are exceedingly so. There also occur olivine, apatite and iron pyrites. Serpentine is quite abundant. The rock is not quite so full of amygdaloidal-like cavities as the preceding. They are similarly filled with calcite. An isotropic mineral, very probably analcite, is quite often present in these cavities along with other zeolites.

Dike No. 26; width 22 inches.

The most abundant minerals are magnetite and augite. Most of the augite crystals are very small. Biotite and olivine are also quite abundant. The secondary minerals, iron pyrites, limonite, hematite, calcite and serpentine, are present in varying quantities. Most of the olivine has been changed to serpentine. The amygdaloidal-like cavities are comparatively few, and as usual are filled with calcite.

Dike No. 28; width 18 inches.

The most abundant minerals present in this rock are the secondary mineral serpentine and biotite. Magnetite and iron pyrites occur, as do also a few crystals of olivine; most of the latter, however, have been changed to serpentine. The amygdaloidal-like cavities are of the same size and abundance as in dike No. 24, and are similarly filled.

This rock, with its well-developed biotite crystals, marks a passage to the ouachitites.[3]

Dike No. 29; width 26 inches.

The most abundant minerals here are augite, magnetite, biotite and olivine. The augite occurs in long narrow crystals.

The secondary minerals, serpentine, iron pyrites, hematite and calcite, are quite abundant. The amygdaloidal-like cavities are not so numerous as in the preceding dike, No. 28.

Dike No. 30; width 6 inches.

The most abundant minerals present in this rock are augite and magnetite. Some of the large augite crystals show a zonal structure. Besides these minerals, olivine and biotite occur, as do also serpentine, hematite, iron pyrites and calcite. There are many exceedingly minute crystals packed away in the interstices of the larger crystals and are apparently feldspar; this rock would then mark a passage to the augite-camptonites.

Dike No. 32; width 2 inches.

The most abundant minerals are augite and magnetite. Biotite and olivine are present in smaller quantities. Of the secondary minerals serpentine is especially abundant; calcite and hematite are less so.

Dike No. 33; width 6 inches.

In this dike the most abundant minerals are augite, olivine and magnetite. Biotite also occurs. Serpentine is not very abundant. The amygdaloidal-like cavities are smaller than in No. 24, and as usual are filled with calcite.

Dike No. 35; width 7 inches.

The most abundant minerals are biotite, magnetite and augite. The brown basaltic hornblende may also occur, but was in crystals too small for accurate determination. The presence of olivine, serpentine, iron pyrites, calcite and probably analcite was also noted.

Dike No. 38; width 30 inches.

The most abundant minerals in this dike are augite, biotite and the secondary mineral serpentine. Magnetite is quite

abundant. Biotite is in sufficiently large crystals to be seen by the naked eye. Calcite and probably a few crystals of analcite fill the amygdaloidal-like cavities.

Dike No. 39; width 14 inches.

The most abundant mineral is augite. Magnetite, biotite and apatite occur in less amount. Iron pyrites, calcite and probably analcite are also present.

Dike No. 40; width 12 inches.

In this rock the most abundant minerals are magnetite and augite. The magnetite crystals are exceedingly abundant. Olivine and biotite are also well developed. Much of the olivine has been changed to serpentine. The secondary minerals, iron pyrites and calcite, also occur.

Dike No. 41; width 10-15 inches.

This rock is composed mostly of augite crystals; these are well developed in two generations. The larger crystals may be seen by the naked eye. Magnetite is quite abundant; olivine, biotite and apatite are less so. Of the secondary minerals calcite, serpentine, hematite and iron pyrites are the most important.

Dike No. 42; width 34 inches.

In this dike rock the most abundant minerals are augite and magnetite. Biotite and olivine occur also, as do the secondary minerals, serpentine and calcite.

AUGITE-CAMPTONITES.

The normal camptonite[6] consists of brown basaltic hornblende, plagioclase and augite, with the hornblende in two generations. In these dikes the augite is by far the most abundant mineral present, and not hornblende. So that with the panidiomorphic or holocrystalline porphyritic structure, which is characteristic of the camptonites, the following dikes are placed under the augite-camptonites.

The following rocks consist mostly of augite, olivine and magnetite. Plagioclase is present, although often in small quantities. Biotite is usually present, but very little hornblende was observed.

Dike No. 13; width 4 inches.

As the crystals are very small for a dike of this width, the specimen was doubtless taken from the margin. There are phenocrysts of augite and plagioclase present, but the rock is mostly composed of an aggregate of very small crystals of augite, plagioclase and magnetite. Both the plagioclase and augite are in two generations. There are also many crystals of biotite tucked in between the feldspars. The augite and feldspar are both automorphic.

Dike No. 14; width 30 inches.

The rock is composed mostly of lath-shaped plagioclase crystals with much augite in their interstices. It thus marks a passage to the diabases; but it is not a true diabase since many of the augite crystals are automorphic. Magnetite and iron pyrites are also present in the rock.

Dike No. 15; width 20 inches. No. 16; width 6 inches.

The plagioclase here is less abundant than in the preceding dike. The most abundant minerals present are augite, plagioclase and magnetite, with a less amount of olivine.

Dike No. 19; width 20 inches.

Augite, magnetite, biotite and olivine make up the mass of this rock. The augite is in large lath-shaped crystals; the biotite has also this development, but is of later growth than the augite, for they are often penetrated by the latter. Plagioclase is present in very subordinate amount; hence this rock marks a passage to the monchiquites. The secondary product hematite is slightly developed. The rock contains many amygdaloidal-like cavities which are filled with calcite.

Dike No. 27; width 19 inches.

The specimen from this dike is so badly weathered that no figure could be obtained from the dark ferro-magnesian mineral, but from its shape it is probably hornblende. The most abundant minerals are plagioclase and augite. About one-quarter of the slide consisted of limonite. Serpentine and calcite were quite abundant also.

As compared with the dikes described in Bulletin 107 of the U. S. Geological Survey[7], these dikes are of special interest in that they have much biotite, a mineral very subordinate in those earlier described by Kemp and Marsters. The presence of biotite recalls the alnoites; and the abundance of calcite likewise makes the observer suspect the presence of melilite, but none could be found.*

Grateful acknowledgment is here made of the kind aid rendered the author by Professor J. F. Kemp and Mr. G. I. Finlay.

[1] L. V. Pirsson: "On the monchiquites or analcite group of igneous rocks." Journal of Geology, vol. 4. No. 6, page 679.

[2] M. Hunter and H. Rosenbush: Ueber monchiquit, ein camptonitisches Ganggestein aus der Gefolgschaft der Elaeolith-Syenite. Tschermaks Min. und Petrog. Mitth., vol. xi, 1890, page 445.

[3] J. F. Kemp: Geol. Survey of Ark. Ann. Rep., vol. 2, page 392.

[4] J. F. Kemp and V. F. Marsters: The trap dikes of the Lake Champlain region. Bull. 107, U. S. Geol. Survey, 1893, page 32.

[5] J. F. Williams: Geol. Survey of Ark. Ann. Rep., 1890, vol. 2, page 107.

[6] H. Rosenbush: Physiographie der mässegen Gesteine, vol. 1, 1886, page 333.

[7] J. F. Kemp and V. F. Marsters: Bull. 107, U. S. Geol. Survey, 1893. The trap dikes of the Lake Champlain region.

* The following account of dikes numbered 20 and 21 is taken from Bulletin No. 107, U. S. Geol. Survey, The Trap Dikes of the Lake Champlain Region, J. F. Kemp and V. F. Marsters, p. 48: "No. 586 (21 of this list) consists of large idiomorphic augite and olivine in a ground mass, consisting of small augites and some feebly refracting mineral, if not a glass. It is a monchiquite. The neighboring dike (No. 20 of this list) is an excellent diabase with lath shaped plagioclase and allotriomorphic augite. This close association of two different types is a striking phenomenon, and when one admits the usefulness of different names for different rocks, as these are, nevertheless their close genetic relations must at the same time be given due weight. Alteration is well advanced in No. 20 and has changed the augite in large degree to a deep honey yellow mineral which polarizes as an aggregate and which is considered serpentine. The Utica slate in which these dikes occur is greatly crushed and disturbed."

INDEX.