REPORT

OF THE

STATE GEOLOGIST

ON THE

MINERAL INDUSTRIES AND GEOLOGY

OF

VERMONT

1921-1922

THIRTEENTH OF THIS SERIES

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STAFF OF THE VERMONT GEOLOGICAL SURVEY, 1921-1922.

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STATE OF VERMONT.

OFFICE OF STATE GEOLOGIST.

BURLINGTON, January 10, 1923.

To His Excellency, James Hartness, Governor of Vermont:

Sir:—In compliance with Act 405 of the General Laws of Vermont I herewith respectfully present my Thirteenth Biennial Report on the Geology of Vermont. This Report covers the years 1921-1922.

The character and scope of these Reports is indicated in the following introduction.

Because of several hindrances, this Report has necessarily been greatly delayed in publication.

It is a source of satisfaction to all who are acquainted with the topographical work that has been carried on in cooperation with the United States Geological Survey to know that this has gone forward very successfully during the past two years and is to be continued during the next two years.

The Montpelier, Bolton, Barre and Richmond Quadrangles have been completed. The finished maps of the first two Quadrangles and proofs of the last two are now available.

Respectfully submitted,

GEORGE H. PERKINS,

State Geologist.

INTRODUCTION.

The Geologist has given in this his Thirteenth Biennial Report a brief history of the establishment of a Vermont Geological Survey by the Legislature, from 1844 until the present time. Such a summary of the Reports of the Survey has long been needed for reference and, it is hoped, will therefore be found useful.

Following this historical summary is a longer compilation, giving the most important matters, as they have seemed to the Geologist, which have been determined by the numerous geologists who, because of its general importance and interest, have come into the State from those adjoining, each adding his conclusions to the knowledge of our geology. Of course, anything like a complete summary of the published results of the work of these investigators would be far too extensive, but such condensed statements as it has been possible to present are given, so far as possible, in the language of each author.

As recent additions to Vermont Geology, the following papers will be found interesting and valuable, at any rate to geologists.

In the second article in this Report, Mr. E. J. Foyles of the American Museum of Natural History, contributes a careful and detailed study of some of the Ordovician rocks of the Champlain valley.

The faults of the Champlain valley, especially in the northern part, are numerous and often complicated. Some of these are studied by Professor G. H. Hudson of the Plattsburg Normal School.

In a previous Report will be found an important article by Professor E. C. Jacobs, University of Vermont, on the Willoughby region and this work is still further carried forward by an article in this Report on the area adjacent to that considered in the former paper. This includes the towns of Westmore, Brownington and Charleston. Little of value has hitherto been known of the geology of these towns.

Professor C. H. Richardson of Syracuse University, who for many years has worked on the Vermont Survey and who has contributed very valuable material in most of the Reports issued, continues his work in the eastern part of the State in the town of Randolph. Dr. Richardson has in this study had the assistance of a graduate student, Mr. Charles K. Cabeen.

Professor C. E. Gordon, Massachusetts Agricultural College, continues his extensive and important study of the geology of western Vermont, the first part of which will be found in the Twelfth Report.

The usual statement as to the nature and extent of the mineral resurces of Vermont follows.

The last article in the volume is a report of the work of the Water Resources Investigation, in cooperation with the State, during the years 1921 and 1922 by C. H. Pierce of the United States Geological Survey, Water Resources Branch.

It should be fully understood by readers that each author is left entirely free to express his own views in regard to such areas as he may have studied and the Geologist assumes no responsibility with respect to the accuracy or otherwise of such views.

HISTORY AND SUMMARY OF GEOLOGICAL WORK IN VERMONT 1810-1923

George H. Perkins.

PART I.—HISTORY OF THE STATE GEOLOGICAL SURVEY.

INTRODUCTION.

In the Eighth Biennial Report of the Vermont State Geologist, 1912, there was a somewhat detailed statement of what had been done on the geology of the Green Mountain region and in the Eleventh Report an account of the physiographic features of the State. The published edition of the 1918 Report was entirely exhausted in little over a year and the demand continues, good proof that Vermonters are glad to learn something of the geology of their State. Because of these facts the Geologist has believed it desirable to reissue the material contained in the above publications.

The original plan, as seen in the Eighth Report, has been greatly enlarged and modified in the present Report as, after looking over the available material, it has been thought more useful to include in the present article everything that could be obtained in regard to the history of Vermont Geology. So far as the author knows, all published material pertaining to the geology of Vermont has passed under his hands, unless it may be some unimportant and fugitive scraps. As is stated later, each writer's own views are given, usually without comment as the object of this paper is not in any way discussion, but simply a presentation of what has been written.

The past history of our own State Survey is first given as it has been found in the various records of successive Legislatures, following which is as full a summary as could be allowed of all work that has been done from time to time, by other than Vermont geologists. Probably very few geologists, even though Vermonters, have ever given much attention to the history of the State Geological Survey, although the story of this Survey goes back, as will be seen, to 1836. It is interesting to note that in those early days when in most quarters very little was known of the science of geology and very little attention given to it, in an eminently agricultural community, a proposal to establish a geological survey should have been made in the legislature and, though not for some time passed, been favorably received and given careful consideration.

In 1836 very few of the States had, apparently, even thought of such a survey. In October, 1836, Senator Howe introduced the following bill: "Resolved that the Committee on Education be instructed to enquire into the expedience of providing for a general and critical Geological and Topographical Survey of the State and to report by bill or otherwise." In response to this the Senate, November 7th, passed the following: "Resolved, that the Governor be requested to procure an estimate of the probable expense of a Geological and Topographical Survey of the State and report to the next General Assembly."

In response to this the Governor, S. H. Jennison, sent to the Session of 1837 a message in which the above question was fully and ably discussed. The principal part of the message consists of letters in reply to enquiries of the Governor as directed in the Resolution of the Senate. The letters were written by Professor G. W. Benedict of Burlington, Mr. John Johnson of Burlington and Mr. James Stevens of Newport. All were very favorable to the project, but Professor Benedict's letter is of much greater importance than any other, as he had evidently given much thought and investigation to the cost of a survey.

The Committee on Education, through its chairman, Mr. H. Eaton, also made a very favorable report which embodied most of the Governor's message. It is interesting to find that at this early time liberal ideas as to the carrying forward of such survey were entertained by some of those interested.

Professor Benedict dared to give an estimated cost $12,500 for the Topographical and $10,800 for the Geological work. In regard to this he says: "The foregoing estimate may seem to individuals who have bestowed little thought on the subjects that are concerned to amount to a very large sum (the amount was to be for three years), but to those who are qualified to form adequate opinions on the matter and who have bestowed that attention to it which its importance demands, I am confident that it will appear a very moderate sum compared with the magnitude of the work proposed and its incalculable value to the State if properly executed."

These benefits are well enumerated. The Governor's message being received by the Senate, it was ordered printed with the report of the Committee on Education and one thousand copies distributed. Considering the time and the large cost it is not a matter of wonder that, notwithstanding the many favorable receptions it had in high places, the bill was laid upon the table.

In October, 1839, Mr. Eaton for the Committee on Education reported: "That the subject of a Geological and Topographical Survey of the State has claimed the attention and received the consideration of the Legislature and people of the State for four or five years past and your committee believe that a full conviction of its importance has impressed the minds of all. * * * * * * * Its important bearing upon the greatest agricultural interests of the State is so invariably acknowledged and the favorable influence it would be likely to exert upon our manufacturing interests is so generally admitted that your committee in approving the design of such survey feel * * * * that they are performing merely the humble duty of reechoing the public and prevailing sentiment of the community." Yet the bill was again tabled. It is well, however, to notice that the sole opposition to it seems to have been the cost involved in its provisions.

In their report the committee say: "A time could scarcely occur when the condition of the treasury would present so serious an obstacle to the prosecution of the Survey as it does at present. The committee recommends a postponement of the Survey for another year." Next year, 1840, the bill was read twice, tabled, later taken from the table, referred to the Committee on Agriculture and again tabled. Finally, 1844, the bill, somewhat modified and with greatly reduced appropriation, passed the Senate and three days later the House and thus became law. It seems very probable that had the scheme been less ambitious and only a moderate appropriation been called for, the bill might have readily passed long before.

This bill, by which the first Geological Survey was authorized, is not different in most respects from that now on the Statute books. It contains five sections, the fourth of which is "For the purpose of carrying into effect the provisions of this act the sum of two thousand dollars annually for the term of three years is hereby appropriated." This act was approved October, 1844, and under its provisions Professor C. B. Adams of Middlebury was appointed State Geologist.

The Topographical clause of the older bills was entirely dropped from that finally passed, which is shown later.

Except the Report of the Committee on Education referred to above, nothing geological was published by the State until 1845, when Professor Adams' first report appeared. This was, therefore, the first report ever issued on Vermont geology. The report was a pamphlet of ninety pages and is largely occupied with the economic geology of the State.

In 1846 Professor Adams issued his Second Report on the Geology of Vermont. This is a pamphlet of 267 pages and some few illustrations. The text is divided into five parts: Part I, pp. 19-108, treats of "Elementary Geology" and is really a brief discussion of general geology, such as was in those days almost necessary to any comprehension of the special geology to follow. Part II enumerates a few of the minerals found in different towns of Vermont. Part III treats of "Concretions" such as are frequently found in the State. Part IV considers especially the "Geology of Vermont," mostly glacial action. Older beds are taken up, but only briefly. Part V, "Economic Geology and

Mineralogy" gives a somewhat extended report by S. R. Hall, Assistant on the Survey, in which many of the towns are named and the rocks found in them discussed. This is followed by a report on "Mining," by Professor Adams.

In 1847 Adams published his Third Report, which is a pamphlet of 32 pages and is little more than a brief report of progress. In 1848 Adams only published a Report of eight pages and this proved to be his last. It is evident from Professor Adams' statements that he intended to publish soon a much larger and more comprehensive volume. He says: "In the Annual Reports but a small part of the results (of the Survey) have been given and this has been done in a disconnected way." No appropriation was obtained for a final report and, therefore, none was ever issued.

In 1847 Adams left Vermont to take a professorship at Amherst College. No one was appointed Geologist in his place and interest in the work appears to have greatly diminished so that during the next few years, after 1848, no geological work was carried on. Meanwhile, Professor Adams had gone to Jamaica to study the mollusks of that region. During this visit he was taken with yellow fever and died. He left among his papers a considerable mass of unpublished notes on Vermont geology, undoubtedly those he had intended for his final report. Very unfortunately, most of these were written in a peculiar sort of short hand which no one but himself could decipher and for this reason this contribution to Vermont geology was wholly lost. As assistants in his geological work during the three years it continued, Adams had Zadock Thompson and S. R. Hall, some of whose work is given in his reports.

The often difficult problems which confronted Professor Adams in his Vermont studies were, of course, the same as all geologists who have come into the State since his time have tried to solve. In one of his reports he states these as follows: "Unfortunately for the geological history of the State, a greater part consists of rocks which are destitute of fossils * * * * * * and whose highly crystalline structure and in many parts mountain masses and ramifying veins of granite indicate the intense heat by which they were metamorphosed. When these rocks were deposited, whether any or all of them were replete with fossils when the granite eruptions burst through them with their intense igneous crystallizing agency, and when they were plicated into long mountain ridges are and are likely long to remain matters of conjecture."

On page 168 of his Second Report we find: "It is proper here to add that considerable labor has been expended in the exploration of the geological boundaries of the several varieties of the rocks which were enumerated in the last report and that, with the exception of the northeast and southwest parts, we have

prepared to exhibit them by colors on a geological map." This map was drawn and colored by Professor Adams and is now in possession of the State Survey, having been given to the present Geologist by Dr. C. H. Hitchcock. A steel plate map made for Thompson's Vermont, by J. H. Hill of Burlington, was used as a foundation upon which areal outlines and colors are distinctly placed. It is a small map, 11" x 7½".

Eighteen formations are shown, some of them no longer recognized. The forms of the long north and south areas, such as any geological map of Vermont must always show, are remarkably well brought out on this the first geological map of the State ever made. Adams finds in Vermont the Hudson River Group, the Isle La Motte limestone and several other beds long since excluded from our geology. This map was made in 1846. Though, of course, of little geological value, the map now has much historical interest. The map also bears a few marginal notes in Adams' writing. The Survey, before Professor Adams left the State, as has been intimated, was neglected.

In the Legislature of 1846 an act repealing the establishing act was introduced and later this was passed and, of course, all means for carrying it on ceased. In 1847 the Governor, in his message, called attention to this lapse of the Survey because of which the question of again providing funds for its continuance was discussed and a bill introduced to renew it, but this was finally dismissed.

The following year, 1848, the matter was again brought before the Legislature by the Governor's message. After some consideration, the matter was referred to a Special Committee, which reported, "It does not recommend the completion of the Survey." It may be noted here that during these years, it was not the continuance but the completion of the Geological Survey that was contemplated. This indicates that the extent and many difficulties involved were little understood, as two or three years, or at most not many, were thought to be sufficient for the entire task.

Even Professor Adams himself had plans for a complete survey to be done in a few years. Very likely this was more because he did not dare ask for more, than because he did not understand the greatness of the work. It is true that as knowledge of Vermont geology has increased, its perplexities and difficulties have become more apparent and also that change in geological ideas and methods have raised additional problems and widened the field of investigation.

Many of the Vermont formations that at first appeared comparatively simple have been found after careful study to be very complex. It is interesting to note that the earliest bills for appropriation for a State Geological Survey called for larger amounts than most since. While it would, of course, be possible to establish a survey on a much larger scale than has ever been done in Vermont, such a survey as most of the States carry on, it seems on the whole wiser in a State presenting the problems which are everywhere found here, where rapid work is in many localities impossible, to attempt only work planned on a moderate scale as is now done.

Another important reason for moving slowly is that no thorough geological work can be carried on without the topographic maps, now in process of construction. Where these maps can be had, work can be very satisfactorily carried on, but not elsewhere. About half of Vermont is now mapped and the work is going forward at the rate of at least one Quadrangle a year. After this digression it will be well to return to the history of the Survey.

In 1849 an act of the Legislature directed that the specimens, books, and reports obtained by the Adams Survey "be collected by a suitable person, to be appointed by the Governor, and be deposited in the State House under the care of the State Librarian." In accordance with this act, the Governor appointed Zadock Thompson of Burlington, one of Professor Adams' former assistants.

In 1849 Professor Thompson made a brief report of what he had done under the above act. During this same year the Governor had again reminded the Legislature of the importance of continuing the Geological Survey and a resolution was passed committing the matter to the Committee on Education. This resolution directed the committee "to inquire into the expediency of resuming and completing the Survey." The committee reported favorably, but the matter was finally dismissed.

Next year, 1850, "A Joint Committee to consider the expediency of completing the Geological Survey" was appointed. Towards the close of the session this committee reported that they had not found time to consider the matter, whereupon the House voted to defer it until the next session.

In 1851, in consequence of a brief report sent to the Legislature by Professor Thompson, a joint resolution was introduced authorizing the Governor to "Appoint a suitable person to collect and prepare the Report of the recent Geological Survey," but was not passed. The following year the State Geological Survey was taken up and referred to the Committee on Education, but no act was passed.

In 1853, however, the persistent discussion by the friends of the Survey urging its value to the State at last bore fruit in the passage by both houses of an act reestablishing it.

Since 1851 Zadock Thompson had occupied the chair of Natural History in the University at Burlington and after the passage of the above act, he was appointed State Naturalist. Professor Thompson accepted the appointment and immediately

formed very extensive plans for carrying on the work in a most creditable manner. His plans were elaborate and could they have been carried to completion would have given the State a lasting and very valuable series of volumes. He wished to prepare under the auspices of the State a work, the outline of which may be found in his "Vermont"—a book so well known and so long consulted by all Vermonters.

There were to be three volumes, one on Geology, one on Zoology and one on Botany. As planned such a work would necessarily have involved considerable expense and whether any Legislature could have been found sufficiently liberal to provide the funds is not certain. However this might be, the great work was finally ended by Professor Thompson's sudden death in 1856. He held the office of State Naturalist for more than two years, but published no other reports than those already mentioned.

Soon after Professor Thompson's death in 1856, Augustus Young was appointed State Naturalist and in September of that year he presented his first report to Governor R. Fletcher. Mr. Young calls this "A Preliminary Report." It is a pamphlet of 88 pages and, while it contains little of scientific value, it presents a good outline of what the author considers to be the proper work of such a survey. A brief summary of previous work is given and an excellent obituary of his predecessor is given by Mr. Young, also extracts from an address by Professor Thompson and a few other items.

Mr. Young died in 1856 and President Edward Hitchcock of Amherst, Mass., one of the then leading geologists of the country, was appointed in his place. Dr. Hitchcock, of course, could spend only a part of his summers in Vermont, but he attacked the work with enthusiasm and, all in all, accomplished a remarkable amount of work. During the first three years of his tenure of office, Dr. Hitchcock published three small pamphlets, 1857, 1858, 1859, simply preliminary reports, the greater part of the notes and other material being held for a final report. Dr. Hitchcock says in his 1859 report, because of the impossibility of making any use of Adams' short-hand notes and the nearly total destruction by fire of the specimens which he and his assistants had collected, it was necessary to begin the Geological Survey anew. In 1859 geology was nowhere what it is at present and many of the most important questions that are now prominent, such as the structure, age, etc., of the Green Mountains, did not appear for consideration in Dr. Hitchcock's plans. He was rather concerned with the varieties, areal distribution and composition of the Vermont rocks, and to this Dr. Hitchcock gave first attention.

The legislative appropriation at first was only $1,000 annually as has been stated, which for the work desired and planned was wholly inadequate. This should be taken into account when one comes to examine the results obtained. Certainly much less was accomplished than might have been, but when all conditions are considered, it seems, as the final reports are studied, remarkable that so much could have been done. Obviously much pioneer work must be carried on, much was necessarily superficial, but much was also accomplished, not only by the chief geologist and his assistants, but also by many others, some of them the equals of any geologists in the country, whom they called to their help in special phases of the work. Dr. Hitchcock's party began work in Vermont in the spring of 1857 and was able to make a final report in 1859.

The next year the Legislature voted that this report be printed and in 1861 it was published in two large quarto volumes of 988 pages, illustrated by 38 plates and 959 wood cuts. Three of the plates are maps and 35 lithographs, mostly of scenery. One of the maps is intended to show in colors the various rock areas as then understood and, as the Adams map was never published, this was the first geological map of Vermont to be made public. It is much larger than the Adams map, 15″ x 25″. This report, "The Geology of Vermont," 1861, 2 vols., has long been out of print but copies are not uncommon in second-hand bookstores. As most of those who read this article will not find it always easy to examine a copy of this report, a summary of its contents may properly be given here.

In the introduction Dr. Hitchcock states that "the publishing of the Report has been entirely under the direction of Mr. A. D. Hagar." In a preliminary report, which may be regarded as a preface to the whole, Dr. Hitchcock says, "The main objects we have aimed to accomplish are:

"1. To gain such knowledge of the solid rocks of the State of Vermont as to be able to delineate them upon maps and sections according to the established system of geological science.

2. To study loose deposits lying upon the solid rocks and trace out the astonishing changes which the surface of the State has undergone.

3. To collect, arrange and name specimens of rocks, minerals and fossils from every part of the State for the State Cabinet.

4. To obtain a full collection, for the same Cabinet of specimens valuable in an economic point of view.

5. To identify the metamorphic rocks of the State with those that have not been changed."

Dr. Hitchcock well emphasizes the importance as well as the difficulty of the last problem. This is and always must be, apparently the most difficult as well as the most important of all our studies of the Green Mountain region. Dr. Hitchcock continues, "And really, in my judgment, this is the most important use of a geological survey. It is not, as many suppose, to make discoveries of new substances that are useful, though this is occasionally done, but it is so to delineate the geological structure of the country that practical men may be directed in their researches and be saved from useless expenditures. Hence the value of a scientific description of the rocks, even of those parts that seem not to have much bearing upon the economic interests of a people, for we do know that the most abstruse scientific principle often has a most important and unexpected practical application." This plan as above stated by Dr. Hitchcock, was certainly a very ambitious one and, while most admirable in the main, he must have foreseen that under the limited conditions then present, it would not be possible for him to carry it to completion.

It is very fortunate for Vermont geology that so far-seeing and able a man as Dr. Hitchcock should have been chosen to direct the work and suggest what should be done in years to follow. His own attitude towards the work is shown by the statement, "To carry out such a plan as above indicated over an area of ten thousand square miles everyone must see to be a gigantic work * * * * * and we fear it will be thought to be only imperfectly performed." That this should be true and that the ambitious program should not, or could not, have been entirely accomplished was inevitable. A much larger part of it than could have been expected was, however, at least in some measure, completed so far as at the time and in the state of geological knowledge was possible. In closing this preliminary part of the first volume of his final Report, Dr. Hitchcock says, "I cannot, therefore, but look upon Vermont as a giant whose full proportions and strength are yet in great measure undeveloped and in this, which is probably my last literary labor, I cannot but pray that God would continue to prosper and bless a State so strong by nature and so rich in noble institutions."

The first chapter in the body of the Report is entitled, "General Principles of Geology," which evidently was written to aid readers not familiar with geological language and principles to a better understanding of the following pages. Most of Volume I is occupied by three long parts or chapters.

Part I, on the "Alluvial and Tertiary Rocks," discusses in its various phases the Drift of Vermont, giving long tables showing the direction in one part of the State or another of the drift striæ, old sea beaches, river terraces, etc. In discussing the Tertiary Rocks considerable space is very properly given to Professor Lesquereux's account of the Brandon lignite, since referred to by many geologists and very fully described by the present geologist in the Fourth and Fifth Reports.

Part II takes up what are called "Hypozoic and Paleozoic Rocks." Probably no part of the Report would need more radical change, if brought into harmony with modern views, than this. In this portion of the work many of the beds of stratified rock, especially the older, are described and if fossiliferous, the more prominent species described and located. This work, though not modern, is of permanent value for reference. Dr. Hitchcock had the good fortune to be able to call to his aid some of the ablest specialists of the time, such as Billings, Hall, Hunt, and others.

Part III of the first volume is devoted to a discussion of the then called Azoic rocks, that is rocks from which no traces of life had been obtained. Some of these were then supposed to be parts of the original crust of the earth. These are the rocks of the whole Green Mountain range, gneiss, schist, serpentine, etc. Dr. Hitchcock seems to be very fond of lists and there are many pages giving the location, dip and strike of these rocks. Dr. Hitchcock discusses the Green Mountain range as a whole, especially the gneisses. His familiary with the geology of Massachusetts enables him to correlate the Green Mountain gneiss with that of Hoosac Mountain and other Massachusetts elevations. He is impressed by the great thickness of the Vermont rocks. "The thickness of the gneiss in Vermont must be very great. The section across the State may perhaps give an average of its thickness. "About 8,000 feet of strata have been removed there, of which we should estimate about 6,000 feet to have been gneiss. Yet, as the bottom of the formation may not have been reached here, the true thickness may be greater."

Also "On the south line of Vermont, almost the whole breadth of the range, not less than twenty miles, is tolerably well characterized gneiss. Yet, as we pass northerly on the line of the strike along the eastern margin, the gneiss is rapidly succeeded by mica and talcose schist and the gneiss becomes so pinched as to form a mere wedge before we get across the State, and it is doubtful whether the mica schist does not absolutely cut off the gneiss ere we reach the north line. We incline to the opinion, however, that a narrow belt of Green Mountain gneiss does extend across the state (Massachusetts) into Vermont. At any rate, as our map shows, as soon as we enter Vermont, the gneiss again spreads out over a very wide belt, though in many places we are obliged to judge of the subjacent rock by the detritus above it." In this connection Dr. Hitchcock gives lists of the various minerals found in the schist, which he discusses after the gneiss.

Part IV is the first chapter of the second volume. This part continues the discussion of the "Unstratified Rocks," especially the granites and dike rocks. A study of the Dikes of Chittenden County by Professor Thompson is included.

Part V is by Professor C. H. Hitchcock and considers a series of sections carried across the State, from east to west, which had formed a not inconsiderable part of the work of the Survey since it was organized. These sections were illustrated by many specimens collected, named and arranged in the State

Cabinet and series were distributed to several educational institutions in the State. It may be said here that a great many of these specimens were small and did not adequately represent the rock of which they formed a part. Moreover, since the modern methods of microscopical study of rock sections have been in use, many names have been changed and the whole system of rock investigation revolutionized. For these and other reasons the old collection is being replaced as fast as possible by new specimens.

Sundry sections across the State, from east to west, have been mentioned. Dr. Hitchcock seems to have considered this method the best for acquiring a complete knowledge of the divers rocks. Thirteen in all were carried across, the last running from the southeast corner of Vernon, going through the towns bordering Massachusetts to Pownal, while the most northern section was carried from Canaan on west through Averill, Norton, Derby, etc., along the Canadian border. As has been stated, hundreds of specimens were collected during this section study and all of these were examined as well as was possible at that time, but in what appears to modern petrology a very superficial and imperfect manner.

Part VI is mainly given up to a "List of Localities of Minerals in Vermont." For many years this must have been very helpful to collectors and it also gave an outline of the mineral resources of the State. But many of the named localities seem to have become exhausted and the list is of only general use at present.

Part VII contains a report on the "Chemistry of the Survey." Numerous analyses of various marbles, ores, clays and other rocks collected by the Survey made by very competent chemists are given. In this part also is found a supplement to Professor Lequereux's article on Brandon which has been mentioned in Part I and should be studied in connection with the former account.

Part VIII is an extended "Report Relating to the Geology of Northern Vermont" by Rev. S. R. Hall, who had been one of Professor Adams' first assistants. This refers mainly to what may be called Agricultural Geology.

Part IX, on "Economic Geology," is by A. D. Hagar and treats especially of building stones, as well as ores, mineral springs, etc.

Part X treats of the "Physical Geography and Scenery" by A. D. Hagar. In this article Mr. Hagar gives a very interesting account of the more conspicuous scenery of different parts of the State. This part is illustrated by seventeen lithographic plates, that are fine for the time.

An appendix containing descriptions and figures of quite a number of paleozoic fossils found in Vermont rocks by E. Billings of the Canadian Survey closes the volume.

There is much in these volumes that is of very little value to the modern geologist, but there is also very much of permanent value, especially to the student of Vermont geology. Perhaps too much space has been given to this Report, but the writer felt that a sufficient outline of its content ought in justice to be presented. That comparatively little was accomplished by the Survey toward solving the most important problems of Vermont geology and that many errors were made in locating some of the beds of stratified rock is surely true. But time and means were very limited and, probably, Dr. Hitchcock and his associates thought wisest to use what opportunities were afforded them in attacking the more obvious and readily settled phases of the field before them. Perhaps the most outstanding and important result they reached was in determining the anticlinal structure of the Green Mountains. After this Dr. Hitchcock continued as State Geologist without pay, living in Amherst, until his death in 1864.

In the fall of 1864, Mr. A. D. Hagar, of whom frequent mention has been made, was appointed State Geologist. So far as appears, Mr. Hagar made only very brief reports during his term of office, his main work being, as has been seen, published in the final Report of 1861. In 1870 Mr. Hagar left Vermont to accept a position on the Iowa Survey. When one comes to read the Act of Legislature under which Mr. Hagar was appointed and must act, it is not difficult to understand why he was ready to exchange his very narrow position in Vermont for a much more liberally supported one in Iowa.

After authorizing the Governor to appoint a State Geologist, the bill provides for the maintenance of the office as follows: "Provided, however, that in no case and under no circumstances shall said geologist charge to or receive from the State anything for expenses, but in accepting such office it is understood that he looks to his employers for any compensation that he may reasonably deserve to have for professional services by him so rendered."

As has been seen, a large collection of the rocks of the State was deposited at Montpelier. These formed the nucleus of the State Cabinet and were arranged and labelled by Mr. Hagar in a room in the State House set apart for this purpose.

Mr. Hagar left the State in 1870, and after his departure Dr. H. A. Cutting was appointed State Geologist. At this time, and for several years after, the above title was only a name. All that the Geologist was expected to do, or paid anything to do, was to care for the State Cabinet. This Dr. Cutting did until 1886, when Rev. G. W. Perry was appointed in his place. Mr. Perry held office until 1898, when on account of serious ill health he resigned. Both these gentlemen did good work in caring for

and increasing the State Collections and under their limitations, this was about all they could do.

During this period, from 1870-1898, only brief reports were published. By this time the collections in each of the departments of natural history had become valuable and occupied the two rooms which had been assigned for the purpose, on the ground floor of the Capitol Building. Here they remained until in 1918 when they were removed to the new State Building. New and very satisfactory cases had been provided and in the new quarters the collections were available for examination and study as never before. As a fairly full account of the various collections has been given in the Seventh Report of the Geologist, it is not necessary to repeat here these details.

It is interesting to note that, beginning with 1845, for several years the various bills introduced into the Legislature by the friends of the Geological Survey all included a Topographical Survey as well and it was apparently the cost of the combined survey that frightened the members, so that all bills were defeated and it was not until after the topographic provision was dropped that any bill was carried. Delay here has been advantageous, for of late years the United States Geological Survey has taken up the topographic work for the whole country and employed methods far superior to any known as long ago as 1845 and consequently far better results have been obtained. Several Quadrangles were surveyed by the United States Survey alone and strips of greater or less width along the Massachusetts and New York borders were completed as parts of Quadrangles, most of which were included in the survey of those states. In this way Vermont secured the survey of quite an area without any cost.

After several attempts to induce the State to cooperate with the United States Survey, as it had been offered the opportunity to do, the Legislature of 1912 passed a bill which has, in substance, been repassed by succeeding Legislatures. Since 1912, topographic mapping has steadily gone on at the rate of a Quadrangle a season and it is hoped that in time the entire State will be covered. Since 1898, this series of Reports has been published and it has been the policy of the Geologist to include everything available that pertained to the geology of the State, whether originally published here or elsewhere. Obviously, if one searching for information as to Vermont geology, can know that all published that is of importance may be found in the Vermont Reports, his investigations will be greatly assisted. This is sufficient reason for the republication in one or another of our Reports of articles that first appeared elsewhere. Of course in such cases the facts are fully stated.

PART II.—SUMMARY OF GEOLOGICAL WORK IN VERMONT CARRIED ON BY GEOLOGISTS FROM OTHER STATES BETWEEN 1817 AND 1923.

The foregoing pages give a summary of the geological investigations which occupied different State Geologists appointed by the Governors of Vermont from C. B. Adams to the present, but only a part of the work that has been done is even mentioned for a great deal, and some of the most important, has been accomplished by geologists from adjoining, or sometimes distant states, and as these men have published reports of their studies in a great number of scientific journals, some of which are not easily accessible, the present Geologist has thought that it would be helpful to anyone interested in Vermont geology if a résumé of all this work could be given in some easily accessible form. Hence in the following pages an attempt is made to indicate where the complete articles can be found, the time of each investigation, its author and some statement as to the conclusions reached.

It is well understood that much of the earlier work is to be set aside and theories based upon it discarded. Still, all of the work and the results which were reached at the time it was carried on have more or less historical value to all geologists. The complexity often found in the structure of our Vermont rocks and the difficulty of reaching any definite conclusions respecting age, sequence, correlation with rocks of adjoining areas and all the many problems which, as is well shown in many of the following articles, have frequently appeared in investigation of the Green Mountain region as also other parts of the State have given rise to many theories and explanations during a century past. And the end is not yet. But, as may be seen later, if one cares to read carefully some of the pages which follow, much has already been discovered and there is great reason for believing that in time most, if not all, of the perplexities which have arisen in Vermont geology will be solved.

Extending, as some of the rock beds do, from western New York across Lake Champlain into Vermont, it is quite natural that the earliest geological investigators here were those who carried their studies of New York beds eastward into and, perhaps, across Vermont. At any rate long before any Vermonter gave attention to its geology, we find men coming from outside of the State to study the Vermont ledges. Apparently the first of these was

WILLIAM McCLURE—1817.

McClure has more than once been called the "Father of American Geology" and certainly he seems to deserve the title. His work was for the most part elsewhere and was carried on in widely different regions, especially in New York State.

McClure evidently had a fondness for mapping geologically the country over which he passed and this led him into Vermont. As quoted by Henry Leighton in his bulletin on *"One Hundred Years of New York State Geologic Maps,"* New York State Museum Bulletin 137, 1908, p. 117: "During an excursion last summer (1817) an opportunity was afforded of ascertaining and extending the limits of transition in the states of Pennsylvania and New York, as well as the boundary of the great primitive formation north of the Mohawk and fixing the limits of the transition on Lake Champlain and in the State of Vermont with more precision." As best he could at the time, McClure mapped this whole region, his revised map appearing in 1818. This, the earliest map on which any part of Vermont is shown on which geological areas are distinguished, is copied on page 189 of the report of the United States National Museum, 1906. Other than this map, no account of any visit of McClure into Vermont seems to exist, but it is evident that he did explore the western part of this State at sometime about 1817, or it may be earlier.

AMOS EATON—1830.

About the same time that McClure was tramping over this region and, as has been noticed, many other states, another geologist was leaving his law study to take up geology. This was Amos Eaton, who exercised a very great influence over the geological work of not only New York State, but a much wider area and for many years.

Though beginning his geological investigations about the same time as did McClure, Eaton did not publish any account of his work till 1830, when he issued a geological map of New York which included also most of western Vermont, *viz.:* The counties of Franklin, Chittenden, Addison and Bennington. This map was colored by hand, of course, and was of fair dimensions, 14½" x 12". A colored copy of Eaton's map is given in Bulletin 133, New York State Museum. With this map Eaton published a Text-book of Geology.

As has always been more or less obvious to any geologist going over the region, the Vermont areas are in five, narrow, north and south bands. Beginning at Lake Champlain, Professor Eaton calls these: Blue, all Calcareous Formations. Yellow, all Quartzose Formations; Transition Formations. Uncolored, Calcareous Formations; Quartzose Formations (this only for Vermont).

Or, classified in another way, "I. Slate Carboniferous Formations (next the Lake). Then Quartzose Formations, next Transition Formations. Then again Calcareous Formations and again Quartzose Formations to the flanks of the Green Mountains."

(A copy of this map is given in Leighton's Bulletin, New York State Museum, 133, p. 118.)

Professor Eaton does not appear to have been at any time State Geologist of New York, but his work was wholly financed by Governor Van Rensselaer from 1820 for some years. Especially in New York, but also in Vermont, it seems certain that Professor Eaton, by his enthusiasm and exploration aroused an interest in geological investigation which greatly and permanently affected New York, but also adjacent states. Apparently Professor Eaton was not seldom in Vermont and to this influence may most likely be due something of the desire for geological work in Vermont which, later, as has been seen, resulted in the forties in the establishment of a State Survey.

EBENEZER EMMONS—1842.

By 1840 New York had established definite State geological work in several parts of the State and in 1842 in Part IV, Natural History of New York, Emmons refers to the geology of Vermont. It was inevitable that in their investigations of many of the terranes of western New York, the geologists of that State, finding that these terrains had nothing to do with political boundaries, should follow this or that bed of rock across the border. Indeed to complete their work they must do this. Emmons did this far more than any of his predecessors and has left far more extensive reports of his work.

He writes, "The rocks of the Champlain group, beginning at the bottom with the Potsdam Sandstone, and including all of what is now known as Ordovician, were found in nearly all their members on the Vermont side of the lake as well as on the west side." This entire group Emmons calls the Transition System. He says that the black marble of Isle La Motte lies "between the Birdseye and Trenton," but gives it no special name.

About this time Emmons published an arrangement of certain extensive beds which he included in what he called "The Taconic System." No student of geology needs be reminded of the well-nigh endless discussions which this began. At first Emmons himself does not appear to have been very certain as to limits of the Taconic System.

He writes, "I may state another result as the consequence of the geographical position of the Taconic System, it is a partial blending of the rocks of the three great systems—the Primary of the Hoosic ranges upon the east, the New York Transition System on the west with the Taconic, creating thereby many doubts and perplexities as regards the limits of either system and inasmuch as the whole belt itself of the latter rocks is narrow, doubts are thrown over the whole as regards the views we are to take of them. "Natural History of New York," Part IV, p. 137.

Emmons held that the rocks of the Taconic System "were not connected or related to those of the Champlain Group" l. c. p. 138.

Again we find "The number of rocks which compose the Taconic System is quite limited."

"As a whole we find granular quartz, slate and limestone to form the entire system."

In a diagram giving a section of the system, Emmons gives eight different beds, some of those named above being duplicated. He says that all dip easterly. In pages following he discusses the characteristic position, age, etc., of the rocks and combats the views of some geologists that the rocks of this system are metamorphic. He adds, "These remarks are intended to disprove the unity of the Taconic rocks and the inferior members of the New York System, differing from each other principally in condition and which difference in condition arises from metamorphism, not that the rocks may not be metamorphic in one sense of the word; that is altered in texture since their deposition, but that they are not members of the Champlain Group thus changed by internal heat or by any other agent." l. c. p. 149.

See Inter. Guide Book #1-p. 18 (Ruderman)

He then, later, describes the various characteristics of the rocks, aided by diagrams, showing dip, etc., and concludes by stating what he regarded as the importance of the system and his reasons for so thinking." l. c. p. 163.

C. B. ADAMS—1845.

In writing the first part of this paper, necessarily the work of Professor Adams has been freqently mentioned, but further allusion to this must be made here, especially since some of Adams' views of the Taconic System are best mentioned in connection with those of Professor Emmons. In the "Second Vermont Report," 1846, pp. 120-121, Adams writes, "The Geological History of Vermont is conveniently divided into three periods, of which the last is the Quaternary, which includes the history of all the unconsolidated materials, the gravel, clay, sand alluvium, etc., which cover solid rocks. The next preceding period embraces by far the greatest and most interesting portion of the geological history of the earth, and is represented in other countries by a long list of formations from the Tertiary down to the oldest of the Paleozoic. The entire absence in Vermont of any deposits which can be referred to this period renders it impossible to give its history. Certain eruptions of trap and porphry are the only events of which there are any relics left."

The third is the Paleozoic period, the most ancient portion of which is commemorated in the six fossiliferous formations of the Champlain rocks. The year before, in his First Report, Adams places the Vermont rocks in two groups: Primary and

Paleozoic. The first includes all the oldest rocks and, of course, the entire Green Mountain area. These are slates, schists, gneisses, etc. Adams, as every geologist must, calls attention to the vast gap between the two groups mentioned. Adams included in the New York System the Cambrian and Ordovician. He recognized Emmons' Taconic System, including slates, quartzite, limestones, etc. In the Second Report (1846) he uses the same two groups, but defines his Primary System as "Azoic." He alludes to the great confusion in the arrangement of these rocks many times as, p. 105, "but not only is the history of the Primary rocks obscure, it is often impossible to determine which of the crystalline strata are Primary and which Paleozoic, but have since been altered by igneous agency. * * * * * * * Thus the history of all the rock which cannot be traced beneath the oldest Paleozoic strata is enveloped in obscurity. Here all sources of knowledge, relative position, fossils and original structure fail the geologist whose lot is cast in such a region. Such is most of Vermont."

In his Third Report, Adams refers the common Red Sandrock to the Medina Sandstone. Dr. Emmons, however, placed the Red Sandstone in either the Calciferous or the Potsdam. Later, Adams reaffirmed his correlation shown by the structure at Snake Mountain. He believed that the beds above what he called Medina were Utica and Hudson River.

ZADOCK THOMPSON—1843-1853.

In 1843 Zadock Thompson published in "VERMONT" a brief account of the "Geology and Mineralogy of Vermont." Thompson quotes Professor Eaton, "The mountains on the west side of the State are nearly in the following order:

"1. Old Red Sandstone in an interrupted range.
"2. Graywacke.
"3. Transition or Metalliferous Limestone alternating to Transition Argillite.
"4. Transition or Calciferous Sandstone.
"5. Transition Argillite.
"6. Primitive Argillite.
"7. Sparry Limestone.
"8. Granular Limestone.
"9. Granular Quartz.
"10. Hornblende Rock.
"11. Gneiss with alternating layers of granite.
"12. Mica Schist, contributing the middle ridge of the Green Mountains and extending down the eastern side."

Most of these ranges of rocks extend through the whole length of the State. "On the east side of the mountains the geological features are not so well defined nor so well known." —"VERMONT," p. 222.

Following this Professor Thompson gives a brief description of each of the above named rocks and to some extent its distribution and adds a list of some of the more common metals found in Vermont. In the Appendix to Vermont, published in 1853, the topography of the State is taken up and an account of the famous fossil whale found in 1849 at Charlotte during construction of the Rutland Railroad. Also the few bones of a fossil elephant found at Mt. Holly in 1848. On pages 40-58 of the Appendix, Thompson speaks of the geology of the State in general and particularly of the numerous dikes found in western Vermont.

Although for several years assistant to Professor Adams, and later himself State Geologist for a time, Thompson, as we have seen in the history of the Vermont Survey, did not publish any report. In an address given before the Boston Society, Natural History in 1851, extended extracts from which are given in Mr. Young's Geological Report of 1856, Thompson gives perhaps the best summary of the geology of the State as he understood it and, as explanation why he never published a report, says, "Just as the examinations were being completed and the results and facts brought together, systematized and weighed, the Survey was suspended" (through the failure of appropriations).

Of the Green Mountain region he says, "To the eastward of the Champlain and Taconic group I am not aware that any fossiliferous rock has been found in place within the State." "Lying next to these is a bed of Talcose slate formation varying from 15 to 30 miles in width and extending through the entire State from south to north. This belt embraces all the highest of the Green Mountain range."

After this Professor Thompson goes on to enumerate the main north and south belts of rock which he had found in the State, supplementing Adams statements in his First and Second Reports. As to age, he says, "With regard to the question whether the rocks which form the Green Mountains and extend eastward to the Connecticut River are truly Primary or "ante-Paleozoic," as was formerly supposed, or are metamorphic Silurian rock which are newer than the Champlain Group, as has been recently suspected, I would only observe that evidence in favor of the latter opinion was constantly accumulating during the continuance of our survey, and has been greatly increased by the labors of Mr. Logan, the Provincial Geologist of Canada, along our northern boundary." He notices the wide distribution of Glacial Drift.

In conclusion, Professor Thompson says, "From the remarks which I have made it must be obvious that Vermont combines in its geology the characteristics of western New England, not those of New York."

EDWARD HITCHCOCK—1853.

Trained geologists have always been few in Vermont and, as we have seen, after the death of Zadock Thompson there was no one in the State who appeared as candidate for the office of State Geologist and the Governor went over the Massachusetts line and appointed Dr. Edward Hitchcock, then President of Amherst College. He could probably have done no better, for Dr. Hitchcock was then one of the foremost geologists not only of New England, but of the whole country. Although Dr. Hitchcock never lived in Vermont, his residence for many years in Amherst, not far distant from the Vermont border, made it quite easy for him to spend several summers in this State.

Dr. Hitchcock associated with him in most of the Vermont work, his two sons, Edward, Jr. and Charles H. and, especially, A. D. Hagar, of whom more later. The work of these geologists has already been quite fully mentioned in the first part of this article, so that less need be said here. Like all other workers in this field, Dr. Hitchcock speaks of the very great difficulty he found whenever he attempted to determine the origin or age of areas of Vermont rock. He especially calls attention to various peculiar schists found, notably, though not exclusively, in Plymouth, Wallingford, etc. These schists are conglomerate, containing numerous quartz pebbles which are elongated in the direction of the strike. Many are also flattened. Figures are given in the Report of 1861, pp. 34-46. On page 731 of volume II, Mr. Hagar also mentions this schist at Plymouth. The study of this conglomerate schist was considered especially important because of its probable relation to the formation of Green Mountain gneiss. Seen on some surfaces there is no resemblance to schist or gneiss, but when edge surfaces are examined, quartz, mica and talc are seen.

In this 1861 Report the Red Sandstone of western Vermont is regarded as of Medina age. Still at this same time, 1861, Billings of the Canadian Survey had published in the *American Journal* an account of a visit to localities of this Red Sandrock and finding fossils which, in his opinion, placed it in the Potsdam. Many of the Vermont slates Adams had placed in the Hudson River Group. James Hall, too, regarded what was considered as an extension of these slates into Vermont, as of course of this age. Adams had sent some trilobites from these beds to Hall in 1859 when Hall described them, placing them in the Hudson River Shale age. And Hall, quotes Logan, "one of the most able stratigraphical geologists of the American Continent," as supporting him in his views. Barrande examined some of the Georgia specimens and published in Bulletin Société Geologique de France a discussion of their age. Barrande decided that the fossils indicated an age like that of the Primordial of Bohemia and that the American geologists were wrong in placing the age of the slates above the Primordial. A little later in 1861, Barrande moved the Georgia Slates up to the Quebec Group and believed that they belonged between the Potsdam and the Trenton. Therefore he appears to have put Olenellus at the bottom of the Ordovician.

In 1861 Dr. C. H. Hitchcock in the Report of that year discusses what had been called Azoic rocks from a lithological standpoint and describes in detail the principal kinds, *viz.:* Gneiss, hornblende schist, mica schist, clay slate, quartz rock, talcose schist, serpentine, saccharoidal limestone. He also finds igneous rocks in this group. In this same Report numerous sections taken from east to west across the State are given, as an aid in understanding the kinds found. As was stated in Part I, samples of these were collected and deposited in the State Collection at Montpelier.

MARCOU—1862.

In 1862 Jules Marcou gave considerable attention to Vermont rocks. In *Proceedings, Boston Society of Natural History,* vol. VIII, page 239, will be found an article on "The Taconic and Lower Silurian Rocks of Vermont and Canada." Marcou refers to what Barrande had written on the stratigraphic position of the Primordial fauna of North America.

Marcou was sent by Professor Agassiz to Vermont and Canada to study the rocks and so far as possible to determine their age. Marcou evidently accepted Emmons' Taconic Series, which he considered "the true base of the sedimentary strata in North America." Again—"I agree wtih all the sections, observations and descriptions of fossils of Dr. Emmons." He speaks of not making out the Lorraine Shale (Hudson River). "I did not find a single trace of this group anywhere on the mainland of Vermont, nor in the vicinity of St. Albans, Georgia, Swanton or Highgate." But he did find this group at Alburg "between the Missisquoi Bay and Rouses Point."

Marcou found what he considered Utica Shale at Highgate "behind the hotel" where Utica on account of overturning lies below the Trenton. He also identified all the lower members of the Ordovician. The Red Sandrock he placed in the Potsdam. Of the Laurentian, recently proposed by Logan, he says, "The Laurentian System is composed of the Lower Taconic to which are added the unstratified crystalline rocks forming the center of the Laurentian Mountains, such as granite syenite, diorite, porphry mixing together strata and igneous rocks, an attempt unexpected from a stratigraphical geologist." And further of Logan—"His Huronian System is formed of a mixture of the St. Albans Group of the Upper Taconic with the Triassic rocks of

Lake Superior, the copper-bearing rocks of Keweena Point and the diorite dike containing the copper pyrites of the Bunce mine." l. c., vol. VIII, p. 252.

BILLINGS—1862.

In an article in the *American Journal Science,* 1862, vol. 33, p. 145, Mr. Billings of the Canadian Survey writes in addition to former statements of the age of the Red Sandrock. After discussing questions of priority and stratigraphy and noticing some confirmations of his former conclusions, Mr. Billings says, "the most important and interesting locality is one and one-half mile east of Swanton discovered by Rev. J. B. Perry and Dr. G. M. Hall, the black slates holding (here some fossils are named including Olenellus). (These slates) are here seen conformably interstratified with the Red Sandrock." l. c. p. 102. Mr. Billings examined the well-known great fault at Rock Point, in Burlington, notices the slickensides of the overlying Cambrian, etc., but evidently failed to understand the conditions presented and interprets the overhanging rock as "either Potsdam or Calciferous." He also discusses the faults at Snake and Buck Mountains. Of Buck Mountain he says that it is "capped by sandstone and magnesian limestone, beneath which is to be seen a great formation of black slate." Emmons called the latter Taconic and the upper mass Calciferous Sandrock. He also maintained that there is a fault running along the face of the mountain by which the Sandrock is thrown up so that its base is seven hundred feet above the Trenton limestone. Of this Billings says, "In this I think he is right, but the rock which constitutes the top and eastern slope is not Calciferous, it is Potsdam." And as to Snake Mountain—"The fault at Snake Mountain must have an upthrow on the east side of three thousand feet, for it is equal to the whole of the unstratified crystalline rocks forming the center of the Laurentian Mountains, such as granite, syenite, diorite and porphy, mixing together strata and igneous rocks, for it is equal to the whole thickness of the seven hundred feet of black shale, the whole of the Potsdam, Calciferous, Chazy, Black River and part of the Trenton.

The mountain at present is only about a thousand feet higher than the surrounding plain, having been reduced by denudation. It appears to me quite certain that there must be a great deposit of slate beneath the Potsdam in the region, otherwise this enormous fault would have brought up the Laurentian gneiss." l. c. p. 103.

C. H. HITCHCOCK—1867.

Writing in *Proceedings, A. A. A. S.,* vol. XVI, 1867, Professor C. H. Hitchcock attempts to correct some of the age determinations of the 1861 Report. He places "The Red Sandrock, part of the Hudson River slates, part of the quartz rock, most of the quartz rock and the Potsdam of West Haven" in group 1. "The Calciferous Sandrock" in group 2. The Levis Groups, including the "Æolian Limestone," the Hudson River Limestone and the greater portion of the Georgia slate in group 3.

4. The Lauzon Group, including most of the "Talcose Conglomerate, "Talcoid Schists," and part of the "Talcose Schists."

5. Sillery Group, the upper part of the "Talcose Schist." The Mica Schist is either 3, 4 or 5.

"6. Chazy, Birdseye and Black River Limestone.

"7. Trenton Limestone.

"8. Utica Slate."

As will be noticed the above grouping of Vermont strata involves very considerable change from any used in the Vermont Reports of 1861. Dr. Hitchcock adds to the above:

Upper Silurian.
1. Calciferous Mica Schist.
2. Clay Slates of eastern Vermont.

Devonian.
Upper Helderberg.

Cenozoic.
Miocene Tertiary and Alluvium.

He recognizes the Lower Silurian age of the Taconic rocks. "It should on paleontological grounds be regarded as a subordinate part of the Lower Silurian System." l. c. p. 122.

J. B. PERRY—1867.

In a paper read before the Boston Society of Natural History, 1867, Mr. J. B. Perry of Swanton discusses at considerable length the relative age of the Red Sandrock. He says among other things, "The late Dr. E. Emmons long ago described it as Potsdam Sandstone and he ever after maintained substantially the same opinion. He notices, however, that in many geological writings it is called Medina."

"It lies in the lower portions of the Champlain slope of Vermont and dips gently to the east. In all localities it has been much eroded, what remains seeming to be only a small fragment of the original formation. At various points it has been very largely cut away, while in not a few cases have been to all appearance entirely carried away." l. c. 342. After referring to Billings' identification of the trilobites found in the Red Sandrock, he declares his belief that it is true Potsdam.

Mr. Perry then discusses the probability that only the metamorphic rock lying east of the Sandrock can be the same, changed by metamorphism and very positively concludes that the Red Sandrock does not extend under the metamorphic formations cropping out along its eastern limits. l. c. p. 345. In reply to those who held that the rocks below the Potsdam were a downward extension of that age, Mr. Perry says, "that cannot be, as there is abundant though not great unconformity and entire absence of Potsdam fossils in the lower rocks, but what fossils have been found have been wholly different.

He then asks as to the relation between these underlying shales and the Potsdam, concluding that they cannot be Utica nor Lorraine, but are older than the Potsdam. Next he enquires whether the Red Sandrock can be referred to the Lower Silurian and concludes that it should be placed at the top of the Taconic and immediately below the Calciferous Sandrock, which is at the bottom of the Champlain and gives the following as his conception of the arrangement:

1. Champlain.	Upper	Birdseye, Black River, Trenton, Utica, Lorraine.
	Middle	Chazy in several divisions, Lower Calciferous Sandrock.
		Potsdam Sandstone, Upper.
	Middle	Black and Brown Slates, with limestone and sandstone.
	Lower	Talcose and Talcoid Slate, with limestone, quartzite and conglomerate. l. c. p. 252.

T. STERRY HUNT—1868.

T. S. Hunt of the Canadian Geological Survey, published in *American Journal*, 1868, p. 222, an article "On Some Points in the Geology of Vermont," in which he takes up the distribution of the paleozoic rocks of the western part of the State. By way of preparation he reviews some facts in the geology of Quebec and then considers the Vermont formations as he understands them. He refers to Billings' identification of some of the Vermont fossils, calls attention to the Great Fault by which great dislocations of Vermont strata have occurred, then referring to the Red Sandrock he says, "The late Dr. Emmons supposed the Red Sandrock to include the Potsdam and Calciferous formations, though he at the same time greatly misunderstood its stratigraphical relations, p. 224.

"The following are the facts observed along a line of section passing from Crown Point, N. Y., across the head of Lake Champlain and through Bridport to Cornwall in Vermont. Passing from the Laurentian across the various members of the New York series we reach the limestone of the Trenton group of the east shore of the lake and encounter the Chazy formation which is brought up along a gentle anticlinal and is succeeded by Trenton, Utica and Hudson River formations, all sloping gently to the eastward until we come to the Great Fault which brings up the Red Sandrock."

After mentioning some of the fossils found in these beds, he continues: "To the east these limestones are cut off by second dislocation, which brings up the Levis formation with its characteristic fossils, against the Trenton. A ravine marks the line of fault which has been followed for more than twenty miles from the southern line of Sudbury northward to Weybridge, where it joins the great western fault." l. c. p. 227.

Mr. Hunt sums up his observations as follows: "All the evidence, paleontological and stratigraphic as yet brought forward affords no proof of the existence in Vermont of any strata older than (a small spur of the Laurentian excepted) the Potsdam formation." l. c. p. 229.

J. B. PERRY—1871.

Though written in 1863, an article by Rev. J. B. Perry did not appear until 1871, "On the Geological Formations of Lake Champlain." This article was published in Miss Hemenway's *Historical Gazeteer,* vol. II, pp. 21-88. The first part of the article is given to general geology and then Mr. Perry takes up more special topics as "The Geographical Position of the Champlain Valley," "The Origin of the Champlain Valley." The article, obviously, is rather popular than technical and in the main repeats opinions expressed elsewhere.

In this discussion Mr. Perry goes back to the origin of the primitive crust, adopting commonly held views and from this to the origin of the Adirondack and Green Mountains and of what he calls aqueous rocks. He speaks of the origin of and early formation of the Champlain valley and the channel of the lake, which he considered in the main caused by a great dislocation or fault supplemented by erosion. He discusses the vicissitudes of the valley, especially through elevation and depression of the land and finally the renovation of the valley is considered at some length. The Crystalline rocks are then described as widely distributed over the State.

Later in this article Mr. Perry has what he calls "The Detailed Structure Exposition of the Geology of Northwestern Vermont." He first gives "A Tabular View of the Rocks of Northwestern Vermont," followed by the "Geologic Position of the Rocks, Beginning on the East." He considers the Ordovician rocks of the region and then the later beds. Dikes are next discussed, after which he takes up the stratigraphic relations of these rocks, the Lithological Characters of the region and last, "The Organic Remains" with a list of known species.

AUGUSTUS WING—1868.

In some respects more important to Vermont geology than any report of work previously published are those of Rev. Augustus Wing of Whiting. Apparently, Mr. Wing was little known even in his own State, as a geologist, though working diligently for years, especially in Addison County. Because of a morbidly retiring disposition, Mr. Wing, though keeping careful notes, did not let his work appear even to those who sought information. He wrote out in full answers to letters of enquiry sent by geologists and, fortunately, keeping them, but never sending them. Only after his death was the entire collection found and made public.

Mr. Wing began his life as a minister, but later devoted most of it to teaching and, for some reason, though his teaching was that of an ordinary country schoolmaster, which required no attention to science, he soon became greatly interested in geology and especially the study of the geology of his immediate surroundings. Though never having any scientific teaching nor association with scientific men, Mr. Wing proved to be a very unusual observer and investigator. He died in 1876 and his carefully preserved notes passing first into the possession of Professor H. M. Seely, finally reached Professor J. D. Dana and by him were published in 1877 in several numbers of the *American Journal* of that year.

As to his own plans, Mr. Wing says that he wished "to ascertain, if possible, the geological age of the limestones, shales and quartzites of Otter Creek valley." From his home in Whiting he went out for many years exploring the immediately surrounding country. His field work began in 1865 and continued until his death.

Of this, Professor Dana writes, "Mr. Wing by the use of his spare time amid the duties of teaching accomplished vastly more for the elucidation of the age of Vermont rocks than had been done by the Vermont Survey. The Vermont Report of 1861 presents divers opinions about the Æolian limestone and the formations adjoining, but settles nothing, while Mr. Wing's discoveries shed light not on these rocks alone, but also on the general geology of New England and Eastern North America." l. c. 1877, p. 333. Also Professor Dana remarks, "The region studied by Mr. Wing is part of an area of middle and southern Vermont, the Æolian limestone as named by Hitchcock in the Vermont Geological Report.

This limestone covers a wide strip of country north and south, extending from the southern boundary north to northern

Monkton, a distance of about one hundred miles. The limestone region is bordered on the east almost continuously by ridges of quartzite, or quartzite and slates which extend along the western foot of the Green Mountains. Besides, there are north and south dividing ridges or belts of hydromica slate and clay slate with sometimes interstratified quartzite. On the west there are other beds of slate and to the north near the Great Fault, areas of Red Sandrock.

These various rocks are so associated that the study of all was involved in the Æolian limestone, moreover, they extend southward into Massachusetts. This limestone, which Hitchcock called Æolian, is found abundantly in Otter Creek valley and it was the investigation of this that mainly occupied Mr. Wing during the years of geological study. As first discovered by Mr. Wing, this band of limestone (that of the west Rutland valley) contains fossils in both its eastern and western borders and also along its center. "The marble quarries are situated on bands of highly crystalline white, clouded, limestone between the fossiliferous borders and the center." l. c. p. 337.

"The fossils on the western border are found in the southwestern part of the valley, just north of an old abandoned marble quarry, the most northern one on the west side of the valley where the rock is grayer than the central belt. The rock here is distinctly and abundantly fossiliferous." l. c. p. 338. Mr. Wing sent some of these fossils to Mr. E. Billings, who reported, "I think this collection is Chazy." Later, other Chazy fossils were found, including Maclurites.

The conclusions which Mr. Wing reached are thus given by Professor Dana:

"1. The Hydromica Slates, Clay States, Æolian Limestone, Quartzite, with the so-called talcose conglomerate on the east are all of Lower Silurian age and conformable superposition.

"2. The Æolian limestone is not Taconic, as made out by Professor Emmons, nor of some one formation, as implied by statements in the Vermont Report, and in the name he gave it, nor of the Quebec group as inferred by Logan. It includes the Lower Silurian limestone of various periods—Upper Potsdam, Lower Calciferous, Calciferous, Quebec, Chazy, Black River and Trenton.

"3. The Red Sandrock on the west of the Æolian limestone, and the Quartzite on the east, which often rises into mountain peaks, are of the same formation and come nearly or quite together in Monkton on the northern limit of the limestone area.

"4. These rocks—the Red Sandrock and Quartzite are the east and west portion of a great abraided synclinal, the axis of which in its northern part has a slight northwest rise, * * * * * *.

"5. The slates of the great central belt are of the age of the Hudson River slates (or that of the Cincinnati group). The reasons for this are given, but it is not necessary to repeat them here and now the whole group is placed at the top of the Trenton.

"6. The several Lower Silurian limestone formations in the north and south belts with the Lowest Potsdam and the Calciferous, nearest to the Red Sandrock and the Quartzite, and the Upper Trenton or Chazy nearest the Central Slate Belt." l. c. p. 414.

Professor Dana endorses these views and with a few changes now would accept them. In connection with Mr. Wing's conclusions, those of Brainerd and Seely, *Bulletin American Museum of Natural History*, vol. III, pp. 1-27, are useful. Also Professor Seely's Geology of Addison County, Seventh Report on the Geology of Vermont, 1890, pp. 257-313, plates XLVIII-LXII.

Professor Dana further writes, l. c. p. 418, "One of the most important points established by Mr. Wing is the conformability of the Lower Silurian throughout the region. From the Red Sandrock or Primordial upwards they make one consecutive series and all are involved, as Mr. Wing urges, in one system of synclines and anticlines. The quartzite, hydromica schist and limestones associated on the eastern border of the region, and the great bands of limestone and hydromica slate and clay slate with some quartzite making the center and western portion are one system and took together their present positions." The Great Fault which made Snake Mountain was simply one of the breaks and displacements attending the mountain making movement as shown years since by Logan.

The observations of Mr. Wing afford nothing to sustain the view that there was an epoch of disturbance at the close of the Primordial or Cambrian period. On the contrary, they prove that the rocks went on forming in regular succession nearly or quite to the close of the Lower Silurian and that then followed, as Mr. Wing concludes, the epoch of upturning and metamorphism. In the sketch of the work of A. Wing by Professor Seely, in the Third Report Vermont Geologist, 1902, we find another summary of Mr. Wing's investigations.

"The limestone region of the Otter Valley lies within a great syncline. On the east it is bordered essentially by ridges of quartzite which extend along the eastern foot of the Green Mountains. On the west by the Red Sandrock whose elevation and fracture forms the Great Fault 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 quartzite and the Red Sandrock very nearly approach and unite. Within this trough lie 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 in the Lower Silurian. These strata originally deposited in regular order by some grand

mountain-making movement, have been folded, compressed, snapped and depressed, the fossils by the same movement being almost obliterated. The great syncline was left with subordinate north and south anticlines and synclines, the whole complex was exposed to the subsequent abrasion of geologic time." Third Report Vermont Geologist, p. 27. "Where the determination of the rocks which Mr. Wing most thoroughly studied a local problem merely, his work would have comparatively little significance, but the age of the Rutland marbles and of part of the whole Green Mountain range is involved in a study of these rocks, which were his special problem." And not only the Green Mountains of Vermont but, as Professor Dana has shown (*Am. Jour. Science*, 1877, vol. XIII, p. 37):

"The great limestone belt of Vermont stretches southward without interruption or diminution in width into Berkshire County, Mass., then through Berkshire into western Connecticut, and continuing a southwardly trend over Canaan and Salisbury, it passes out of Connecticut still as wide as any northern portion into eastern New York in the towns of Amenia and Dover to Pawling. There it stretches southwest for seven or eight miles, but with narrowing limits to finally end in a narrow strip among the flexures of hard gneiss rocks. It is one of the lower Green Mountain formations."

So, too, we find the Vermont Quartzite continues a thin mass into Connecticut and the slates and schists of the Taconic in Vermont continued southward. l. c. p. 202, "From the facts brought forward it is manifest that the limestone, schist and quartzite making up the limestone series of Vermont and Berkshire are continuous formations throughout. Hence we have proof that the conclusions deduced for Vermont from Mr. Wing's discoveries are true also for Berkshire, etc." In a later article, Professor Dana compares in detail the rocks of Vermont with those of Berkshire and shows close relationship between them. For a satisfactory understanding of Mr. Wing's work and Professor Dana's valuation of it one should refer directly to the series of papers referred to above.

JULES MARCOU—1880.

In a paper published in *Bulletin Société Geolique de France*, 1880, Professor J. Marcou, who had studied in the Champlain valley, gives a summary of his work. He gives sections which show that the Potsdam does not conform with the contiguous Georgia Slates and that below them he places the Phillipsburg, Swanton Schists and St. Albans Group.

C. D. WALCOTT—1888.

In a number of the *American Journal of Science,* 1888, vol. 32, Dr. C. D. Walcott describes an observed section in Georgia and later in greater detail he writes of the same section in Highgate in Bulletin 30, U. S. G. S. In the Georgia section Dr. Walcott found the rocks 1,000 feet thick and at Highgate 1,170 feet. In this paper Dr. Walcott referred the Red Sandrock to the Georgia Slates, following Logan. Walcott also considered the Granville roofing slates just across the Vermont line in New York, as equivalent to the Georgia Slates in age.

In this Bulletin Dr. Walcott groups in the Georgia Slates, "clay slate, roofing slate, clay slate approximating a micaceous sandstone, several sorts of limestone, brecciated limestone and conglomerate." l. c. p. 14. At this time he wrote (1881), "As we now know the Georgia formation it appears that Dr. Emmons was correct in placing it below the Potsdam Sandstone as was also done by Mr. Billings and later writers."

The typical Georgia formation as it exists in the town of Georgia, Vermont, consists, as seen at the base, of a great thickness of magnesian limestone that passes in the upper portions into an arenaceous magnesian limestone that is overlaid by a bed of arenaceous-argillaceous-calcareous shales and this by a great thickness of a purer argillaceous shale that high up carries a brecciated limestone conglomerate and lenticular masses of sandstone and limestone from the size of a bean to masses 2,000 feet in thickness and several miles in superficial area. "A carefully measured section, beginning at the base of the westward falling cliff overlooking the level that reaches the shore of Lake Champlain and extends southeast through Parker's quarry and a little south of Georgia post office gives the following:

"1. Massive bedded bluish gray, dolomite limestone with many inosculating threads of a yellowish drab sandy limestone that weathers in relief. .... 35 feet.

"2. Number 1 passes into a steel gray, dolomite limestone that weathers to a dark buff and bluish black, with angular fragments of bluish gray limestone appearing irregularly at the surface. At a hundred and sixty feet from the base the first band of limestone, "calico or Winooski marble," is met with. The latter grades into a reddish dolomite free from mottling and then into a gray limestone (Hyolithes) offset the figure... 2,000 feet.

"3. Gray dolomite limestone in massive layers, some of which are mottled, but the larger part are gray and yellow. Many of the gray layers break up into a columnar structure, the columns being at right angles to the bedding. In the reddish limestone two hundred feet from the base, a slender elongate tube occurs, probably Hyolithes micans .... 475 feet.

"4. Reddish pink, dolomitic limestone weathering to a reddish brown and decomposing on the exposed edges to an arenaceous dark brownish red rock that shows numerous fragments of fossils, Kutorgina, Ptychoparia, Olenellus.

"5. Gray arenaceous limestone in rough massive layers, passing into more evenly bedded light gray, arenaceous limestone. Fossils, similar to those above, No. 4, occur in the lower portions. .... 100 feet.
Total thickness of limestone .... 1,000 feet.

"6. Georgia shales—argillaceous, micaceous and arenaceous shales containing numerous fossils at Parker's ledge and showing deposition contact on No. 5 .... 200 feet. (A list of fossils is here given.)

"7. East of the Parker quarry the rocks are argillaceous shales with occasional layers of hard gray limestone, one-half inch to two inches thick that carry numerous fragments of a linguloid shell .... 3,500 feet.

"8. Light gray quartzite .... 50 feet.

"9. Gray limestone in narrow layers with occasional intercalated bands of hard argillaceous shale similar to that beneath the limestone. Many of the beds appear to have been broken up into fragments to be recemented in situ........... 1,700 feet

"10. Argillaceous shales very similar to those in Parker ledge continue on up to the opposite side of the line of the Central Vermont Railway. At the base the shales rest conformably against the limestone of No. 9 and above appear to be cut off by a fault—to fault line .... 3,500 feet." l. c. pp. 16-17.

In the Bulletin Dr. Walcott gives a full page to this sectional figure and from it one gets the best idea possible of the variability and character of this somewhat well-known section. Following the above discussion of "The Cambrian Faunas of North America" Dr. Walcott discusses the "Taconic" system, but as an extract from a later article by him will be given in following pages no more need be said of it here.

EZRA BRAINERD—1885.

In *Proceedings of the Middlebury Historical Society,* Dr. Brainerd, pp. 9-21, 1885, gives a good general account of the marble region of western Vermont, with special reference to Mr. Wing's work and how by these investigations errors of previous geologists are corrected. Two colored maps showing the geology of the region are given, also a summary of the geological history of marble.

H. M. SEELY—1885.

In *American Journal Science,* November, 1885, pp. 355-357, Professor Seely describes "A New Genus of Chazy Sponges," Strephochaetus, and in a number of the same Journal for July, 1886, he gives further details, with figures.

R. P. WHITFIELD—1886.

In *Bulletin American Museum of Natural History*, vol. 1, 1886, pp. 298-345, plates 24-35, gives an account of certain explorations made at Fort Cassin, Vt., by Drs. Brainerd and Seely, "Notices of Geological Investigation Along the Eastern Shore of Lake Champlain." This is the first published account of a locality since become well-known because of a very unusual series of fossils found there. A full account is also given in Professor Seely's article in the Seventh Report of the Vermont Geologist on the "Geology of Addison County." In the second volume of the Bulletin named, 1889, pp. 48-68, plates 7-13, he add considerably to his former paper.

JULES MARCOU—1887.

Mr. Marcou's interest in the geology of the Champlain valley has been already mentioned. In a paper read before the Boston Society of Natural History in 1887, vol. IV, pp. 105-131, he gives a much more extended account of his work on these rocks. Mr. Marcou calls attention to the fact noted by all who have studied the region, saying, "The geology of the eastern region of Lake Champlain and of the whole band of country extending from Albany to Poughkeepsie on the Hudson River, varying in breadth from ten to forty miles eastward and extending north to Quebec, Trois Pistoles and Gaspé is by far the most difficult and complicated that I have met with during my forty years of research in both hemispheres. Nothing even in the central Alps is more puzzling and complicated.

"The slates predominate as a general fact, but there are enclosed among them lenticular masses of ordinary limestones and marble, magnesian limestone, calcareous sandstone and pure sandstone varying from the size of the fist to small islands or even mountains two thousand feet long and one thousand feet broad.

"At first sight the slates are too uniform to establish stratigraphic divisions and easily recognized groups and lenticular masses of limestone and sandstone appear so suddenly from place to place with such capricious distribution that instead of being a help in classification they are on the contrary a cause of constant error and considerably increase the difficulties. The sections are rarely clear and require more than ordinary caution in their surveys and interpretations, l. c. p. 105."

Then, after noticing that only the most careful and minute investigation can reveal the facts, he refers to Emmons' work, goes on to review that of those geologists who immediately followed Emmons and gives a section as he thinks it should be. Following this comes a discussion, mainly historical, of the uses of the name Georgia. Marcou then considers the more important fossils found in the Taconic beds. He evidently is a strong adherent to the Taconic views presented by Emmons.

BRAINERD AND SEELY—1888.

In *American Geologist*, November, 1888, pp. 1-7, Dr. Brainerd and Professor H. M. Seely give a much condensed account of "The Original Chazy Rocks." This article naturally refers especially to New York rocks, but Vermont localities are mentioned, with some sections.

C. D. WALCOTT—1888.

In *American Journal of Science*, vol. XXXIII, pp. 229-307, 394, Dr. Walcott again takes up some phases of the question, "The Taconic System of Emmons" in three articles. From these there is space for no more than a few brief summaries, but the whole is important.

"The stratigraphy shows the quartzite series to be the oldest of the Paleozoic sediments known on the eastern side of the Taconic area and the fauna correlates it with the middle division of the Cambrian but not as low in position as the fauna of the lower strata of the Georgia terrane." The stratigraphic and paleontogic evidence unite to prove that the limestone and marbles of Terrane No. 3 (the limestone and marble belt of that outcrops both on the eastern and western side of the Taconic range) are the geological equivalents of the Calciferous, Chazy and Trenton limestone of the Champlain and Hudson valleys and belong to the system of strata characterized by the second fauna of Barrande. "I have briefly noticed the strata included in the Taconic area with the exception of the beds west of the great fault line" (229-242) the strata of the Taconic area are grouped under six terranes and identified as follows:

Terranes 1 and 5—equal Middle Cambrian.

Terrane 2—equals Upper Cambrian.

Terrane 3—equals Calciferous, Chazy and Trenton Limestones.

Terranes 4 and 6—equal Hudson River Shales, Sandstones, etc., p. 242.

In a second article Dr. Walcott gives, page 307 l. c., a "History of the Taconic System as known to Dr. Emmons," and considers each of the five systems of the Emmons Taconic Group. As to the stratigraphic position of the Taconic, Dr. Walcott writes, "I think we may say that Dr. Emmons regarded the original Taconic system as stratigraphically unconformable and subjacent to the Potsdam Sandstone of the Lower Silurian of the New York group and believed it to rest unconformably on the gneiss at its base to form a great system of sedimentary rock between the gneiss and the Potsdam Sandstone," p. 315. After a series of comparisons of present and past Taconic beds Dr. Walcott concludes: "The Lower Taconic is essentially a repetition of the Lower Silurian (Ordovician) section of the Champlain valley. It differs in lithological details and in having a less abundant fauna in the typical Taconic area."

"The Upper Taconic is found to be comformably subjacent to the Stockbridge Limestone of the Lower Taconic and to include the Potsdam horizon," p. 32. Accompanying the third article Dr. Walcott gives a geologically colored map of the Taconic area of eastern New York and western Vermont which is instructive. He then discusses the use of the name Taconic, concluding that the evidence presented in the preceding pages proves that the Taconic system was founded on error of stratigraphy of such character and magnitude that the name Taconic has no claim upon the geologist for recognition in geological nomenclature."

There is further discussion of the use of the name Cambrian and "A Description of the Map and Section." Dr. Walcott referred the fossils found in the Red Sandrock to the Middle Cambrian, until in 1888, he visited New Foundland localities and especially a section on Manuel's Brook, where he found that the Olenellus fauna was lower than the Paradoxides. He, therefore, reviewed the classification of the Cambrian and thereafter places the Olenellus zone (Red Sandrock) in the Lower Cambrian. I think that the first publication of this new arrangement was in *Nature,* 1888, vol. 38, page 551.

R. P. WHITFIELD—1889.

In the *Bulletin of the American Museum of Natural History,* 1889, vol. 11, page 41, has some "Observations on some imperfectly known fossils from the Calciferous Sandrock of Lake Champlain." Though this paper refers mainly to New York localities, especially Beekmantown, a few fossils are described which were found in Vermont.

C. D. WALCOTT—1890.

A much more extensive discussion of the Cambrian, embracing the whole country, is given by Dr. Walcott in the Tenth Annual Report, U. S. G. S., 1890. This is *"Fauna of the Lower Cambrian or Olenellus Zone,"* pp. 509-658. Plates 49-98. In this article Dr. Walcott definitely fixes the location of the Red Sandrock and Parker Shales as Lower Cambrian or "The Olenellus Zone." On page 552 Dr. Walcott says, "In northern Vermont the section of the Olenellus Zone extends from the upper portion of the limestone through a considerable thickness of shales." The location of various beds of the Olenellus Zone is given and lists of fossils are included.

Of Vermont, he says, "In northern Vermont a massive and more or less arenaceous dolomite occurs at the base of the Cambrian section, and the upper part of the Olenellus Zone is found of dark, arenaceous, argillaceous shales." He names twenty species of fossils found here and continues, "Near the boundary line between the United States and Canada, east of Highgate Springs, a number of species occur at the same relative horizon as the Parker Quarry, all but two of which have been found at the latter locality." "On the eastern side of the outcropping of the strata of the Olenellus Zone in central and southern Vermont is massive quartzite that was formed along the old pre-Cambrian shore line." "In central Vermont, green and purple slates begin to appear in the Lower Cambrian, and in Washington County, New York, about 8,000 feet of green and purple slates that are identical in lithological character with the slates of the Lower Cambrian slates of North Wales are found." l. c. p. 569. "Below the green and purple slates there is great thickness of dark argillaceous and sometimes arenaceous shales in which the Olenellus fauna occur." l. c. p. 569.

BRAINERD AND SEELY—1890.

In *Bulletin American Museum of Natural History,* 1890, vol. III, p. 1, Drs. Brainerd and Seely write of "The Calciferous Formation in the Champlain Valley."

Excellent maps show the arrangement of the Calciferous beds in Shoreham, Ticonderoga, N. Y., West Charlotte and Providence Island. There are also two maps of sections taken southeast of Shoreham village, Orwell, Fort Ticonderoga, S. W. Charlotte and Providence Island.

The Fort Cassin beds are also discussed.

In the same Bulletin, in a following article, Mr. R. P. Whitfield adds to a former discussion of these same beds. l. c. pp. 25-39. Plates I-III. Here eleven new species are described and figured.

PUMPELLY AND WOLFF—1891.

During the seasons 1888 and 1891 Professor R. Pumpelly, Professor J. E. Wolff and Mr. T. B. Putnam, the two latter as assistants, spent several weeks in a study of the Green Mountains in the Rutland region. The results of this work were not published till 1891, when they appeared in volume II of the *Bulletin of the U. S. G. S.,* pp. 209-224.

Some of Professor Pumpelly's views as to the disintegration of pre-Cambrian rocks and the value of these in explaining the nature of succeeding periods seem to the writer of a good deal of importance, at any rate as helps in determining some of the phenomena observed in the Green Mountain area. He writes "That a land surface exposed during a long period to the influence of a moist climate and protected by vegetation would be subjected to disintegration and decomposition of its rocks. The waters circulating in depths charged with O and Co_2 and bearing acids derived from vegetable decay would set in motion a disintegration action which begins with disintegration and ends with the reduction of the rock to its most insoluble products, such as quartz, clay and ferric oxide. The depth of this decomposition, other things being equal, is determined by lapse of time, by the permeability of the rock, by the solubility of its contents, rather than by its hardness." l. c. p. 210.

On page 210 he writes as follows: "Our work in the Green Mountains and recent studies of the mountains of North Carolina have given me proof that the recognition of the importance of secular disintegration is essential to the proper interpretation of some of the most difficult points in the study of the crystalline schists. Throughout the Green Mountains and the Appalachians the Cambrian conglomerates and quartzites resting on an older crystalline complex contain large quantities of detrital feldspar in fragments or pebbles up to three-fourths of an inch and more in diameter together with grains and pebbles of blue quartz, all clearly derived from the destruction of older granitic rock. These feldspars are the same as those in the older rocks and show their own detrital character. They often show partial kaolinization * * * * * * * * * And in some cases these fragments have been enlarged by a growth of new feldspar which, with mica and independent albitic grains, some secondary quartz and magnetite, are all products of metamorphism formed in place in the clastic rocks. It seems quite clear that the kaolinization preceded the deposition of the conglomerate. Now whence came these detrital feldspars? I can imagine no other source than the débris of the decayed mantle. The transgression which in this case ushered in the Cambrian found the dry land deeply disintegrated. I think the hypothesis of a pre-Cambrian decay of the ganitoid gneiss gives the key to the problem in the Green Mountains.

The lower zone of semi-kaolinization and the still lower one in which the feldspar crystals were loosened by alteration of micaceous and hornblendic constituents furnished the fragments of feldspar and the less altered cores of blocks for the conglomerate beds."

In the Sanford dike in Clarksburg Mountain, Pumpelly found proof that before the Cambrian "there was unconformity by erosion of dry land as well as previous rock decay." l. c. p. 211.

Of the Green Mountains, Professor Pumpelly says, "One of the chief difficulties we met with in studying the rocks was the sudden change from true quartzites overlain by the Lower Silurian limestone in the valley to white gneiss overlain by schists on the main ridge east of the valley." l. c. p. 214.

"As the breaching waves of the sea advanced landward during the positive movement the upper zone of finer and wholly kaolinized material was removed to a distance while coarser material of the deeper zone of semi-kaolinization was deposited nearer at hand, forming beds consisting chiefly of little altered feldspar and quartz with larger pebbles from the veins of quartz and of harder granites, as well as from occasional cores of partly disintegrated blocks. Beneath these lay a zone in which the cohesion of the granite had been weakened by the first stages of disintegration, the alteration of the mica or hornblendic constituents, lying between the other minerals," p. 214. On the following page, l. c. 215, Professor Pumpelly writes: "I think I have thus explained the puzzling variation in character of the Lower Cambrian quartzite, conglomerate, coarse gneiss, and white gneiss of the Green Mountain range. The transitional beds in Hoosac Mountain under the Cambrian gneiss on the eastern and western flanks of the arch represent, I think, not only beds formed from coarse feldspar, gneiss and pebbles from the granitoid gneiss, but also the semi-disintegrated zone of the granitoid gneiss which had escaped abrasion by the waves and which by the weakening of its cohesion mentioned above, acted under the lateral thrust to a great extent like the sediments above it. This unabraided zone of crystalline rock which had its rigidity weakened by beginning disintegration would, under folding, pressure and metamorphism, show on the one hand a perfect and true transition into the parent crystalline rock and, on the other, pass into younger beds through the similarity of constituents derived from it and an apparent conformity would be forced upon the whole series and the true break would be masked by the foliation, induced by shearing action due to slipping movement." l. c. p. 215.

The transition from crystalline schists, Pumpelly regards as due to the following: "The granite zone was in such a condition of weakness as caused it to act like the overlying clastic beds, such a condition, in fact, as exists in the lowest zone of disintegration where only the stronger of the micaceous constituents are affected." l. c. p. 216.

A remark as to the formation of the basal conglomerate is worth quoting: "I am disposed to regard all basal conglomerates and limestones and sandstones that mark the beginnings of geological periods as being produced during positive movements by the breaching action of the ocean advancing over previously deeply disintegrated land surfaces." l. c. p. 217.

However, at the time of writing, Professor Pumpelly thought best to confine his theories "to inferences drawn from those clastics in which the detrital feldspars with or without rock pebbles play an important part. It would be wrong to assert that all of the detrital material forming such basal clastic beds were derived only from a disintegrated mantle, for any geologist who has observed the breaching action of the ocean on a cliff-bound coast will recognize the importance ascribed, particularly by Von

Richthofen, to this greatest of all abraiding forces." l. c. p. 217. In the Green Mountains, however, Pumpelly does not think that this force has been very important or general.

Further, "In the central ridge of the Green Mountains we have one or more limestones which have been assigned by President Hitchcock to the Azoic, and a series of highly crystallined gneisses which, like the limestones, are represented in the pebbles of the basal conglomerate of the Cambrian." l. c. p. 218. "These limestones, like those of the Adirondacks, rest generally on coarsely crystalline granitic or gneissoid rock without any intervening clastic sediments, but the underlying rock having everywhere, almost, the appearance of having been originally a coarse granite which has undergone a crushing action. The feldspar grades from large 1 inch crystals, with heavy cleavage to coarse and fine aggregates, the quartz is also granulated. Moreover, some of the large crystals of feldspar which have wavy cleavage are penetrated by the mica, which in blotches marks the foliation of the rock. The rock presents in the wavy cleavage or its feldspars, in the granulation of its feldspars and quartz and in the foliation apparently contemporaneous with the crushing, the characteristics which should result from the action of a folding force upon the lowest zone of disintegration, the zone in which the integrity of the grain is weakened. Of course we are dealing here with a period of much greater age than the Cambrian, and the conditions of depth and pressure may have presented very different relations to the rigidity of the granite from those ruling during the folding of the Cambrian sediments. But with the evidence of a previous disintegration presented by the detritus in the Adirondack limestone * * * * * I am disposed to ascribe the crushing and defoliation of the granite underlying the old limestone to an action of a folding force in the pre-Cambrian upon a rock which had lost its integrity before the formation of the limestone." l. c. p. 219.

In a later study of this region, Professor Pumpelly expressed again the same views. *Monograph U. S. G. S. XXXII*, 1905. "The Green Mountains, coinciding with the prolongation of the axis of the Archean core of the Appalachians through western New England stands between the less disturbed fossiliferous Paleozoic strata of New York and the highly crystalline rocks of New England. They consist of three principal structural elements, the Green Mountains, the Taconic range, lying several miles to the west, and between these the great valley. But the whole region between the Hudson and the Connecticut has very properly been placed by Dana in one mountain system. * * * * * * The Green Mountain range is composed of crystalline schists, which our results show to be of Cambrian and Lower Silurian age, resting on pre-Cambrian rocks and it was long ago shown by Edward Hitchock to be of anticlinal structure.

The western edge of this axial range is for long stretches marked by a lofty brow of quartzite and for this reason the mountains present a very steep flank to the west. At the base of this flank lies what is known as the valley of Vermont, or in Massachusetts, the Berkshire valley. This valley has a floor of crystalline limestone, often a saccaroidal marble, of Cambrian or Lower Silurian age, on which stand long island-like ridges of schist of Lower Silurian age, and it extends with a width of several miles from northern Vermont to Alaska. The schist is everywhere underlaid by limestone, which is marked by the fertility of its soil. Along its whole length its wealth of limonite ores has for more than a century formed the basis of important iron industries. In the folded strata of this valley belt in Vermont and Massachusetts subsequent erosion has left island-like mountains, sometimes of anticlinal, but generally of synclinal structure, with more or less pitch in their axis. Instances of the latter are Dorset, Anthony and Greylock, rising 1,500-2,000 feet above the valley, surrounded to a greater or less height above the base by the limestone and heavily capped by the weather-resisting schist. Instances of the less elevated anticlinal structure are Pine Hill near Rutland and the ridge which connects it with Danby Hill. On the west this limestone valley has for a wall the Taconic mountains with peaks rising 1,500-2,000 feet above the valley. This is a synclinal range of the same Lower Silurian schist, but, having its trough at a lower level, the limestone formation appears only at the base.

Turning now to the region having its axis east of the Green Mountain anticline, we find no great and continuous depression comparable to the valley of Vermont until we reach the Connecticut valley and this is occupied by much later strata, Triassic resting upon Devonian." l. c. pp. 55, 56. The pre-Cambrian core of the Green Mountains reappears at frequent points along the ridge. In places it forms island-like masses of old, hard gneisses, surrounded by Cambrian quartzites and allied rocks as in the northwest corner of Connecticut. Again, as in Chittenden, Vermont, it consists of long, narrow lines of coarse gneiss at eroded points in the backbone of the range. Finally, as between Clarendon and Ludlow, in Vermont, where the range has been cut down by the removal of the younger rocks, the core of the folded range shows itself in a variety of old granitic and gneissoid rocks cut by intrusives and with extremely irregular structure." l. c. p. 25.

J. E. WOLFF—1891.

In *Bulletin G. S. A.*, vol. XI, pp. 331-337, we find an article by Professor J. E. Wolff, "On the Lower Cambrian Age of the Stockbridge Limestone" (about Rutland). Here Professor Wolff reports finding fossils, considered Lower Cambrian in limestone in the Rutland valley. He also studied other rocks of this area and says, "In the high, abrupt frontal range of the Green Mountains there occur crystalline schists, often gneissic, which pass eastward into the gneissic rocks proper of the Green Mountains. These schists contain beds of true conglomerates with a metamorphosed crystalline cement and pass westward on the slope into the quartzite of Vermont, which the discoveries of C. D. Walcott prove to be of Lower Cambrian age (Olenellus zone). This is succeeded by a broad belt of limestone occupying the Rutland valley." An outline map of the region about Rutland is given, on which the fossil localities are marked, as well as the distribution of the different rocks.

Professor Wolff further says, "The character and position of the rocks are as follows: On the slopes of the frontal range the Cambrian quartzite varies greatly in lithological character; it is massive or micaceous, contains beds of schist and passes into the metamorphic conglomerate and cement which intervene between it and the gneisses proper of the Green Mountains eastward. This cement rock contains a small bed, or beds, of crystalline limestone; the rocks are very much folded, and the structure is complicated by secondary schistosity and cleavage. The limestone is variable in character; in some beds it is white and coarsely crystalline, in others, fine-grained gray dolomite. It is often filled with small, rounded, detrital grains of quartz, so that it resembles phases of quartzite save that the quartz cement is replaced by lime. It extends many miles southward in this valley, but toward the north is cut off by the rocks of Pine Hill, which bend around to join the main range of quartzite. In this respect, geological maps need correcting, for in them this limestone is made to join the next belt westward in Pittsford. At its western edge the Rutland limestone is found resting conformably on the quartzite of Pine Hill. * * * * * * * * * * This contact line can be followed from the section northward two miles and eastward one mile, the strike turning to east and west with a gentle southerly dip; drift then covers the contact. It is evident, therefore, that the limestone lies in a trough of quartzite which dies out northward." l. c. p. 334. "The belt of limestone in which fossils occur * * * * * can be traced almost without a break to Center Rutland and into the Center Rutland belt. In the same way the schists bounding it on the west were followed into the schist ridge of Center Rutland and the West Rutland limestone belts." l. c. p. 336.

"The facts here stated prove that the limestone of the Rutland valley is of Lower Cambrian age, that in Pine Hill it overlies conformably a massive quartzite with associated beds of metamorphic conglomerate, cement rock, crystalline limestone and gneiss which bend around to join the similar series lying west of the limestone, and that the Pine Hill quartzite must, therefore, be of Olenellus age." l. c. p. 336. "The whole series has an easterly dip, but the apparent great thickness of the Cambrian limestone—3,000 feet if the strata lie in a single overturned synclinal—seems improbable, especially as it is near the shallow ending of a trough." l. c. p. 337.

As to the age of the Center Rutland limestone, Dr. Wolff says, "It seems, therefore, established that the Center Rutland limestone belt is of the same general age as that of West Rutland (Trenton, Chazy, Calciferous), and that the Cambrian Rutland limestone is either not represented in it or at best by a very small strip."

C. D. WALCOTT—1891.

In the volume of Correlation Papers, *Bulletin U. S. G. S. 81*, Dr. Walcott discusses the Red Sandrock as follows: "The Red Sandrock series is confined almost entirely to northern Vermont, not appearing south of Addison County. In the northern part of Addison County it comes in contact with and merges into the Granular Quartz series. It has not been recognized in contact with the Archaen rocks of the Green Mountains. From this and its having less of the character of a shore deposit and from its occurring west of the line of outcrop of the Granular Quartz, it is quite probable that it is a deeper water accumulation, though contemporaneous with the Granular Quartz. The Georgia Slates * * * * * are conformably superjacent to the Red Sandrock. As the formation is traced south the Red Sandrock disappears and the Georgia Slates and Shales, with their interbedded limestone and sandstones represent the entire Cambrian section," p. 277. "The discovery of the Olenellus fauna in the lower portion of this magnesian limestone series gives the fauna a range through 1,000 feet of the Olenellus fauna in the lower portion of this magnesian limestone series and the 250 feet of the superjacent Georgia Shale." l. c. p. 280.

C. L. WHITTLE—1892.

In the *American Journal of Science*, vol. 44, pp. 270-277, Mr. Whittle writes on *"An Ottrelite-bearing Phase of a Metamorphic Conglomerate in the Green Mountains."* This is mainly a petrographic paper and gives a detailed account of the author's study of the mineral named, but it also contains certain geological data which should be noticed here: "The geological position of the limestone and quartzite of the Rutland valley has lately been definitely determined, the limestone paleontologically and the quartzite stratigraphically. Occuring just below the limestone, the quartzite is the northern continuation of the Clarksburg Mountain quartzite in Massachusetts in which has been found the Olenellus fauna characteristic of the Lower Cambrian horizon.

* * * * * Northeast of Rutland the quartzite is found associated with a sandy phyllite schist that belongs to a series of metamorphic clastics having a vitreous quartzite or conglomerate at its base. This whole series, barring the Lower Cambrian quartzite and limestone, has been subjected to the most intense dynamic action. The sequence of the different members of the series is in many regions hopelessly disturbed and confused by the mountain building forces that have produced new structural planes and a new mineral composition and have additionally complicated the geological order of succession by sharp folding, as a rule too much involved for decipherment." l. c. p. 270. "One of the most conspicuous phases of the conglomerate is due to the development of ottrelite in great abundance, so that it is not uncommon to find fully 25% of the rock made up of this material. The ottrelite is most abundantly developed where the rock has now a well-marked schistose character that is due either to an original fine grained deposit or is the result of shearing and crushing action of the dynamic forces. * * * * * * The rock is a very variable one, but considered as a whole, it forms one of the most important stratigraphical horizons found in the more crystalline areas of the Green Mountains. In lateral extension it has been traced, with unimportant breaks, all the way across the Green Mountain anticlinal axis, as mapped by Hitchcock from Mendon to North Sherburne. Its vertical extension has considerable thickness, though accurate determination is very difficult owing to the obliteration of the planes of bedding, in many instances, and the complexity of flexures, but it seems safe to assume a thickness of several hundred feet at least in several localities that have been most carefully studied." l. c. p. 271.

All traces of clastic material in the rock have disappeared; feldspar detritus, if it once occurred, has been converted into a mosaic of quartz, sericite, biotite, and probably albite, and the detrital quartz has been granulated. There is evidence of two periods of dynamic action indicated by a faint wavy extinction in the feldspar, in some instances, and by the bending and breaking of ottrelite prisms.

T. N. DALE—1892.

In *Bulletin G. S. A.*, vol. III, p. 564, we find an article by T. N. Dale on "The Structure and Age of the Stockbridge Limestone in the Vermont Valley." From this paper we quote the following: "Between the Green Mountain range and the Taconic range and on the western side of the Vermont valley lies a ridge which, beginning with Pine Hill, in Rutland, extends southward through the towns of Clarendon and Wallingford and about twenty-four miles to Danby Hill in Danby. Mr. Dale refers to previous studies in this region and also to the areal geology. He then gives five sections through the above ridge, refers to fossils

which indicate the age of different strata, and concludes: "The Rutland-Danby ridge is an anticlinal of gneiss, Cambrian quartzite, conglomerate and schist flanked by Cambrian limestone and Lower Silurian limstone and schist. * * * * Owing to a fault, extending from Pine Hill to Wallingford, about sixteen miles, causing a displacement measured at Clarendon at 1,500 feet, the Cambrian quartzite, conglomerate and schist have been brought up to the level of the Lower Silurian schists which latter they in one place overlie." l. c. p. 518.

In the *American Journal of Science*, vol. 43, 3rd series, 1892, Mr. Dale discusses "Plicated Cleavage and Foliation." In this article Mr. Dale calls attention to the opportunities offered in parts of Vermont for such study. He writes, "The schists and shales of the Taconic range in western Massachusetts and Vermont afford a good field for studying the various phases of cleavage, slaty cleavage, close joint cleavage and slip cleavage." He especially mentions an exposure in a mass of sericite on the west side of the West Rutland valley. Four figures are given which show some of the fractures observed. His conception of the formation of these is as follows:

1. Plication of the beds and consequent cleavage-foliation.
2. Plication of the beds and cleavage-foliation in consequence of secondary pressure operating in the direction of the cleavage dip.
3. Cleavage-foliation and slip cleavage, passing into close-joint cleavage produced by plication of cleavage foliation. l. c. p. 319.

J. F. KEMP AND W. F. MARSTERS—1893.

In *Bulletin 107, U. S. G. S.*, the above authors discuss "The Trap Dikes of the Champlain Region." In this paper there is first a general topographical description of the region. Many Vermont and New York dikes are mentioned and more or less discussed, but the paper does not include half of the dikes to be seen in the Champlain valley, the authors having studied only the more accessible ones. Some of these dikes were studied petrographically, some analyzed. So far as studied, "The dikes are formed by two strongly contrasted kinds of rock, the one feldspathic porphyries or trachites, which are called bostonite in this paper, the other dark basic rocks which, under he microscope, are subdivided as diabases, camptonite, monochiquites and fourchites. Both kinds occur closely associated in the same districts." l. c. p. 17. Each group of dikes is defined.

AUGUST FOERSTE—1893.

In the *American Journal of Science*, vol. 46, p. 435, Mr. Foerste describes certain fossil localities recently discovered. Among these localities is the Rutland valley. Mr. Foerste not only mentions the fossils of the Rutland valley, but makes a very interesting comparison between that region and New Jersey and Pennsylvania, where similar conditions occur.

"Lithologically the Olenellus Cambrian sandstone can be traced into eastern Pennsylvana, its limited thickness and constant character throughout this extent, with the knowledge that the base of the magnesian limestone series in New Jersey, at least, is Cambrian, making it probable that all hitherto called Potsdam in eastern Pennsylvania is to be classed as Olenellus Cambrian until fossils are found which will shed further light on the subject.

With these sections as exhibited in New Jersey, Pennsylvania and eastern Vermont, lower paleozoic rocks show a striking similarity. That the sandstones along the western flanks of the Green Mountain area were Olenellus Cambrian was made sufficiently evident by the work of C. D. Walcott. The Stockbridge limestone of Vermont corresponds to the magnesian limestone of New Jersey. At its top there is again a thin blue or dark blue limestone bed occasionally recurring, as in Pennsylvania, as thin beds, intercalated in the basal portion by overlying shales, and containing a Trenton fauna. As in New Jersey, localities for fossils can be multiplied *ad libitum*." l. c. p. 441.

Mr. Foerste gives definite directions as to some of the localities, *e. g.*, "the most southern being near Danby Four Corners, making then a length of twelve miles southward from Rutland. The chief difference between the lower paleozoic sections in the southern half of Vermont between the Taconic and Green Mountain areas and those of New Jersey and Pennsylvania lies in the fact that in Vermont the typical Olenellus sandstone, besides being thicker, overlies considerable thickness of other sandstone and conglomerates evidently belonging to the same geological unit, but of which, in the absence of fossils, the precise age cannot be definitely determined. In other respects the resemblance is striking, necessitating the belief that both regions have passed through a closely similar geologic history. * * * * * * This simplicity is more apparent owing to the dissimilarity from this simplicity of lithologic structure in regions farther north and west and southwest than in the Rutland valley belts of southern Vermont as here discussed." l. c. p. 443. "The remarkable agreement between southern Vermont and New Jersey, Pennsylvania and more southern sections and the great longitudinal extent of the area having this structure would lead to this conclusion: The sections represent the main lithologic features of the early paleozoic geology—a basal Cambrian sandstone overlain by a great series of limestone embracing a considerable range of faunas and a great mass of Hudson River slates, shales and sandstones overlain by more or less conformable Oneida conglomerate." l. c. p. 444.

C. ~~M.~~ L. WHITTLE—1894.

In an article on "The General Structure of the Main Axis of the Green Mountains," Mr. Whittle discusses the above subject in the *American Journal of Science*, 1894, vol. XLVII, p. 347. In this article Mr. Whittle gives the results of three summers' work, his field extending from Chittenden to Stratton between Windsor and Rutland valley. He says, "Lower Cambrian and quartzite occupy Rutland valley." As he gives in a following paper the areal geology, little need be noticed here. He considers the whole region as Algonkin in age—"The lowest rocks exposed in Shrewsburg and Mount Holly, although of extreme age and gnarled and crinkled into a hopelessly involved structure, still in larger part reveal their sedimentary origin by associated beds of limestone, now altered in part to serpentines or amphiboles and scattered outcrops of quartzite." l. c. p. 350. The upper part of the Algonkian or border series affords evidence of orographic disturbance.

As a working hypothesis, Mr. Whittle gives the following, which is summarized from his account. The rocks are well exposed on the west side of Blue Mountain. "Descending geologically from the base of the Olenellus quartzite, the next rock is a bed of chloritic mica schist very much crumpled. * * * * * * In Vermont the mica schist has a minimum of not more than fifty feet, and in places it is certainly five hundred feet, in thickness and may reach one thousand feet. Below the schist comes in several hundred feet of micaceous quartzite, locally a schistose phase, or, on the other hand, becoming massive and compact. All phases, carry pebbles of orthoclase, monocline and quartz feldspar being most abundant. * * * * * * * Next below is a white crystalline limestone carrying the same varieties of pebbles, some phlogopite secondarily developed and graphite. Two hundred feet may be postulated as its maximum observed thickness in the heart of the range. Another thin bed of micaceous quartzite occurs below this, containing one or more beds of interstratified limestone ten or fifteen feet thick. These lie upon the lowest member of the border series, the metamorphic conglomerate horizon which is separated from the lower rocks by no line of demarcation." l. c. p. 352.

"A measure of the stretching and consequent thinning of the strata on the backs of the folds is frequently found in the effect on the pebbles in the quartzite or upon secondarily developed tourmalines. Pebbles of feldspar having an original diameter of a fourth of an inch are now found drawn out to four inches. Crystals of tourmaline which one may fairly assume were not more than one inch in diameter are now seen as linear films over a foot in length." l. c. p. 354.

"The structure of the main axis of the Green Mountains is thus seen to be a series of sharp, compressed folds striking approximately north and south and overturned to the west in most localities, so that induced schistosity and stratification dip eastward." l. c. p. 355.

In the *Journal of Geology*, vol. II, p. 396, 1894, Mr. Whittle has an important discussion of "The Occurrence of Algonkian Rocks in Vermont and the Evidences for their Subdivision." Mr. Whittle's field included "From the town of Stratton on the south to Rochester on the north"—a distance of fifty miles. Naturally the views presented in the preceding article are prominent in this one, but much is added.

Mr. Whittle divides the Algonkin series into Mendon and Mount Holly, giving his reasons quite fully. "The Lower Cambrian quartzite is underlaid conformably by the Mendon series. This series consists of mica schists from fifty to a thousand feet thick, and micaceous quartzites one hundred to five hundred feet thick. It has scattered through it abundant pebbles of feldspar besides quartz. Owing to their occurrence the horizon is particularly easy to identify. Next, immediately below the quartzite, are fifty feet of pebbly crystalline limestone, the pebbles being largely feldspar like those in the quartzite. This has a greatest thickness of four hundred feet. Some fifty feet of green muscovite schists occur immediatey below what may be considered a laminated phase of the micaceous quartzite which usually appears below the limestone." l. c. p. 412.

Various phases occur in this section. It is in this schist that the ottrelite, discussed in a previous paper, occurs. "One mile north of Chittenden a remarkable phase occurs, the rock as a whole being still a vitreous quartzite, but made up almost entirely of angular and rounded boulder-like areas of the same material. The boulders seem to represent in part an original conglomerate. * * * * * After the rock was cemented into a vitreous quartzite, brecciation took place and today we see a mixture of genuine boulders, some having a diameter of several feet, and pseudo-boulders of larger dimensions, some angular, some having rounded outlines imitating genuine clastics." l. c. p. 412. This quartzite and conglomerate is about three hundred and fifty feet thick at this point, so that the whole Mendon section is thirteen hundred feet.

Below this Mendon section Mr. Whittle finds the Mount Holly series and in it conditions quite unlike those found in the Mendon beds. "A description of the different beds cannot be given as the rocks are too variable in character and dynamic action has involved them in such complication that no definite stratigraphy has been made out. Some of the prominent rocks of the series are biotite schist and muscovite schist, garnetiferous schist, vitreous quartzite, augen-gneiss, and various kinds of limestone. The limestones are irregular lenses and are extremely local. There may be two horizons of limestone or there may be a dozen. The series, because of the undoubted areas of sedimentary rocks, are regarded as clastics. The two series of Algonkian rocks are regarded as unconformable." Evidences of discordance between the Mount Holly and the Mendon series is given in some detail.

T. NELSON DALE—1894.

In the *Annual Report, U. S. G. S.*, vol. 14, part II, p. 525, Mr. Dale has an article on "The Structure of the Ridge Between the Taconic and Green Mountain Ranges in Vermont."

Of the topography of this region Mr. Dale writes, "In the town of Manchester, Vermont, the Taconic and Green Mountain ranges are conspicuously distinct. The former in Mt. Equinox rises steeply on the west more than 3,000 feet above the valley, while two miles east the Green Mountain range presents an equally bold front, though less elevated. Three miles northeast of Equinox, Dorset Mountain crowds in between the two ranges, leaving narrow valleys on either side. The Dorset Mountain mass extends seven or eight miles northeast, terminating in Danby with a bold east and west face, but its northern face, still 500 feet above the Vermont valley, merges in Danby Hill, which is the beginning of a series of hills and saddles ranging from 500 to 1,500 feet above the Vermont valley and extending twenty-one miles farther north to the Rutland-Pittsford line, where it dies out. The entire length of this intermediate range, including the Dorset mass, is thirty-two miles." l. c. p. 531.

In several figures Mr. Dale shows sections taken in this region and goes on to say: "The foregoing sections establish the general anticlinal structure of the range—the intermediate one—it is a complex anticline of Lower Cambrian quartzite and the associated conglomerate, 'cement rock,' sericite schists and gneisses of the Vermont formation overlain by the Cambro-Silurian Stockbridge limestone followed by a variable thickness of the Lower Silurian Berkshire schists representing a total thickness of at least 2,000 feet and on Dorset Mountain probably more than 3,200 feet. The anticline has been faulted in two ways by a double fracture, resulting in letting down a keystone-shaped block of schist and limestone several hundred feet in width into the anticline to a depth of about 1,500 feet. This fault extends from Pittsford line south into the town of Wallingford, a distance of at least twelve miles, but not exceeding eighteen miles, as it does not reach the town of Danby. In this town, at a distance of twenty-two and a half miles, south of the north end of Pine Hill the ridge is crossed by a zigzag east and west reverse fault by which the Cambrian quartzite is brought up to the level of the Silurian schists in a vertical displacement of about 1,450 feet. Thus the northern part of the Dorset Mountain mass was thrust up to nearly its entire altitude above the summit of the ridge north of the fault. That this entire range has been subjected to great strain is also manifest from the numerous dikes which traverse it in Rutland, Clarendon, Wallingford and Danby. It corresponds to a line of both great strain and least resistance. It has also been subjected to such powerful or long erosive influence as to have greatly altered in places its form and its height."

As to the age of the formations in this region, Mr. Dale calls attention to the fact that the base of the Stockbridge limestone has been shown to be of Lower Cambrian and, Mr. Wing showed, as has been seen in former pages, that the upper part of the Stockbridge limestone is Lower Silurian, and also that the Berkshire schists, which overlie this, are Lower Silurian.

As has been noticed, most of the investigations which have been carried on in Vermont geology have been confined to older rocks, as always must be the case. Surface geology, as indicative of the Pleistocene, has been studied by few. The first published paper discussing this phase of Vermont geology is by

S. PRENTISS BALDWIN—1894.

In the *American Geologist,* vol. XIII, pp. 170-184, plate V, Mr. Baldwin has an excellent article on the "Pleistocene History of the Champlain valley." In this article the main surface features, terraces, sands, clays, etc., from Whitehall to Burlington are mentioned as each appears in various towns and the deposits of marine shells described, as are various deltas, such as that of the Winooski and Lamoille. Both sides of the lake are considered and early stages of the Champlain valley discussed, as Champlain River, Glacial Lake Champlain, Champlain Estuary, etc.

T. NELSON DALE—1895.

In the *Thirteenth Annual Report, U. S. G. S.,* part II, pp. 337-339, Mr. Dale discusses, "The Continuance of the Rensselaer Grit in Vermont." Little of this paper is concerned with Vermont rocks, but it does deal with the same sort of rocks and the same plications, cleavage, etc., and, naturally, a study of these adjacent ledges throws light on Vermont problems. One Vermont locality, at West Rutland, is mentioned in detail. As to this Mr. Dale says, "It occurs west of the marble quarries at the foot of the Taconic range in the Berkshire, schist formation being a very pale green sericite schist. The exposures are on the south side of the vertical east to west joint faces. The direction of the stratification is determined by certain beds of calciferous schist or impure limestone, one to four inches thick, which have a horizontal or low westerly dip. Crossing these with westerly dip of thirty degrees is the dominant cleavage foliation of the Taconic region in Vermont and Massachusetts. Here and there are indications of a secondary cleavage foliation dipping about 80 degrees east." l. c. p. 322.

In portions of the ledge, cleavage foliation undulates in gentle folds about one inch in diameter across the calcareous beds. The steps in the process of formation of the rock structure at West Rutland seem to have been: First, plication of the beds; second, resultant cleavage foliation; third, plication of the cleavage foliation by pressure in the direction of the cleavage dip; fourth, resultant cleavage foliation passing into close joint cleavage." l. c. p. 324.

In an Appendix, Mr. Dale especially considers the extension of the Rensselaer grit into Vermont at Bird Mountain and elsewhere. l. c. p. 337.

Mr. Dale also writes of "Structural Details in the Green Mountain Region and Eastern New York" in the Annual Report, U. S. G. S. (vol. 16, part I, pp. 549-570). As most of this paper refers to New York or Massachusetts little notice need be here given to it.

C. R. VAN HISE—1896.

In a large volume, *"Principles of Pre-Cambrian Geology,"* Part I of the *Sixteenth Annual Report, U. S. G. S.,* p. 571, there is a section which discusses the "Green Mountains of Vermont." In this, Dr. Van Hise adopts Whittle's classification of the Green Mountain rocks, as given in the abstract of the paper on a preceding page.

T. N. DALE—1896.

In the *Seventeenth Annual Report, U. S. G. S.,* Mr. Dale has a paper on "The Limestone Quarries of Eastern New York, Western Vermont and Massachusetts and Connecticut." (Part III, pp. 795-811).

In Vermont quarries at Fairhaven, East Dorset, West Rutland, Proctor and Brandon are briefly considered, several analyses of the stone are given, and some other details. In what is called "The Black River Limestone" belt other quarries are considered.

BRAINERD AND SEELY—1896-1897.

Drs. Brainerd and Seely continue in *Bulletin American Museum of Natural History,* vol. VIII, pp. 305-315, accounts of the Chazy of Lake Champlain. Besides several New York localities, there are mentioned in Vermont, Ball's Bay, Isle La Motte, and Providence Island.

R. P. WHITFIELD—1897.

In volume IX of the *Bulletin American Museum of Natural History,* Mr. Whitfield reviews some of his previous papers on the rocks and fossils of Fort Cassin and describes twelve new species.

THEODORE G. WHITE—1899.

In *Bulletin G. S. A.,* vol. X, pp. 452-462, T. G. White has a paper on "The Upper Ordovician Faunas in Lake Champlain Valley." Of course both sides of the lake are studied, but most of the localities named are in Vermont, and a somewhat detailed account of each locality is given.

On page 461 Dr. White notices that "Messrs. Matthews and Ruedeman have traced the Utica as a cold current from Europe invading the warm seas of the Trenton and passing from northeast around the southern slopes of the Adirondacks island. There seems to be evidence that the limestone in the clear seas of the earlier period studied in this paper were from the southwest to the northeast and that the currents gradually changed to a reverse direction over the soft muds which closed the period." Again, "The Black River zones are well marked in character and differ considerably from those of western New York. The Trenton carries a very abundant fauna, the spécies not so strikingly limited to zones as in adjacent regions, but comingling New York and Canadian types." "The Utica presents at least 475 feet of shales carrying a 'stunted' fauna for the most part, but a great variety of linguloid forms. No fossils characteristic of any higher formation are found in the region." l. c. p. 461.

T. N. DALE—1898.

In the *Nineteenth Annual Report, U. S. G. S.,* Part II, pp. 151-307, Mr. Dale has a very thorough investigation of "The Slate Belt of Eastern New York and Western Vermont." The whole article is by far the most helpful that has been published on this region. In several former Reports extensive quotations have been made from the above paper, but for the sake of completeness some parts will be introduced here. It may be added that a very full bibliography of works on slate is given at the close of this paper.

The author first goes over the physiography of the slate region as also its petrography and structural geology. I am sure that to anyone at all interested in the slate belt the following history will be interesting.

"*First.*—A land surface chiefly of granites and gneisses.

"*Second.*—The advance of the sea in the earliest Cambrian time. The nearest land masses then were the Adirondacks and adjacent pre-Cambrian masses on the northwest and portions of the Green Mountain range on the east. The ocean extended northward to the St. Lawrence and westward to the Rockies, forming, however, a land arm between the Adirondacks and the Green Mountains.

"*Third.*—The deposition of the Lower Cambrian sediments from the products of erosion of these land masses. These sediments were mainly sandy and clayey, but sometimes calcareous and then largely of organic origin. The frequent alternation of fine and coarse sediments and of this with calcareous ones and the occurrence of conglomerates indicate changing conditions. There was deep and shallow water, quiet water and rapid currents, occasional exposures of the seabottom to wave action and to submergence owing to oscillations of the earth's crust. These disturbances were sometimes simultaneous, but at different places, or alternate at the same place. Slates and their interbedded quartzites correspond to extremely fine argillaceous sediments from the waste of feldspathic micaceous and quartzite rocks (granites and gneisses), and to coarse sandy ones representing coarser materials, probably from the same sources. The purple slate probably indicates access of limonite from the land and the black slate more organism from the sea floor. During this period there flourished a rich invertebrate fauna sponges, anthozoa, hydrozoa, annelids, brachiopods, lamellibranchs, pteropods, trilobites and phyllocarids. Trilobites, brachiopods and annelids were the groups represented by the largest number judging from fossils. Minor oscillations of land characterize Cambrian time.

"*Fourth.*—Along the Adirondack shore Cambrian sediments continued till Upper Cambrian time, but within the slate belt for some reason there was no deposition during Middle or Upper Cambrian time.

"*Fifth.*—The Lower Cambrian sediments, followed by grits, black, green, red shales and slates of the Ordovician. The same alternation of fine and coarse sediments continues. The Ordovician grits contain not only fragments from the granitic and gneissic masses, but also from the sedimentary beds, limestones, slates and quartzites which must have been somewhere above water. The black Ordovician slates abound in graptolites and owe their carbon to organic matter. The red slates and shales with their high per cent. of ferric oxide and their proximity to the black slates suggest the possibility of decomposing organisms in their formation, and that either on land or in the sea.

"*Sixth.*—Probably at the close of the Ordovician, the accumulated sediments, both Cambrian and Ordovician, gradually emerged in gentle folds closer and overturned toward the west. * * * * * * * * At the east where the movement was more intense, the sediments were finely plicated and slip cleavage ensued. During the strain, percolating alkaline waters took up the silica and deposited it in such openings as were formed by the folding.

Beds of quartz sandstone by the same agency were cemented into quartzite and veined with quartz. Percolating acid waters took up the lime and deposited it in new places. This folding resulted in such elevation of land that the sea retreated from the island arm but it still covered the area west and south of the Adirondacks, where the eastern shore was not far from the Hudson. To this period of folding probably dates the great fault of the Champlain valley.

"*Seventh.*—At some later time, another movement occurred resulting in various secondary structures, diagonal joints, slip cleavage, superinduced on slaty cleavage, quartz veins, minor faults and shear zones (hogbacks). Some of the fractures were so deep as to occasion dikes which traverse both Cambrian and Ordovician sediments.

"*Eighth.*—The Cambro-Ordovician area between the Adirondacks and the Green Mountain highlands was then exposed to a long period, all of the Mesozoic, and nearly all of Cenozoic time. Large areas of the Cambrian became thus denuded of Ordovician sediments. The Ordovician schist mass became deeply dissected. Oscillation in the level also took place during these ages.

"*Ninth.*—Atmospheric erosion was interrupted, however, by the southward extension of the polar ice cap which rounded and furrowed, scratched and polished, the surface of every exposed slate ledge in the region.

"*Tenth.*—The retreat of the glacier left the region covered with boulder and morainal material which was redistributed by the great streams from the thawing ice.

"*Eleventh.*—A later depression of the Champlain valley region amounting to from three to four hundred feet let in the sea from the north. This formed a bay probably extending as far south as Albany and left sea beaches with marine shells above the lake.

"*Twelfth.*—The reelevation of the region brought in the present conditions and closed the history." l. c. pp. 299-300.

FIRST REPORT, VERMONT STATE GEOLOGIST—1899.

The Reports of the earlier Geological Surveys have been already mentioned in writing the History of Vermont Surveys. Only brief summaries of the contents of the Reports issued by the present Survey, which began in 1898, can well be given here; these will be mentioned under the years in which they were issued, being biennial by law. Most can be obtained from the State Librarian at Montpelier. As both time and appropriation in which the First Report had to be issued were very limited, the result had to be small. This Report is a pamphlet of sixty-six pages and is mainly devoted to the three great stone industries of the State—marble, granite and slate—but there is little which is not to be found in later volumes.

T. N. DALE—1900.

In the *Twentieth Annual Report, U. S. G. S.*, Part II, pp. 15-23, Mr. Dale describes a careful study of Bird Mountain, a part of the Taconic range in Vermont near West Rutland. To quote Mr. Dale's own words: "After the areal geology was worked out it appeared that the central crest of Bird Mountain forms but a part of a large area of metamorphosed grit and conglomerate alternating with beds of senicite schist." To be more detailed, Mr. Dale shows by colored maps that the mass of the mountain is composed of Berkshire grit, Bird Mountain grit, Berkshire schist, and Cambrian slate, grit, etc. He discusses these various rocks as to origin, character, etc., and concludes, "Bird Mountain is an open syncline within the Taconic range and consists of about 500 feet of grit and conglomerate interbedded with muscovite schist, and underlain on all sides by schist of a similar character, but frequently containing small beds of quartzite. The presence of pebbles of crystalline limestone, calcareous quartzite and granitic quartz in the conglomerate shows that at no great distance rocks of these kinds were above sea-level at the time of deposition. The presence of a carbonate of iron, magnesia and lime, both in the cement and in the pebbles—like masses that are in the grit, shows that these pebbles may be due to brecciation and solution and that the area of Bird Mountain may have been a basin in which fine ferruginous and calcareous sedimentation took place, and in which also coarser detritus was collected." l. c. p. 23.

"While some of the sediments must have come from pre-Cambrian rocks, others originated in Cambrian beds and the carbonate pebbles may also be of this age."

SECOND REPORT, VERMONT STATE GEOLOGIST—1900.

In 1900 the Second Report on Vermont Geology was issued in pamphlet form. The same limitations as to finance limited this issue to a very narrow scope as they had the first, and not very much could be accomplished during these two years, either in field work or report of such work. This Report was a pamphlet of only 81 pages and 23 plates. Like the First Report, this was mainly given up to economical geology. Both of these Reports have long been out of print and for this reason, largely, most of that which was important has been repeated, in one form or another, in following volumes.

THIRD REPORT, VERMONT STATE GEOLOGIST—1902.

During the previous session of the Legislature the appropriation for geological work had been considerably increased so that much more could be accomplished and we have a volume of 191 pages and 61 plates. In this Third Report may be found sketches of the life of Zadock Thompson and Augustus Wing with their portraits. An article on the Granite Area of the Barre district will be noticed later. Professor C. H. Richardson gives here the first of a series of reports on the geology of eastern Vermont which are still appearing and which must be found of great value to students of the geology of Vermont east of the Green Mountains. In this Third Report also, Professor Richardson has discussed the "Terrane of Orange County," pp. 61-101, Plates 9-23. The Geologist has a preliminary account of the Geology of Grand Isle County, pp. 102-107, which discusses the general geology and the beds of Ordovician strata found. In the same Report the numerous Dikes found cutting the sedimentaries are more or less fully described by Dr. H. W. Shimer.

T. N. DALE—1902.

In *Bulletin 195, U. S. G. S.,* Mr. Dale has an article on "Structural Details in the Green Mountain Region and in Eastern New York." Mr. Dale here give interesting details and instructive illustrations and some of his numerous observations on the folding, crumpling, faulting, etc., in the rocks of Clarenden, Dorset Mountain and adjacent regions.

R. A. DALY—1903.

In *Bulletin 209, U. S. G. S.,* 1903, Professor Daly has given a very thorough and helpful study of the Geology of Mount Ascutney from which quotations may well be given. Of the mountain in general Mr. Daly says, "Mount Ascutney like most of the mountains of New England is a result of erosion, a mountain which overlooks a dissected rolling plateau. The relief as a whole and in details is controlled by rock composition in a specially definite manner. Proofs of differential hardness are evident in the present topography, intrusive bodies contrasting in this respect with each other and with the adjacent sedimentaries. The drainage of the area is that of an ancient mountain system." l. c. p. 13. "The general form of Ascutney was not affected by the Pleistocene glaciation."

Detailed descriptions of the varieties of schists, gabbros, granites, etc., are given, also an excellent geological map of the region. The whole pamphlet is well worth studying by anyone interested in this mountain, but only brief quotations can be given here. In conclusion Dr. Daly says, "The igneous rocks of Ascutney are all irruptives and each irruptive body assumed its present position and full volume only after some process had prepared the corresponding space within the country rock." l. c. p. 91. He then discusses the theories as to the above intrusion and the manner of intrusion.

His final summary is as follows: "The conclusions necessitated, it is believed, by these facts are:

"1st.—That the various chambers now occupied by igneous bodies were not opened by bodily movements in the earth's crust, but by some kind of assimilation of the invaded formation.

"2nd.—That this assimilation did not take place, except in subordinate degree, by caustic solution on the main contacts.

"3rd.—That even in its relatively inactive state near the moment of final consolidation each magma was capable of rifting off numerous large and small blocks from the walls with which it came in contact.

"4th.—That during the much longer period of high fluidity each magma was capable of still more powerful rifting action.

"5th—That throughout the period there must have prevailed a more or less steady rain of rifted blocks down into the lower depths and a corresponding enlargement of the magma chamber, the size of which would depend on the time during which the action continued; independent testimony may be had of the high probability than the time taken in all plutonic intrusion is very great.

"6th.—That in the abyssal region the blocks must undergo active solution by the magma which would have become mixed and gradually more complex.

"7th.—That some compensation for the increased volume of the rock digested must be made. * * * * *

"8th.—That the original magma was at least as basic as the gabbroitic phase of the older stock.

"9th.—That there would be a tendency for the mixed magma to become more and more acid by reason of assimilation of the schistose terranes.

"10th.—That this magma would be expected to differentiate by slow gravitation action through which the lighter, more acid submagmas would float on the heavier basic residue.

"11th.—That such differentiation must be supplemented by other causes, real and universal, though at present ill-understood, leading to a compensating definite splitting of the main magma; thus homogeneous rock bodies would be produced similar to that in other parts of eastern North America and elsewhere.

"12th.—That the Ascutney stocks are the crystallized product of such differentiation from an ever-changing magma constantly enriched by assimilation.

"13.—That the series of petrographic events at Ascutney constitute a cycle that might be repeated as a whole or in parts in the same area.

"14th.—That the later basic dikes may be explained as the beginning of a second petrographic cycle or as the basic poles of a secondary differentiation." l. c. pp. 109, 110.

T. N. DALE—1904.

Mr. Dale in the *American Journal of Science*, 1904, p. 185, in an article on "The North End of the Taconic Range," concludes as follows: "The Lower Cambrian slate formation which is now regarded as the offshore equivalent of the quartzite of the Green Mountain range (Vermont, formation of, U. S. G. S., Monograph XXIII) was folded at the close of the Lower Cambrian time and in places raised above sea-level, forming one or more islands in the Champlain oceanic arm. The direction of this Cambrian folding was generally the same as that of Ordovician time known as the Green Mountain movement, but at this point the axes of these Cambrian folds for some reason had a more easterly course resulting in northeast strikes.

"A very gradual depression beginning during the latter part of the Stockbridge limestone, and continuing into Hudson time, caused the depression of some of the limestone and of all the schist upon these former islands of Cambrian rock. This, as suggested to the writer by Professor C. R. Van Hise, resulted in some places in the overlapping of the limestone by the Hudson schist and slates immediately upon the Cambrian slates. This overlapping accounts for the absence of the Stockbridge Limestone for fifty miles along the west side of the Taconic range. * * * * Then came the Ordovician folding which here, and as far north as West Rutland, produced N. 15-W. 25 secondary cleavage in the Cambrian slates and must have otherwise modified the Cambrian structure as well as the Cambrian surface. * * * * Denudation through long geological periods must account for the presence of only shred-like remnants of the great mass of the Ordovician argillaceous sediments and for the severance of the northern extension of the schist from the Taconic range and generally for the exposure of the Stockbridge Limestone.

"The salient fact is the unconformity between the Lower Cambrian and the Ordovician, which is masked in the slate region of Washington County (N. Y.) either by parallelism in strike of the two foldings or by the effect of the later one upon the earlier, but which is accentuated at the north end of the Taconic range by the original divergence in the strike of the two periods and is still shown in the dips. This unconformity thus confirms stratigraphically the time break shown paleontologically by Dr. Walcott's fossil localities." l. c. pp. 189, 190.

FOURTH REPORT, VERMONT STATE GEOLOGIST—1904.

This volume contains: A Sketch of the Life and Works of C. B. Adams; The Glaciation of the Green Mountain Range; An Account of a Portion of the Serpentine Belt of Lamoille and Orleans Counties; Stromatocerium of Isle La Motte; Investigations in Grand Isle County; The Brown Coal or Lignite of Brandon, with descriptions of many new species of Tertiary fruits; and a Report on the Hydrology of Vermont. As in all the Reports of the Geologist, a report on the Mineral Resources and Quarrying Industry of the State is given.

C. E. PEET—1904.

In the *Journal of Geology*, vol. XII, pp. 415-417, Mr. E. C. Peet published an extended paper on "The Glacial and Post-Glacial History of the Hudson and Champlain Valleys."

Of the east side of this valley, Mr. Peet writes, "North of Rutland County line the more hilly, higher land recedes eastward from the lake shore, and from the descriptions of Baldwin and observations of the writer it seems correct to state that the lower land near the lake is marked by a side clay-mottled plain as far north as the Winooski, where gravel and sand deposits interrupt. It accumulates north of the sand and gravel plains of the Missisquoi River. To the east the clay decreases in quantity or ceases altogether, and on the higher land the drift-covered or bare rock hills are no longer mantled with clay. The higher hills are drift-covered and the rock outcrops frequently. Other lower hills, which sometimes have the form of ridges, have rock cores, are till-covered, and are mantled by the clay so as to subdue the original irregularities of the rock and drift." pp. 457, 458.

Necessarily, much of this article deals with the west side of the Champlain valley or with territory south of Vermont and cannot properly be considered here. Such subjects as the position of the edge of the Pleistocene ice edge in the Hudson-Champlain valley, the Hudson-Champlain water body, and the different stages of Glacial Lake Champlain, are taken up with accompanying maps.

T. N. DALE—1905.

In *Bulletin 272, U. S. G. S.*, Mr. Dale adds to his numerous papers on Vermont Geology a very interesting study of "Taconic Physiography." He especially studies "That part of the Taconic range * * * * extending from a point west of the village of Great Barrington to the northern end of the range, a half mile south of the Rutland-Addison County line, a distance of about 113 miles." It may be said here that for nineteen years Mr. Dale, often with able assistants, had studied the above indicated area. This article is freely used in the article by the Geologist on "The Physiography of Vermont" in the Eleventh Report of this series. In Mr. Dale's article the two ranges, Green Mountain and Taconic, are compared and attention called to differences which cannot be enumerated here.

In conclusion, Mr. Dale says, "The history of the Taconic landscape from a geological point of view is a long one. Its chief events briefly summarized are: The accumulation in a broad area of arenaceous, argillaceous and calcareous material by erosion and by mechanical and organic sedimentation; then the formation in these stratified sediments and their crystalline basement of a series of great parallel folds, diminishing in altitude from east to west, which caused a retreat of the sea. This folding resulted in faults, metamorphism, and secondary structures of several kinds. There were three periods of folding: One at the Lower Cambrian, affecting the central portion of the basin; another at the close of the Ordovician, more far-reaching in its effects; and a third seems to have occurred in post-Silurian time (Devonian or Carboniferous), as shown in the Rensselaer plateau and Bird Mountain. The various materials thus collected, folded, altered and traversed by structural planes became exposed as great longitudinal ridges and valleys to stream erosion and that erosion was retarded as it approached base level or was accelerated by uplifts. The first anticlinal ridge became denuded of all its sediments, although these amounted to several thousand feet, and the ancient sea floor became exposed. The anticlinal ridges west of this were carved into valleys and the synclines remained as ridges, but in some instances the original forms persisted with modifications. Erosion operated laterally completely across these synclinal and anticlinal mountains, and also sculptured them on all sides into forms bearing little resemblance to their structure. Eventually, completely buried under the continental glacier which moved south to southeast, the surface features became still further modified by the shattering of the ledges, the removal of blocks, the gouging and scoring action of boulders and gravel held in the ice. The melting of this vast body of ice gave rise to streams which freshly eroded the surface, scattered moraine material and formed glacial lakes.

The Taconic landscape is thus the result of erosion acting upon rock material of various composition and structure. * * * * * The chief agents of erosion were the mechanical action of streams through the material they transported or rotated, of frost operating in fissured due to structure, of ice operating through boulders and gravel, of roots growing into structural openings and acting as wedges, and chemical action of carbonic acid of the atmosphere, and of organic acids of vegetation upon all calcareous rocks and to some extent upon siliceous ones. Of the three topographic types described * * * * the plateau type may be largely ascribed to the toughness of granular granitic or gneissic material which offered more uniform resistance to erosion; here structure was of minor, and often of no consequence. The ridge and valley type is probably due to the complex structure and the mutual relations of its soluble and schistose rocks and to the varying resistance of both structure and material to erosion. * * * * * * The Hudson-Champlain valley type consists of an undulating surface with several series of low hills which are traceable to the behavior under erosion of soft, but insoluble rocks in small folds with occasional more resistant miniature anticlinal or synclinal folds. Here, however, the general rock surface has been modified by the addition of morainal and terrace material. To such a history and to such causes the Taconic landscape owes its varied and its picturesque features." l. c. pp. 47-49.

FIFTH REPORT, VERMONT STATE GEOLOGIST—1906.

The volume opens with a paper on Mineral Resources which includes a summary of a study by Professor Marsters on the Asbestos region at Belvidere Mountain in Eden. In the following paper Professor C. H. Richardson continues a report on northern Vermont, including Caledonia, Essex, and Orleans Counties. Dr. Richardson gives a section across the State from Wolcott to Lunenburg and the various rock formations are discussed.

Mr. G. E. Edson gives a paper on "Cambrian in Vermont" and one on "The Geology of St. Albans and Vicinity." Professor H. M. Seely discusses the "Cryptozoa of the Early Champlain Sea," in which several new species are described and figured. The extended study of "The Brandon Lignite," begun by the Geologist in the previous Report, is continued with important additions and descriptions of many new species. Professor C. H. Hitchcock has a paper on "The Surface Geology of the Region About Burlington." This volume closes with a detailed study of the "Drinking Waters of Vermont."

E. F. FISHER—1906.

In *Proceedings of the Boston Society of Natural History,* vol. XXXIII, pp. 9-42, Miss Fisher gives us a careful study of "Terraces of West River, Brattleboro." As introductory, Miss Fisher says, "The flights of stepping terraces which border our New England rivers are of singlar interest and add much to the beauty and charm of our river topography. The almost level terrace plains and especially low-lying meadows are agriculturally the most fertile in New England. They represent river deposits and carved remnants of clays, sands and gravels which once occupied in larger volume than today the rock-floored valleys of still earlier origin. They are but transitory waste forms on the way to the sea. The meadows, irrigated each year by the floods, and hence the richest of these terrace plains, are steadily increasing or decreasing in extent as attacked by the river and all the time some of the flood plain is being washed down the valley toward the sea. The river terraces of New England may be accounted for by the behavior of meandering and swinging streams slowly degrading previously aggraded valleys without necessary change in volume and by the control here and there over the lateral swinging of the stream through the discovery of rock ledges."

The early pages discuss, with some fullness, theories of river terrace formation, illustrated by diagrams. Following this general discussion, Miss Fisher takes up the special locality she has studied. "The West River has been swinging and slowly degrading its aggraded valley since the Glacial Period. In following its left hand wanderings there are remnants of seven terrace levels, marking at least as many and probably more left hand swings."

"Having carved the three highest terraces, the river continued to degrade, swerving back and forth across the valley, carving and depositing four terraces at successively lower and lower levels as accidentally determined by rock barriers, short cuts or cut-offs. This West River branch of the Connecticut rises among the hard, crystalline hills of the Green Mountains of southern Vermont and flows southward and eastward across the metamorphic rocks to the Connecticut. A valley, narrowed upstream, was carved pre-glacially in these rocks. During and at the close of the glacial period, the valley became aggraded, with more or less wash drift to the elevation of the highest plains which now rest against the rock boundaries of the valley. The river has since by wandering and degradation carved the present valley topography, wandering at first freely and in unconsolidated material until at lower levels the rock reefs were encountered and served as a defence for the remnants of the higher flood plains. The highest plain in the valley, *viz.,* the golf links area, is not of simple origin. Its surface is rolling, consisting of morainic and kame-like material. The upper layers are of coarse gravel, then sand, and below that clay—a clay outcropping at an elevation of 375 feet. These deposits may have been continuous across the valley at the early stage when the river began its degrading work. The general appearance and character of the deposit would suggest that the high area is one of outwash from the higher ground during the period of aggradation. The area may be considered as delta surface built up in standing water, perhaps the flooded West River. As we descend from this delta plain and its lobate slopes, we pass successively younger and younger terrace patterns. The older and higher show deeply incised valleys, rounded edges and long, wasting slopes of erosion. At the bottom of the series, in contrast, we have sharp terrace edges and steep terrace scarps with few or no evidences of erosion." l. c. pp. 38, 39.

SIXTH REPORT, VERMONT STATE GEOLOGIST—1908.

In this volume we find a most comprehensive report on "The Granite of Vermont," which is mainly a reprint of T. N. Dale's *Bulletin 404, U. S. G. S.,* which is noticed later under Economic papers.

A paper by the Geologist, illustrated by plates, is on "The Cetacea of the United States and Canada," in which all known specimens are mentioned and some are fully described and figured. The Geologist was inspired to write this paper by the presence in the State Museum of a nearly complete specimen of a skeleton of a whale.

Professor C. H. Hitchock discusses "The Geology of the Hanover Quadrangle." As more than half of the Hanover Quadrangle is in Vermont, the place of this paper in a Vermont Report is obvious. On page 139, Mr. H. E. Merwin discusses "Some Late Wisconsin and Post-Wisconsin Shore Lines of Northwestern Vermont." There is a brief report on "The Geology of Franklin County" by the Geologist, followed by "The Geology of the Town of Swanton" by Mr. G. E. Edson. The Geologist contributes "A Preliminary Report on the Geology of Chittenden County," pp. 221-264, which gives by far the most complete account thus far published of the kinds of rock which occur in the county, their distribution, fossils, if any, etc. The work in eastern Vermont carried on for several years by Professor C. H. Richardson here includes "The Geology of Newport, Troy, and Coventry." In this all the various rock formations of the region are taken up and two geological maps show their distribution.

T. N. DALE—1910.

In *American Journal of Science* for October, 1910, Mr. Dale has a short article on the "Cambrian Conglomerate of Ripton, Vermont." The age of the conglomerate pebbles is fixed by contained fossils. A sketch map of the locality is given on page 267. "Its most interesting outcrops are about half a mile E. N. E. of the top of Mount Moosalamou and also near the Chandler house, 1¼ miles N. E. of Ripton village." Mr. Dale concludes, "The generally rounded or discoid form and the unstriated surface of these pebbles from the Cambrian Conglomerate point to their having been formed on a beach, and their magnitude points to their local origin, which is corroborated by the occurrence of identical gneisses, quartz, magnetite, and blue quartz in the underlying or adjacent pre-Cambrian."

SEVENTH REPORT, VERMONT STATE GEOLOGIST—1910.

The first part of this Report contains a full account of the State Collections at Montpelier, with lists of Mammals, Birds, Minerals, etc. As nearly all of these are from Vermont these lists give a good idea of what is to be found in the State.

Mr. T. N. Dale's very complete report on "The Granites of Vermont," originally published in Bulletin, U. S. G. S., is here re-issued in full, and is mentioned again under Economic Geology. The "Surface Geology of the Champlain Basin" is discussed by Professor C. H. Hitchcock, who also take up the "Glacial Lake Memphremagog," and the valleys and deltas of the Missisquoi, Lamoille and Winooski Rivers. Dr. P. E. Raymond discusses "Trilobites of the Chazy in Vermont" and describes several new species, which are shown in plates. The "Geology of the Burlington Quadrangle" is described by the Geologist. A fine article on the "Geology of Addison County" by Professor H. M. Seely follows: This is by far the most full account of the geology of this region that has been published, though the reports of Professor C. E. Gordon, when finished, will be still more complete. Professor C. H. Richardson has an article on "Asbestos in Vermont" and the Geologist concludes the volume with the usual statements as to the condition of "The Mineral Resources" of the State.

C. D. WALCOTT—1910.

In *Cambrian Geology and Paleontology,* Smithsonian Miscellaneous Collections, vol. 53, p. 336, Dr. Walcott discusses the trilobites of the Parker Ledge in Georgia, Vermont, giving not only descriptions, but plates and bibliography.

T. N. DALE—1912.

In the *Americal Journal of Science,* vol. XXXIII, pp. 97-102, February, 1912, Mr. Dale gives an account of "An Ordovician Outlier at Hyde Manor in Sudbury." From careful examination of the locality, Mr. Dale concludes: "The isolated mass of Ordovician limestone on the old golf course of Hyde Manor is surrounded and underlain by schists of Lower Cambrian age upon which it rests unconformably and with which it is interfolded in synclinal attitude, and with which it is interfolded in a part of its northern side in a direction at right angles with the strike. * * * *

A little north of the outlier a well-marked anticline appears in the Ordovician limestone. The little outlier is a specimen, still in situ, small indeed, but preserving the record of one transgression, two coastal movements, and two periods of erosion which affected seven hundred miles of Taconic region." p. 102.

EIGHTH REPORT, VERMONT STATE GEOLOGIST—1912.

In 1912 the Eighth Biennial Report of the Geologist was issued. The volume opens with a somewhat general account of the "Geology of the Green Mountain Region" by the Geologist, written especially for the use of teachers in Vermont schools in which geology has been added to the courses, there being a frequent demand for such an account.

Professor C. H. Hitchcock, in the following article, presents a full account of "The Geology of the Stafford Quadrangle." This includes the towns of Chelsea, Vershire, Tunbridge, Strafford, Sharon, Norwich, and part of Thetford. Five diagrams illustrate sections across the quadrangle. Professor C. H. Richardson reports his field work for the two years in Irasburg, Craftsbury, and Albany, giving an account of the geology of the region.

An investigation into the effects of electricity upon some kinds of slate and marble is furnished by Mr. W. A. Bristol. Messrs. E. A. Barker and A. R. Davidson also furnish a bit of investigation on the "Strength and Weathering Qualities of Vermont Roofing Slates." Professor G. H. Hudson has an article on "Rill Channels and Their Cause." Of these Mr. Hudson says, "On many of the elevated and more exposed portions of Valcour Island and adjacent territory on the mainland one meets with bared knobs or bosses of the Middle Chazy limestone which appear to have been curiously cut by the action of small streams of running water. At first sight it appears as if we had before us the effect of past glacial precipitation on exposed glaciated surfaces, but a careful study of the matter leads us to the conclusion that these rill channels were cut by subglacial waters loaded with sediment and at times moving under extra pressure." In following pages the author presents the evidences for such a conclusion.

As has been already mentioned, Dr. Walcott has from time to time published more or less upon the Cambrian of western Vermont and he is by far the leading authority on this subject.

C. D. WALCOTT—1912.

Number 10 of Dr. Walcott's papers in the Smithsonian Miscellaneous Collections, pp. 305-307, is important in this connection as in it are suggested certain name changes, one of which relates to the Georgia Cambrian. Before this time the Cambrian of western Vermont, Parker Ledge, etc., had by all writers been called "Georgian," but in this paper we find "the term Georgian as used by me in 1891 (*Bull. U. S. G. S. No. 81*) is in bad form and should be replaced by a geographic name that has not been used for any geologic formation or group of formations. In view of the fine section east of Waucoba Springs on the east side of Saline valley and the great development of Lower Cambrian strata to the north and east in Nevada, the term Waucobian is selected to replace Georgian as a group name for the formations included in the Lower Cambrian."

T. N. DALE—1913.

In the *American Journal of Science* for October, 1913, Mr. Dale gives additional data as to the Sudbury Ordovician outlier. He regards these further investigations as confirming those previously published.

NINTH REPORT, VERMONT STATE GEOLOGIST—1914.

This volume is mainly devoted to as full an account of the Vermont Marble industry as the Geologist was able to compile and it is believed that as complete an account can be found nowhere else. All the various phases, occurrence, methods of manufacture, varieties, etc., are discussed and many plates illustrate the text.

Besides much other material, Mr. Dale's two Bulletins of Marble are reprinted. Professor C. H. Richardson continues his work on the geology of eastern Vermont, carrying his studies into Greensboro, Hardwick, and Woodbury, and presenting much information as to the geology and mineralogy of those towns. Professor C. E. Gordon gives a reconnaissance study of Bennington and the region immediately about the town. Some account of the work in Vermont carried on by the U. S. Topographical Survey is given and a full list of maps completed to date. Professor E. C. Jacobs begins in this volume a series of studies on the "Talc Deposits of the State," which are continued in following Reports.

EDWARD WIGGLESWORTH—1915.

In the *Proceedings of the Boston Society,* vol. 35, pp. 95-107, Mr. Edward Wigglesworth publishes the results of a season's study of "The Serpentines of Vermont." "In the summer of 1912 an attempt was made by the writer to visit all the occurrences of this rock (serpentine) so far as reported in the State, and to collect material for a petrographic examination at a later date." The author notices "The occurrences in Vermont form part of the fairly continuous belt of serpentine which exists in the eastern part of the United States and Canada. This band extends with many interruptions from Alabama, parallel with the Appalachian structure as far as Gaspé Peninsula and even into Newfoundland." Each of twenty Vermont localities is briefly noticed. The petrography is then studied, analyses and a discussion of the origin of the rock follow. This article, slightly revised, is published in the Tenth Vermont Report.

TENTH REPORT, VERMONT STATE GEOLOGIST—1916.

The Tenth Report of the Vermont Geologist was issued in 1916. The volume opens with an important paper by Professor H. L. Fairchild on "Post-Glacial Marine Waters in Vermont."

Professor Fairchild has for a number of years studied this subject in New York State and various parts of New England, and in this paper he extends his work into Vermont, thereby adding much to our knowledge of the surface geology of this State.

Professor J. W. Goldthwait in the next article gives "Evidences For and Against the Former Occurrence of Local Glaciers in Vermon." After a résumé of former studies in this field, the author considers the areas in Vermont in which supposed proof of former small glaciers is found, beginning at Plymouth and going to Mount Mansfield. After studying the region carefully he concludes that it "is very unlikely that local glaciers ever existed in Vermont."

Mr. D. P. Jones, who worked with Dr. Richardson, writes of the "Physiography of Greensboro, Hardwick and Woodbury." Mr. H. L. Smith of the Vermont Marble Company describes a new Lime Plant established at West Rutland by that company, by which the abundant waste from the mills is utilized. Professor C. H. Richardson continues his studies of the geology of eastern Vermont to include the towns of Calais, East Montplier and Berlin. A very important result of Dr. Richardson's work is the discovery of Ordovician Graptolites in some of the shales of these towns. "Graptolite beds have now been found by the author in either calcareous or non-calcareous sediments and in some towns in both—in Newport, Coventry, Calais, Montpelier, Berlin, Brownington, Irasburg, Albany, Craftsbury, Greensboro, Hardwick, Woodbury, Northfield and Barre." Finding these fossils determines, as had never been done before, the age of the containing rocks. These are located as Lower Trenton.

For convenience of reference the Geologist gives a "List of Altitudes in Vermont" so far as these have been definitely ascertained by the U. S. Topographical Survey. A "History and Discussion of Copper Mining in Vermont" is given by Professor E. C. Jacobs. In this paper all important localities that have ever been worked are considered. Some notes on the "Geology of Western Vermont" are given by the Geologist. A general account of the geology of this region mainly forms this paper. The "Talc and Verde Antique Deposits of Vermont" are taken up by Professor Jacobs.

An Index of the ten Reports issued is given at the close of the Tenth Report.

T. N. DALE—1916.

In the *American Journal of Science*, vol. 42, pp. 120-124, Mr. Dale has a paper on the "Algonkian-Cambrian Boundary," east of the Green Mountain axis. After reference to literature of this region, Mr. Dale gives a general account of its geology. The Boundary in question begins "on the south near the town of Heartwellville, Readsboro township in Bennington County and ends on the north near the southern line of the town of Stockbridge in Windsor County * * * * the whole latitudinal distance being a little more than sixty miles, of which, however, two stretches were not studied, reducing the distance to 46.7 miles." As to this, Mr. Dale concludes, "The original strike of the pre-Cambrian granite, gneiss and associated Algonkian sediment areas in the southern Green Mountain range in Vermont is probably W. N. W. and was due to the direction of the post-Algonkian movement, but in many places the pre-Cambrian rocks yielded to the greater crustal contraction and acquired a general N. N. E. strike."

ELEVENTH REPORT, VERMONT STATE GEOLOGIST—1918.

The above Report opens with a general article on the Physiography of Vermont as a whole. In the second article, Professor Richardson reports the results of his work on the "Ordovician Terranes of Eastern Vermont." Professor H. L. Fairchid continues his studies on "Sea Water Levels in Eastern Vermont," the first of which is given in the preceding Report. A somewhat detailed account is here given of some towns of eastern Vermont from Vernon to Barnet and further north along the Connecticut valley to Upper Waterford and also the Passumpsic valley.

Dr. W. G. Foye reports his work in the Rochester Quadrangle, pp. 76-98. Many interesting rocks and their location are described in this paper.

Professor E. C. Jacobs has a detailed article continuing that in the Report preceding, on "Talc in Vermont," and also a short article on "The Lime Industry." The Geologist gives a short addition to his previous "List of Vermont Altitudes."

A careful study of the very complex rocks of Cuttingsville is furnished by Mr. W. W. Eggleston. This very technical paper was first published in the *American Journal,* but is extended and revised here.

Professor C. N. Dale gives a "Preliminary Report on the Rocks of the Western Flank of the Green Mountain Range." The completed paper follows in the Twelfth Report. Mr. C. H. Pierce, U. S. Engineer, gives a full report on "The Progress of Stream Gauging in Vermont" during the last two years.

TWELFTH REPORT, VERMONT STATE GEOLOGIST—1921.

The first paper by Dr. J. W. Merritt is a very technical and thorough study of the "Structural and Metamorphic Geology of the Hanover District." It should be noticed that this District includes several Vermont towns. Indeed, more than half the area studied lies on the Vermont side of the Connecticut River. Dr. Merritt finally concludes "The rocks of the Hanover District consist of schists, intruded mainly by granite in the form of a laccolith. The probable sequence of events from the time of deposition of sedimentary rocks to the present as far as can be read in the geology now seen is—the deposition of the sedimentary rocks, probably during Paleozoic time, and dynamic metamorphism during a mountain-building epoch, during the latter part of which or closely following which, came the intrusion of the Lebanon granite. This was attended by some metamorphism of the overlying schists. Subsequent to this group of events, erosion has removed the cap of the deeply buried laccolithic, exposing the upper part of the granite."

A brief account of the Geology of Essex County is given by Mr. R. A. Schroeder, especially that region near the Averill Lakes. The report on the "Areal and Structural Geology of a Portion of the Western Flank of the Green Mountains," mentioned in the former Report, by Professor C. N. Dale, is here given in full. In this paper the rocks of Bristol, Starksboro, Hinesburg, Huntington, New Haven, Lincoln, Middlebury, and Ripton are described in some detail. Professor Dale concludes, "The rocks of this region are largely of sedimentary origin, now thoroughly metamorphosed, a product of the orogenesis at the close of the Ordovician and Permian Periods, and belong to the Cambrian and pre-Cambrian Periods." In the following article we have the Report of Dr. Richardson's work in Braintree which adds much to our knowledge of the geology and mineralogy of that area.

The Geologist gives a "Detailed Study of the Trenton Beds of Grand Isle," and Dr. Ruedemann a "Report on the Fossils of the so-called Trenton and Utica Beds of Grand Isle." The study of these articles will be necessary to anyone who wishes to investigate the region concerned. Professor Jacobs continues his study of the "Talc of Vermont."

A long and important article is by Professor C. E. Gordon on the "Geology of Western Vermont," which gives by far the most complete account of the character, position, etc., of the various terranes.

Professor Jacobs gives a full account of the "Geology of Willoughby Lake." All of the above papers are well illustrated.

The usual Report by the Geologist on the "Mineral Resources of Vermont" concludes the volume.

T. H. CLARK—1921.

In the *Proceedings of the Boston Society of Natural History,* vol. 36, pp. 135-163, Mr. T. H. Clark has a "Review of the Evidences for a Taconic Revolution." Most of this paper, naturally, deals with territory outside of Vermont, but in that part which discusses the Taconics and the Green Mountains, Mr. Clark writes as follows: "That the bulk of the rocks of the Taconics and of the Green Mountains is of Cambrian age no one now seriously doubts. That these ranges contain rocks of later date no one has been able to prove. * * * * * On the face of it the only conclusion which is strictly dependent on facts is that the mountains were folded after the deposition of the youngest contained sediments of the Trenton-Utica. Nowhere are these Ordovician rocks overlain, conformably or unconformably, by Silurian sediments. * * * I have stated above that all we can say about the age of the deformation of this region is that it must be post-Upper Ordovician. We may, however, modify this somewhat. Such modification as that of the rocks of the Taconics and Green Mountains have suffered is not generally thought of as having been induced near the surface. Such metamorphism is a factor, among other things, of the depth to which rocks are buried and, in the opinion of the writer, the metamorphism which the rocks of the Taconic and Green Mountains could only have occurred under a cover of rock measured by thousands of feet. What this cover was we may never know, but that it was not Ordovician is probable for the Upper Ordovician is but scantily represented in eastern New York State."

ARTHUR KEITH—1923.

In the *American Journal of Science* for February, 1923, appears a most important article on "Cambrian Succession in Northwestern Vermont" by Mr. Arthur Keith of the U. S. Geological Survey. As it is hoped that the entire article may be reprinted in the next Report, no more than brief mention will be given at this time. Probably this is of greater geological value than anything heretofore published on the region discussed, and gives a more accurate account and more complete explanation of the wonderfully tangled and difficult area found in western Vermont.

PART III.—ECONOMIC GEOLOGY.

In the course of the foregoing pages much has necessarily been written as to the development of the mines and quarries of Vermont so that it is not necessary to devote very much space in this section to this branch of the subject. Nevertheless, a few references to articles treating solely of matters belonging to Economic Geology should not be omitted.

As has more than once been stated in various Reports, nothing is now done at any of the mines formerly worked for copper ore. None of these has in the long run proved profitable and, therefore, all are abandoned. Articles giving the main facts as to Copper Mining in Vermont will be found in several of the Geological Reports.

Much the same may be said of attempts to mine asbestos profitably, though this has not yet been given up. Professor Jacobs' articles on "The Talc Industry" in the last four Reports, to which reference is given on previous pages, should be noticed here.

Publications treating only of the Economic Geology of Vermont are few, as the following list indicates.

H. M. SEELY—1885.

In a pamphlet published by the Middlebury Historical Society in 1885, Professor Henry M. Seely furnishes an excellent paper on "The Marble Border of Western Vermont." This paper gives interesting details as to past and present methods of preparing marble for market and the distribution of ledges, etc.

T. NELSON DALE—1898.

Probably no one has done so much to make known the economic resources of this State as has Mr. Dale, working under the auspices of the United States Geological Survey.

Mr. Dale's elaborate paper on "The Slate Belt of Eastern Vermont and Western New York," published in the *Nineteenth Annual Report of the United States Geological Survey,* part III, pp. 153-307, has been fully considered on a former page.

G. I. FINLAY—1902.

A report on *The Granite Areas of Barre* by Mr. Finlay is mentioned in the list of articles in the Third Report of the Geologist.

T. N. DALE—1906.

In *Bulletin No. 275, United States Geological Survey,* Mr. Dale has published a later account of Vermont slate areas.

T. N. DALE—1909.

In *Bulletin No. 404, United States Geological Survey,* 1909, Mr. Dale gives a very full and detailed account of all known Granite Areas in Vermont This bulletin is republished in the Seventh Report of the Geologist.

T. N. DALE—1912.

In *Bulletin 521, United States Geological Survey,* 1912, Mr. Dale has given a detailed account of the Marbles of western Vermont, and in Bulletin 589 of the same Survey, 1913, Mr.

Dale discusses the *Marbles of Eastern Vermont*. Both of these valuable papers are reprinted, with additions, in the Ninth Report of the Geologist, 1913-1914.

OLIVER BROOKS—1922.

In *Bulletin No. 218, United States Bureau of Mines*, 1922, Mr. Brooks publishes a very interesting discussion on *The Technology of Slate.*

PRELIMINARY REPORT ON THE ORDOVICIAN FORMATIONS OF VERMONT.

EDWARD J. FOYLES

TABLE OF CONTENTS.

INTRODUCTION.

The present preliminary report is the result of a study of the Fort Cassin rocks and fossils in the American Museum of Natural History undertaken in connection with an examination of the Ordovician formations of Vermont during the summers of 1921 and 1922.

The three principal localities where these exposures were studied in the field are Shoreham, Fort Cassin and Providence Island (figure 1).

The purpose of the present paper is to suggest the limits of the Beekmantown formation of the Lower Ordovician as it occurs in the Champlain valley of Vermont; to show that the Fort Cassin rocks constitute, not a single formation known as the Beekmantown [1, p. 20],[1] but a terrane consisting of two formations, neither of which is Beekmantown; and to demonstrate that the Providence Island rocks, which have mostly been assigned to the Beekmantown [1, p. 17], have very few if any beds of Beekmantown age, but belong to higher horizons.

For assistance in the preparation of this paper I desire to express my thanks to Doctors W. D. Matthews, E. O. Hovey and C. A. Reeds of the American Museum of Natural History; Professor G. H. Perkins, State Geologist of Vermont; and Professor J. J. Galloway of Columbia University.

[1] The numbers within brackets refer to the bibliography attached to this paper.

REVIEW OF PREVIOUS WORK.

In 1845-1847 Professor C. B. Adams, in his pioneer work in northwestern Vermont [2], stated that the Beekmantown, which he called the Eolian limestone, was about three hundred feet thick. The Reverend Augusta Wing, however, was the first man

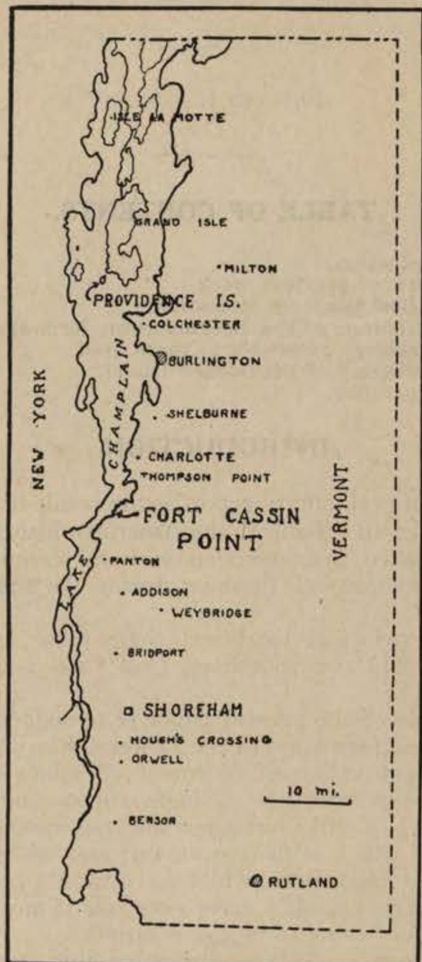


FIGURE 1. Map of part of Vermont showing localities listed in this paper.

to describe fossils from the formation. Later the Beekmantown formation was known by the name Calciferous Sandrock; still later it was called simply the Calciferous formation.

In 1861 Professor C. H. Hitchcock [9, p. 266] described the Calciferous formation as a compact and thick-bedded sandy lime-

PLATE I

Outcrop of the Little Falls formation at Shoreham Center, Vt., showing its appearance in surface exposures.

stone. During his survey of the State he collected from these rocks seven species of fossil invertebrates.

In 1890 Professors E. Brainerd and H. M. Seely [1, pp. 1-3] published a careful study of the Beekmantown formation and fossils of the Champlain valley. Partly on the basis of lithology and partly by fossils they separated the Beekmantown, into five divisions and eleven zones, their type section being in the town of Shoreham.

Shortly before 1886 Professors H. M. Seely and George H. Perkins collected at Fort Cassin a remarkable series of fossils. Many of these specimens were sent to Professor Robert P. Whitfield, Curator of the Geological Department in the American Museum of Natural History, who described them [8, pp. 300-345]. He was inclined to believed that they were mostly Black River in age with some Chazy forms [3, p. 25]. Whitfield's study of this collection greatly advanced the knowledge of paleontology in Vermont.

In 1906 Mr. Rudolph Ruedemann [4, pp. 393-611] described the cephalopods of Fort Cassin.

In 1919 Professor C. E. Gordon [5, pp. 114-279], in his studies in the geology of western Vermont, described many outcrops of Beekmantown rock in the Champlain valley.

THE BEEKMANTOWN FORMATION OF VERMONT.

According to Brainerd and Seely [1, pp. 1-3] the Beekmantown formation of Vermont is composed of Divisions A to E, having a total thickness of eighteen hundred feet (table I). Division A is composed of magnesian limestones which have yielded no fossils. Division B, a limestone and dolomite facies, contains *Cryptozoon* as its most characteristic fossil. In lithologic character these two divisions are different from the overlying stratum. The fossils of Division B suddenly disappear at the end of Division B, yet the overlying facies is favorable for any of the forms which occur in Division B.

In his Revision of the Palaeozoic Systems, 1911, Doctor E. O. Ulrich [6, pp. 650-651] assigns the Divisions A and B of Brainerd and Seely's Beekmantown to the Little Falls formation, as follows: "Probably nine-tenths of the fossils regarded as characteristic of the Beekmantown come from Division D. A few of these occur in the underlying C, but none found in C, D or E crosses the line into Divisions A and B. The faunal break between B and C, therefore, is complete. The unconformable stratigraphic relations between the two divisions, as observed in the vicinity of Ticonderoga, emphasizes the importance of the break. The unconformity is rendered more apparent by overlap extinction of a fine-grained limestone which is sometimes included by Brainerd and Seely in Division B. This basal member of the

Table I.

The Beekmantown formation at Shoreham, Vt.

Brainerd and Seely, 1890. Stage	Thickness.	Characteristics of rock.	Fossils	Foyles, 1923. Formation.	Fossils
E	470'	Fine-grained magnesian limestone in beds one or two feet in thickness, weathering drab, yellowish or brown. Occasionally pure limestone layers occur which are fossiliferous, and rarely thin layers of slate.	Bucania tripla Whitfield. Murchisonia confusa Whitfield. Bathyurus extans Hall. Primitia seelyi Whitfield.	Chazy	Ecculiomphalus lituiformis (Whitfield)
D-4	100'	Blue limestone in thin beds separated from each other by very thin, tough, slaty layers which protrude on the weathered edges in undulating lines. The limestone often appears to be a conglomerate, the small enclosed pebbles being somewhat angular and arenaceous.	Fort Cassin fauna. Wingia congregata Seely. Wingia discoidea Seely. Wingia lapilla Seely.	Chazy	Wingia congragata Seely. Wingia discoidea Seely. Wingia lapilla Seely.
D-3	120'	Sandy limestone in thin beds, weathering on the edges in horizontal ridges one or two inches apart, giving to the escarpments a peculiar banded appearance. A few thin beds of pure limestone are interstratified with the siliceous limestone.	Asaphus canalis Conrad. Lituites eatoni Whitfield. Maclurea affinis Vanuxem. Ophileta complanata Vanuxem. (D-3 to D-1)	Chazy	— Saint Peter break —
D-2	75'	Drab and brown magnesian limestone containing toward the middle several beds of tough sandstone.		Beekmantown: D-2	
D-1	80'	Blue limestone in beds one or two feet thick, breaking with a flinty fracture; often with considerable dolomitic matter intermixed, giving the weathered surface a rough, curdled appearance; becoming more and more interstratified with calciferous sandstone in thin layers, frequently weathering to a friable, ochreous rotten-stone.		D-1	Ophileta complanata Vanuxem. Leperditia nana (Jones).
C-4	120'	Magnesian limestone frequently containing patches of black chert.		C-4	
C-3	70'	Sandstones, sometimes pure and firm, but usually calciferous or dolomitic.		C-3	
C-2	100'	Magnesian limestone in thick beds, weathering drab.		C-2	
C-1	60'	Gray, thin-bedded, fine-grained calciferous sandstone, on the edges often weathering in fine lines, forty or fifty to the inch, and resembling close-grained wood. Weathered fragments are frequently riddled with small holes called Scolithus minutus.	Scolithus minutus Brainerd and Seely.	C-1	
B	295'	Dove-colored limestone intermingled with light gray dolomite, in massive beds; sometimes for a thickness of twelve or fifteen feet no planes of stratification are discernible. In the lower beds and in those just above the middle the dolomite predominates; the middle and upper beds are nearly pure limestone; other beds show on their weathered surfaces raised reticulating lines of gray dolomite.	Orthoceras primigenium Vanuxem. Cryptozoon steeli Seely. Cryptozoon wingi Seely. Holopea Hall.	Tribes Hill.	
A	310'	Dark, iron gray, magnesian limestone, usually in beds one or two feet in thickness, more or less siliceous, in some beds even approaching a sandstone. Nodules of white quartz are frequently seen in the upper layers and near the top irregular masses of impure black chert, which, when the calcareous matter is dissolved out by long exposure, often appears fibrous or scoriaceous.		Little Falls.	

Canadian seems to be entirely absent in the Fort Ticonderoga section.

"The boundary between divisions B and C being of great importance, and as the two lower beds do not show in the typical section of the Beekmantown, it seems unwise, not to say unwarrantable, to include them with the typical members of the formation. Viewed solely from the standpoint of the lithologist, the desirability of distinguishing the divisions A and B (Brainerd and Seely) from the overlying beds is scarcely less manifest than it is to the palaeontologist and stratigrapher. As A and B are strictly equivalent to the Little Falls dolomite of the Mohawk valley, this discrimination may be said to have been carried out already. Finally, as long as we endeavor to draw formational and group boundaries in accordance with the important stages in geological history, the Ozarkian divisions A and B should be grouped with the underlying Theresa and Potsdam. Indeed, the boundary between B and C is thought to be of such high significance that if it were decided to continue the present division of the pre-Silurian part of the Palaeozoic into but two systems instead of the four here advocated the separation of the two should be at this line."

I did not see evidence of the break in sedimentation, and whether or not the disconformity suggested by Ulrich proves to be present, the main purpose of my discussion is to correlate the Vermont Beekmantown with established horizons in New York State. Division A is equivalent to the Little Falls (figure 2), and Division B to the Tribes Hill formation of the Mohawk valley.

The first stage of Brainerd and Seely's Division C consists of a calciferous sandstone (table I). Weathered fragments contain small holes which Wing considered to be the molds of the burrows of an annelid. Other than this doubtful occurrence no fossils have been taken from these beds.

Division C, stage 2 of Brainerd and Seely is one hundred feet in thickness. It is composed of thick beds of magnesian limestone which weathers to a drab color. No fossils have been found in it.

Division C, stage 3 of Brainerd and Seely comprises seventy feet of sandstone which are sometimes pure and firm, but which are usually calciferous or dolomitic. These beds have yielded no fossils.

Division C, stage 4 of Brainerd and Seely has a thickness of one hundred and twenty feet. It consists of thick beds of unfossiliferous magnesian limestone which weathers to a drab color. It frequently contains patches of black chert.

Division D, stage 1 of Brainerd and Seely is eighty feet thick. It contains blue limestone one or two feet in thickness which breaks with a flinty fracture. Dolomite is often mixed in it, giving the weathered surface a rough appearance. Going upward it becomes more and more interstratified with thin layers of calciferous sandstone. This division has yielded the fossils which are listed in table I, Division D-1.

Division D, stage 2, of Brainerd and Seely is composed of seventy-five feet of drab and brown magnesian limestone which contains toward the middle several beds of sandstone. No fossils have been taken from these strata.

It is thought that here occurs the Saint Peter break, which is described in the standard text-books of geology. At this time the seas withdrew from this area, leaving the land exposed. There is a striking absence of fossils through three hundred feet of strata. On the basis of structural relationships and lithological characters the overlying bed is correlated with the lowest Chazy stratum at Fort Cassin. This bed weathers in thin bands one to two inches apart at Shoreham, Fort Cassin and Providence Island.

The intraformational conglomerate of Brainerd and Seely's Division D, stage 4 of the Beekmantown is filled with a so-called fossil alga to which the generic name of *Wingia* Seely has been given. Thin sections of this form have revealed no organic structure. The specimens which I studied were collected near the white schoolhouse at Shoreham Center, Vermont. This peculiar structure is also found at Fort Cassin, Vermont, where it occurs in one of the lowest beds, being just below the one which has yielded *Eccyliomphalus lituiformis* (Whitfield), which is a Chazy fossil. This indicates to some extent that Division E of Brainerd and Seely's Beekmantown formation is Chazy in age, a fact which is further supported by the presence in this bed of *Bathyurus extans* Hall, a trilobite which is not known below the Chazy.

To summarize my determinations, the Beekmantown formation of Vermont includes divisions A, B, C and D-1 to D-2 of Brainerd and Seely, some 1,110 feet, embracing the Little Falls, Tribes Hill and beds C-1 to D-2, as noted in table I. The upper 690 feet of Brainerd and Seely's section is referred to the Chazy formation.

DISTRIBUTION OF THE BEEKMANTOWN FORMATION IN THE CHAMPLAIN VALLEY.

In illustration of the present conception of the stratigraphic limits of the Beekmantown the following pages contain a description of the geology and palaeontology of an area lying between the southern border of the town of Shoreham and the land mapped by Brainerd and Seely in the vicinity of the village of Shoreham, and also short accounts of several other localities in the Champlain valley where Beekmantown strata occur or are supposed to occur.

The strata of the area in Shoreham (Plate I) dip east and west on a fold at angles varying from thirty degrees at the top of the anticline to eighty degrees at the edges. The strike of the strata is generally N. 18° W. The conditions and positions of the beds indicate great pressure from the east forcing the strata against the Adirondack pre-Cambrian rocks on the west. In this great westward movement of the strata, one large section consisting of Beekmantown and Chazy strata was dislocated and dragged behind. This block, which is bounded on either side by transverse normal faults, may now be seen in the hill one-half mile south of Shoreham Center.

Along the northern border of the area, deformed sections of strata and a valley indicate a great normal fault separating the area mapped by Brainerd and Seely from the region to the south. On the northern side of the road between Shoreham Center and Shoreham village this rift has exposed a vertical section of strata showing the contact between the Potsdam quartzite and the overlying beds.

The area in Shoreham does not possess many favorable outcrops for a successful study of its geology. The valleys and the slopes of the hills are covered with glacial drift, except in a few places where one may observe scattered outcrops. The tops of the hills present many comparatively good exposures in the form of ledges or low cliffs.

Owing to the fracturing and metamorphosis of the strata the state of preservation of the fossils is poor. A comparatively long list of fossil invertebrates has in past publications been assigned to the Beekmantown formation of Vermont, but the assignment to the Beekmantown of most of these forms, especially those from Fort Cassin, is questionable. The true Beekmantown of Vermont carries but few species which are mostly confined to Division D-1.

Among the fossil invertebrates which I found in Shoreham are two which have not been discovered in the region heretofore. One of them is a *Billingsella,* which is apparently a new form, but the material collected is too poor for description. The other species is *Leperditia nana* (Jones). These specimens are from Division D-1 of the Beekmantown formation.

In Benson, extending eastward from Benson Landing and Stony Point to Benson village outcrops giving a fair sequence of the Ordovician strata are exposed at various localities. The beds form a low arch which near the shore of Lake Champlain dips at a low angle to the east. At Stony Point, which is one mile north of Benson Landing, a cliff is formed in a low anticline of Little Falls siliceous limestone. One hundred yards south of the boathouse the Little Falls formation outcrops in layers one-half to two feet in thickness, forming cliffs ten to fifty feet high along the water's edge. At Cole's camp on the lake shore the Tribes Hill formation is exposed in a cliff of horizontal strata of dove and light-gray dolomite. About three hundred yards south of the boathouse at Stony Point a brook debouches into the lake where the Little Falls formation outcrops. Higher up the brook beds of Beekmantown C-1 are exposed in ledges which dip N. 65° E. at an angle of 12°. Chazy ledges with numerous fossils may be seen three-fourths of a mile east on the road from Stony Point. The following sequence of strata has been determined, extending eastward from the shore of Lake Champlain:

1.—At the water's edge a coarse, siliceous dolomite dipping 15° northeast .... Little Falls.
2.—Sandstone yielding many trilobite fragments.
3.—Siliceous limestone with ridges on the weathered edges .... Beekmantown C-1.
4.—Intraformational conglomerate .... Chazy.
5.—Limestone with fossils on the weathered surface. Dip 10° east .... Chazy.
6.—Drab or buff dolomite .... Chazy.
7.—Extensive outcrops of slate east of Benson Village.. Trenton.

In Orwell, one hundred and fifty rods south of the southern promontory south of Chipman's Point, outcrops of Trenton slate and Little Falls dolomite with an easterly dip occur in the bed of a brook. In the field northeast of this brook are dark, magnesian limestones of the Little Falls formation. These are succeeded eastward by gray magnesian limestones which are probably Beekmantown in age.

In the bed and banks of the North Branch near Hough's Crossing, higher beds of the Beekmantown are exposed. The blue limestone of Division D-1 yielding *Ophileta, Maclurites* and other fossils appears on the axis of the anticline. It is succeeded on each limb by the other members of this division. In the stream channels near Hough's Crossing divisions C-4, D-1 and D-2 are followed by the Chazy. The Beekmantown rocks forming the anticline south of Hough's Crossing are traceable eastward by scattered outcrops across their strike to the old stage road to Shoreham village.

In Bridport tilted Beekmantown rocks are found very near the northeast border. In the southern portion of the town, particularly near the head of West Branch and again on the road connecting Bridport village and Shoreham there are strata yielding *Isochilina*. These rocks have not been studied in detail, but they are provisionally assigned to the Chazy or Black River.

Immediately east of the Lemon Fair Creek in Weybridge there is a mass of so-called Beekmantown strata which occupies one-half the area of the town. Otter Creek in its irregular course has found its bed largely in these rocks, which are considered in this paper older than Beekmantown.

Along and near the east road to Addison there are good exposures of the blue limestone of Beekmantown D-1, carrying *Maclurites, Ophileta* and other fossils.

No true Beekmantown strata have been observed in Panton.

In the eastern part of Burlington there are many outcrops of sandy limestone of doubtful age, but they are held to be older than Beekmantown.

In Charlotte the Beekmantown formation may be seen at Thompson's Point, where it forms a monocline, dipping southeast from 12° to 20° and extending from the north shore of Thompson's Point two and one-half miles across the strike to the line of the Rutland railroad. The lowest strata visible are thirty or forty feet of iron gray magnesian limestone containing chert in beds one or two feet thick. This formation is followed by light gray, massive dolomites. Together they constitute the Little Falls and Tribes Hill formations. The sandstones of Division C-1 of the Beekmantown; which are concealed by the deep bay at the end of Thompson's Point, outcrop at the head of the bay. Magnesian limestones of Division C-2 occupy the remainder of the point. The small bay at the south end indicates the position of the sandstone beds of Division C-3. The beds of Division C-4 are evidenced by large masses of black chert on the shore and on the ledges just south of the road. North of the road the ledges of Division C-4 continue to the head of the bay east of Cedar Island. The strata of divisions D-1 and D-2 are concealed by one hundred and fifty feet of soil. Following a gap the banded sandstones and blue limestones of the Chazy and Trenton extend for a mile northeast of the schoolhouse in ledges two hundred feet thick.

In the eastern part of the town of Colchester there is a large amount of sandy limestone which has yielded *Cryptozoon*. This rock is older than Beekmantown, being one of the lowest Ordovician formations. The same rock extends south through Chittenden and Addison counties.

THE GEOLOGY OF THE FORT CASSIN AREA.

The rocks of the little peninsula of Fort Cassin (Plate II) have furnished fossils which undoubtedly indicate the strata here to be, not Beekmantown in age as they have previously been classified, but Chazy and Trenton. The evidence for this statement is based on a study of the type fossils from Fort Cassin in the American Museum and on additional studies in the field (table II).

In 1890 Brainerd and Seely [1, p. 20] classified the strata at Fort Cassin as Beekmantown Division D, stage 4 (table II).

In 1905 Professor H. P. Cushing [7, p. 362] proposed the term Cassin Formation for the series of dark siliceous dolomite, shaly limestone and tough impure limestone on the peninsula of Fort Cassin. This terrane is exposed in beds which have a southerly dip of 5°. Surface outcrops and cliffs may be observed at various points on the promontory.

TABLE II.

THE SECTION AT FORT CASSIN, VERMONT.

Brainerd and Seely, 1890.		Foyles, 1923.		
(Cassin formation of Cushing.) Beekmantown, Division D, Stage 4.	Dolomite weathered yellowish.	Trenton.		3′+
	Black siliceous limestone.	Trenton.	*Isotelus maximus* Locke. *Piloceras explanator* Whitfield. *Ribeiria ventricosa* Whitfield. *Ribeiria compressa* Whitfield.	6′
		—	Disconformity	—
	Thin shaly limestone merging into massive beds at the top.	Chazy.		34′
	Impure limestone with steel gray appearance on fresh fracture, but weathering to a rusty color.	Chazy.	*Eccyliomphalus lituiformis* (Whitfield).	6′
	Sandy limestone weathering in parallel ridges one inch apart. Dip 5° S. on the northwest point.	Chazy.		10′+

When Professor Whitfield described [8, pp. 300-345] [1, pp. 29-39] the Fort Cassin fauna he treated it as a unit. Although he expressed some doubt as to the fossils being from a single formation he suggested that if anything, they were Black River in age. Close study of these specimens in the American Museum of Natural History shows that their matrices vary in lithological character and that in the group there are fossils characteristic of two different formations. Relying on these facts the fossils may be separated into two groups. The matrix of the first group corresponds in lithological character with the black siliceous limestone near the top of the series. Among the fossils of this group are:

PLATE II

The Trenton formation lying disconformably upon the Chazy formation at the north end of the Fort Cassin promontory.

Billingsella (?) primordialis (Whitfield).
Dalmanella (?) evadne (Billings).
Polytoechia apicalis (Whitfield).
Syntrophia lateralis (Whitfield).
Sinuites cassinensis (Whitfield).
Clisospira lirata Whitfield.
Eccyliopterus volutatus (Whitfield).
Euomphalus ?? circumliratus Whitfield.
Eccyliomphalus perkinsi (Whitfield).
Plethospira arenaria (Billings).
Plethospira cassina (Whitfield).
Eotomaria ? cassina (Whitfield).
Maclurites acuminatus (Billings).
Maclurites affinis (Billings).
Hormotoma obelisca (Whitfield).
Murchisonia ?? prava Whitfield.
Seelya difficilis (Whitfield).
Euconia etna (Billings).
Raphistoma compressum Whitfield.
Raphistoma hortensia (Billings).
Fusispira obesa (Whitfield).
Scenella cassinensis Bassler.
Tryblidium ovale Whitfield.
Tryblidium ovatum Whitfield.
Archinacella simplex (Billings).
Cyrtoceras ? acinacellum Whitfield.
Cyrtoceras confertissimum Whitfield.
Cyclostomiceras cassinense (Whitfield).
Cyclostomiceras minimum (Whitfield).
Schroederoceras eatoni (Whitfield).
Schroederoceras cassinense (Whitfield).
Trocholites internistriatus (Whitfield).
Tarphyceras seelyi (Whitfield).
Tarphyceras champlainense (Whitfield).
Eurystomites kelloggi (Whitfield).
Eurystomites rotundus Hyatt.
Tarphyceras perkinsi (Whitfield).
Protocycloceras whitfieldi Ruedemann.
Cameroceras brainerdi (Whitfield).
Orygoceras cornuoryx (Whitfield).
Piloceras explanator Whitfield.
Isotelus maximus Locke.
Eoharpes cassinensis (Whitfield).
Nileus striatus Whitfield.
Ribeiria compressa Whitfield.
Ribeiria ventricosa Whitfield.

Isotelus maximus Locke was described by Whitfield as *Asaphus canalis* and is figured, much reduced, in the Seventh Report, Plate 58, Vermont Geological Survey. Raymond has shown that Whitfield's *Asaphus canalis* is not that species [10, p. 36]. The lowest horizon in which *Isotelus maximus* Locke has been found is the Black River. In the black siliceous limestone at Fort Cassin I collected *Piloceras* within three inches of a large *Isotelus* (table II). In this bed I also discovered impressions the size and shape of *Ribeiria,* which has been called a typical Beekmantown fossil. Its presence with *Isotelus,* a Trenton form, indicates that it is not confined to the Beekmantown. Professor Whitfield [3, pp. 25-27] suspected that these fossils came from Trenton beds.

Doctor Rudolph Ruedemann remarks on the affinity of the Fort Cassin cephalopods with those of higher formations. In Bulletin 90 of the New York State Museum, page 525, he states: "The Fort Cassin fauna of the Champlain basin of New York and Vermont has no species in common with the Newfoundland Beekmantown fauna. * * * All evidence goes to show that the Phillipsburg beds, like the typical beds at Beekmantown, are older than the Fort Cassin beds. * * * * The Fort Cassin fauna is not yet known from the Saint Lawrence Channel and Newfoundland. * * * * Since the Newfoundland Beekmantown limestone is well developed and its faunas have been described by Billings and later on searched for cephalopods by Hyatt, the fact that no Fort Cassin forms have as yet been recorded from there does in some measure indicate their absence in the Newfoundland basin and thereby an interruption of the connection between the Newfoundland embayments and the Champlain basin, for the Fort Cassin stage at least."

Below the black siliceous limestone there exists a hiatus (figures 3-4) indicated by a wavy line of contact and a sharp lithological and faunal break. The rock below this line is thick-bedded at first and then grades into thin-bedded limestone from which *Bathyurus* and other trilobites were collected. Below these thin layers is seen an impure limestone which has a steel-gray appearance on fresh fracture and which weathers to a rusty color. The matrix of the second group of fossils corresponds to this in lithological character.

The fossils of this group are:
Protorthis ? cassinensis Whitfield.
Protorthis ? minima Whitfield.
Eccyliomphalus lituiformis (Whitfield).
Hormotoma ? cassina (Whitfield).
Bolbocephalus seelyi (Whitfield).

These species are closely related to Chazy forms. Whitfield has stated [8, p. 295] that: "The *Calaurops* (*Eccyliomphalus*) layer I suppose to be Chazy limestone, and is a tough, heavy bedded limestone greatly resembling the *Maclurea* bed." He elsewhere writes [8, p. 316]: "*Calaurops* is from the lowest rock exposure, which is a coarse, somewhat crystalline limestone closely resembling the *Maclurea* beds at Chazy, New York, and on Isle La Motte. * * * no other fossil has been found in the same bed except the caudal plate of a trilobite of small size, resembling *Bathyurus extans* Hall."

The lowest bed exposed on the north shore of the Fort Cassin promontory is a sandy limestone which weathers in parallel ridges about one inch apart. Throughout the State of Vermont the third stage of Division D of Brainerd and Seely's Beekmantown does exactly this. Moreover, if the thickness of Brainerd and Seely's Beekmantown D-3, D-4, and E and their Chazy are added they give a thickness of about one thousand feet, which is the normal thickness of the true Chazy. It is similar in lithological character to Stage 3, Division D of the Beekmantown as defined by Brainerd and Seely. This stage is regarded as Chazy in age. It contains no Beekmantown fossils. All of the beds below the unconformity described above appear to belong to the same formation. Although the evidence may be considered meager, it is thought that the lithological characters, position and contained fossils indicate these strata all to be Chazy in age.

THE GEOLOGY OF PROVIDENCE ISLAND.

Having considered the localities of Shoreham and Fort Cassin we may now turn to Providence Island, where the structure of the rocks has been excellently worked out by Brainerd and Seely [1, pp. 17-20]. They classified the strata as the upper part of their Beekmantown, Division D, the lower part of E, and the Chazy (table III). The strata dip N. 75° E. at an angle of 5°. Their sequence is described as a thickness of 450-500 feet. My observations at Providence Island in the summer of 1922 lead to the belief that the above classification should be revised. (Plate III.)

On the west shore of Providence Island the banded sandy limestone, which is characteristic of the northwest promontory at Fort Cassin, is exposed in small escarpments. From a layer fourteen feet from the top *Eccyliomphalus lituiformis* (Whitfield) has been taken. Above this sandy limestone, which weathers in parallel ridges one inch apart, the beds become thinner, as they do at Fort Cassin, and exhibit small grottoes due to wave action. These layers, which in places have a shaly appearance, have yielded *Asaphus canalis* Conrad. The banded sandy limestone, together with this thin-bedded formation which has massive beds at its top, is similar to the lower beds at Fort Cassin, where an attempt has been made to prove that these strata are Chazy in age.

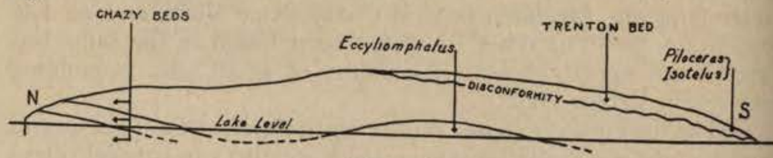


FIGURE 2

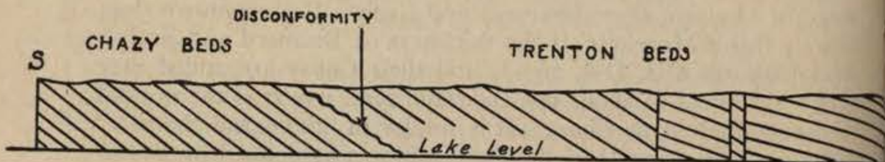


FIGURE 3. North-south section of Providence Island.

At this point there is a hiatus (figures 2 and 3) which is evidenced by a wavy line of contact between the strata just described and the rock which succeeds. The disconformity is further indicated by a sharp faunal and lithological break. In character it is similar to the disconformity observed at Fort Cassin. The rock above yields fossils and matrix analogous to the Fort Cassin fauna. The rock below is identical with that at Fort Cassin. There can be no doubt that these are different exposures of the same strata.

As observed at Fort Cassin, the strata above the disconformity belong to the Trenton formation. The large cephalopods taken from this bed at Providence Island are identical with those which similar strata yielded at Fort Cassin. In the Providence Island collection at the University of Vermont there is a fragmentary shield of a large *Isotelus* embedded in a matrix corresponding to the present rock. These facts indicate that this layer is Trenton in age (table III).

On the northern point of Providence Island large gastropods were taken from the surface of the ground twenty-five feet above the water. Although it is difficult to see the fossils embedded in the nodular and irregular layers (Plate IV) of the east cliff of the north point, several specimens which resemble *Prasopora* were observed *in situ*. On the shore below the cliff, boulders were collected containing *Trinucleus concentricus,* or as called by Raymond, *Cryptolithus tessellatus, Prasopora* and other Trenton fossils. On the north shore Professor Perkins collected large pieces of rock which had apparently broken loose from the cliff and become weathered at the water's edge. This rock contains a specimen of *Mesotrypa whiteavesi* (Nicholson), a Trenton species.

PLATE III

The Trenton formation lying disconformably upon the Chazy formation on the southeast shore of Providence Island, Lake Champlain.

PLATE IV

Trenton cliff on the west side of the north point at Providence Island, Lake Champlain, showing nodular layers of limestone.

TABLE III.

THE SUCCESSION OF BEDS ON PROVIDENCE ISLAND.

Brainerd & Seely, 1890.				Foyles, 1923.	
Chazy.		30′+	Dark, nodular limestone of the north point breaking in uneven layers. Dip 13° N.	Trenton.	*Mesotrypa whiteavesi* (Nicholson).
Beekmantown, E.	k	5′	Very tough, dark-colored limestone with lenticular masses of compact black chert, in two layers parallel to the bedding and two feet apart.		
	j	7′	Tough magnesian limestone weathering yellow with numerous fine black lines appearing on the fracture surfaces.		
	i	20′	Concealed.		
	h	12′	Magnesian limestone with chert weathering yellow.		
	g	3′	Magnesian limestone holding small nodules of white chert.		
	f	10′	Magnesian limestone in beds 2 to 3 feet thick, holding at top abundant masses of scoriaceous black chert.		
Beekmantown, D.	e	44′	Blue or dove-colored limestone in beds 4 to 8 feet in thickness separated by thinner layers of magnesian limestone, containing *Lituites seelyi* Whitfield, *L. eatoni* Whitfield, *Nautilus kelloggi* Whitfield, *Maclurea affinis* Billings, *Orthoceras sp.*, *Holopea cassina* Whitfield.		
	d	31′	Magnesian limestone more or less siliceous thin-bedded at first, then in massive beds, holding *Asaphus canalis* Conrad.	Chazy.	Disconformity.
	c	28′	Sandy limestone weathering on the edges in ridges one or two inches apart, holding in a layer 14 feet from the top *Calaurops lituiformis* Whitfield in abundance.		
	b	5′	Tough magnesian limestone weathering yellow in layers 1 foot in thickness.		
	a	71′	Calciferous sandstone at the south end of the island in layers 6 to 10 inches in thickness containing *Maclurea affinis* Billings and *Asaphus canalis* Conrad.		

CONCLUSION.

The statements in the foregoing pages show that the Beekmantown formation of the Champlain valley as defined by Brainerd and Seely is composed of the Beekmantown and Chazy formations (table I). On the other hand, the evidence furnished by the geology of the Fort Cassin locality and Providence Island suggests that the strata of these areas are not Beekmantown as has been indicated by Brainerd and Seely, but that they are Chazy and Trenton in age as noted in tables II and III.

BIBLIOGRAPHY.

(1) Brainerd, E. and Seely, H. M. 1890. The Calciferous Formation in the Champlain Valley. Bull. Amer. Mus. Nat. Hist., III, pp. 1-25.

(2) Adams, C. B. 1845-1847. Annual Report of the Geology of Vermont, I, II, III.

(3) Whitfield, R. P. 1890. Observations on the Fauna of the Rocks at Fort Cassin, Vt., with Descriptions of a few new species. Bull. Amer. Mus. Nat. Hist., III, pp. 25-29.

(4) Ruedemann, R. 1906. Cephalopoda of the Champlain Valley, New York State Museum Bull. 90, pp. 393-611.

(5) Gordon, C. E. 1919-1920. Studies in the Geology of Western Vermont, Report of the Vermont State Geologist, XII, pp. 114-279.

(6) Ulrich, E. O. 1911. Revision of the Palaeozoic Systems, Bull. Geol. Soc. Amer., XXII, pp. 650-651.

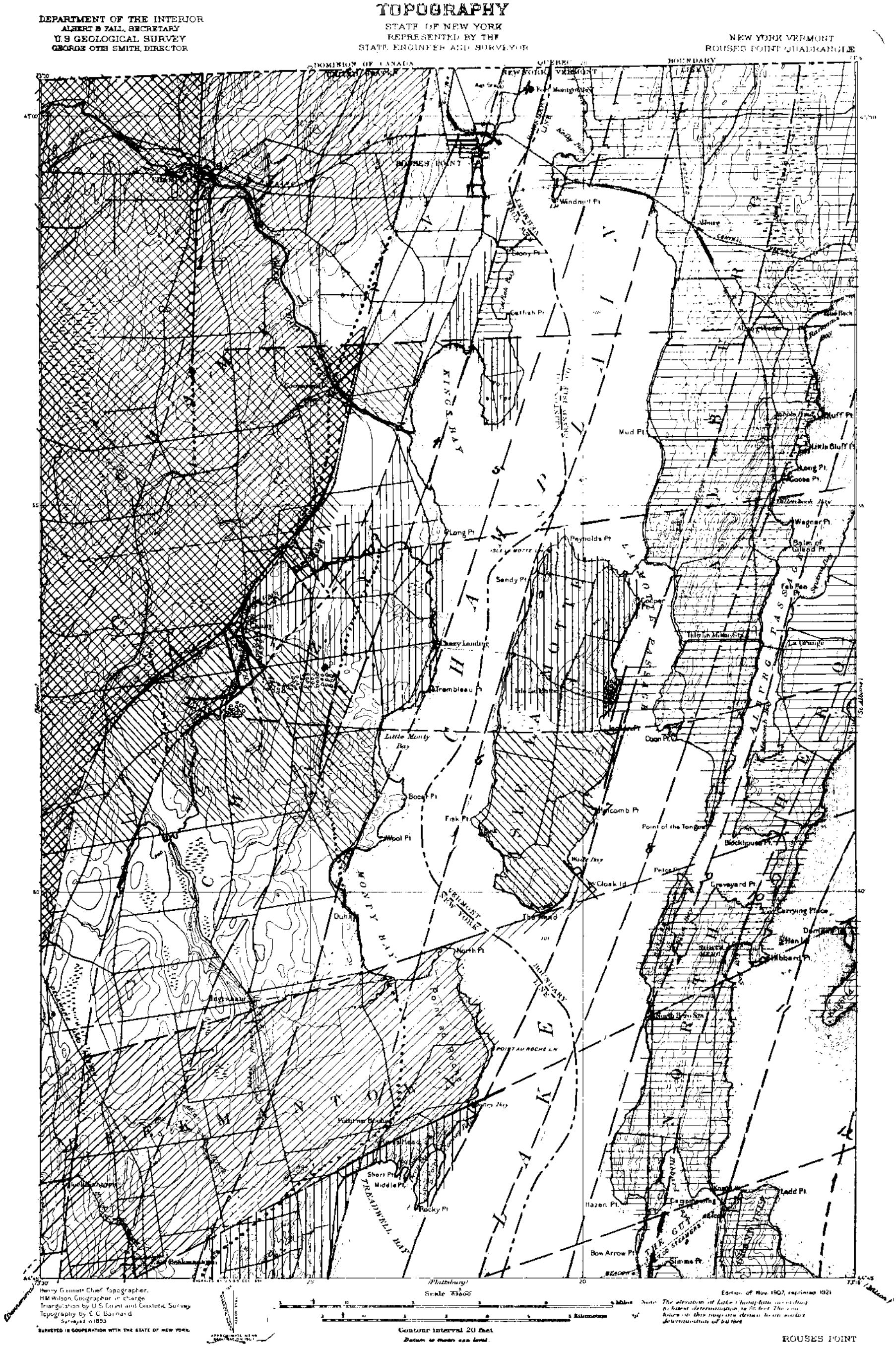
(7) Cushing, H. P. 1905. Geology of the northern Adirondack Region, Bull. N. Y. State Mus., 95, p. 362.

(8) Whitfield, R. P. 1886. Notice of Geological Investigations along the Eastern shore of Lake Champlain. Bull. Amer. Mus. Nat. Hist., I, pp. 293-345.

(9) Hitchcock, C. H. 1861. Report on the Geology of Vermont, I, p. 266.

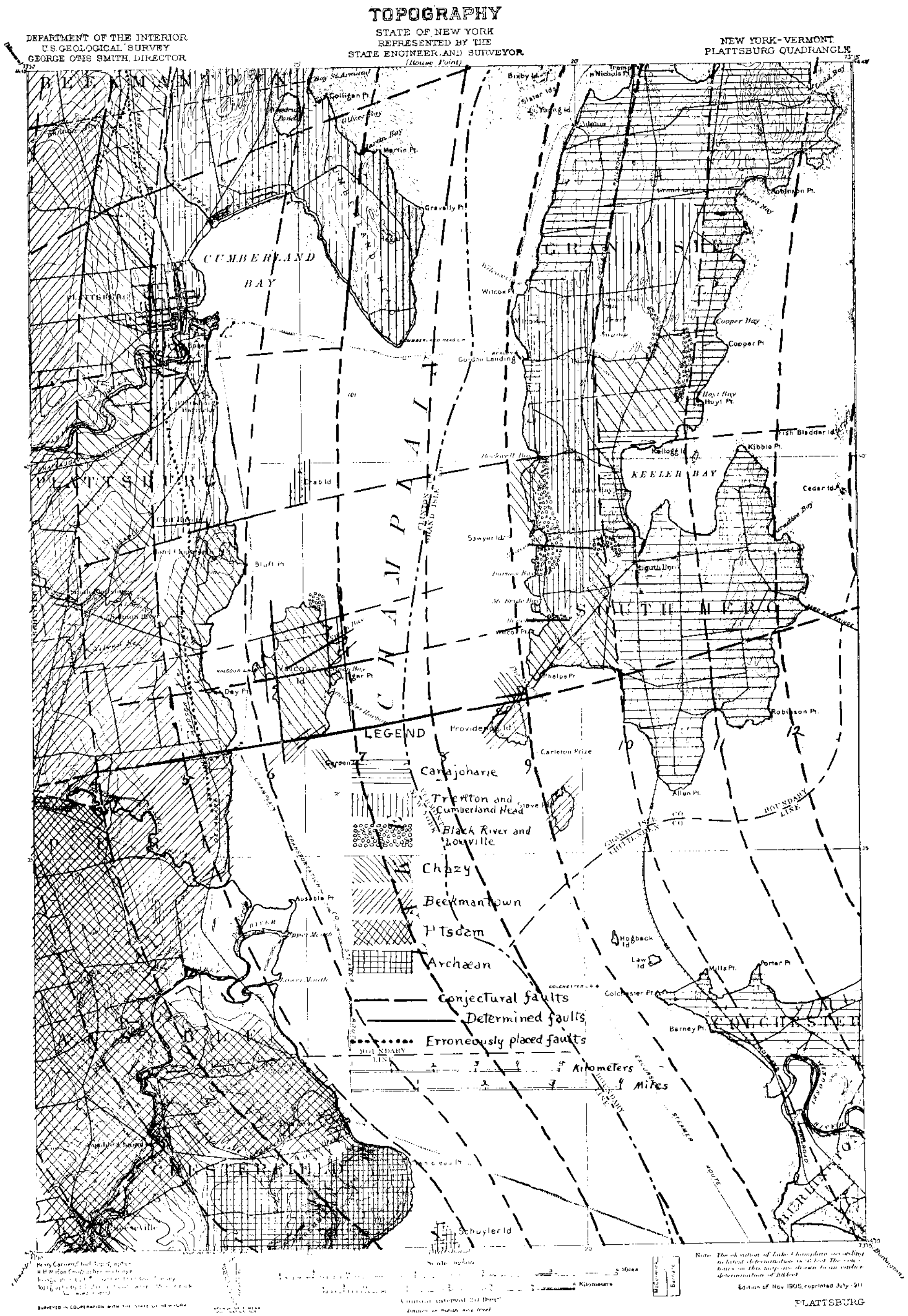
(10) Raymond, P. E. 1910. Notes on Ordovician Trilobites, Annals of the Carnegie Museum, VII, pp. 35-45.

PLATE V



Faults and conjectural faults of the Rouses Point Quadrangle.

PLATE VI



Faults and conjectural faults of the Plattsburgh Quadrangle.

A PRELIMINARY PAPER CONCERNING THE FAULTS SYSTEMS OF THE NORTHERN CHAMPLAIN VALLEY

George H. Hudson,
Plattsburgh, N. Y.

A meridional system is clearly to be distinguished in the area covered by the Plattsburgh and Rouses Point topographic sheets of the U. S. Geological Survey. On the middle portion of the area of the Plattsburgh sheet, we find ten members of this system running nearly north and south and averaging about 1.3 miles apart. On the southern portion of this area, the trend of these fault lines is north-northwesterly and in the northern portion, the trend is seen to be swinging north-northeasterly. This bend is clearly to be noted in the general trend of the contours of the two maps in question and is a deformation due to westerly thrust. Because of the easterly swing of the faults on the Rouses Point sheet, we lose some of the members of this faults system on the east and gain new members on the west.

Three of these more westerly faults are the Champlain, Tracy Brook, and Little Chazy faults given in Cushing's "The Geology of Clinton Co., New York" (Report of the New York State Geologist, 1895) and in his Geology of the Northern Adirondack Region (New York State Museum, Bulletin 95). We shall hereafter refer to these references as Cushing 1895 or 1905.

The next fault to the east is the Beekmantown Fault of Cushing 1905, Plate 13 (see Plate VI, fault). Continued southerly, this fault would cut Trembleau Mountain. Northerly it does not take the erratic course indicated in Cushing 1895, but continues its uniform course until it enters the area of Cushing's 1905, Plate 12, where a portion of the true Beekmantown fault is represented.

East of the Beekmantown runs the Plattsburgh fault. The southern end of this fault practically follows the coast line from Trembleau Mountain to near the lower mouth of the Ausable River, where it is covered by the Ausable delta. The conjectural portion of this line in Cushing 1905, plate 13, is swung too far easterly. The line crosses Plattsburgh nearly a quarter of a mile west of the position indicated by Cushing and it does not swing westerly as it runs north of the city, but continues along the Dead Creek Marsh, cuts off the west lobes of Monty and Little Monty Bays, passes east of Chazy Landing and Point au Fer and probably enters Alburgh nearly a mile east of Windmill Point.

This fault nowhere joins the Beekmantown fault, but runs everywhere sub-parallel with it.

East of the Plattsbugh fault, we find a fault which runs along the western side of Valcour Island, is responsible for the cliff line at Bluff Point, joins the Woodruff Pond fault of Cushing 1905, Plate 13, follows the west shore of Treadwell Bay, crosses the Point au Roche headland a little to the west of the line which Cushing drew for his Beekmantown fault of 1897, and is responsible for the western side of the Isle La Motte fault blocks.

Next east comes the Cumberland Head fault, which bounds the eastern side of the Valcour Island fault blocks, divides Cumberland Head into two nearly equal portions, and is responsible for the eastern shores of Point au Roche and Isle La Motte.

The line of Alburgh Passage and Pelot Bay and the whole western shore of Grand Isle is indicative of another fault of this system which, on its way south, runs to the east of Providence Island and close to Colchester Point. The whole trend would closely parallel that of the faults already outlined. This postulated fault we shall call the Alburgh Passage fault and the space between this and the Cumberland Head fault would require another fault of this series, midway between, which we shall hereafter refer to as the Northern Champlain Basin fault.

Another fault of this series is responsible for the mile of approximately north-south coast northwest of Allen Point on Grand Isle and this, running northerly separates Canajoharie shale on the east from Chazy beds on the west. This is a difficult fault to follow still farther northerly, but it seems to be responsible for the general direction of the east side of North Hero.

There is another nearly north-south fault west of Hoyt Bay and this has Canajoharie shales on the east and a mile or more of Black River beds on the west. We may call this the Kellogg Island fault and it is evidently responsible for the bay east of Allen Point, and for a south and a north lobe of Keeler Bay. This fault seems also to be responsible for the bay east of Simm Point and for its mile or more of northerly running coast. Westerly thrust has no doubt somewhat covered the original position of this fault line, but it still seems to be manifest in present surface features. These features suggest also the presence of an East South Hero fault which is responsible for Paradise Bay and the small bay a little more than a mile south of it; and also for Ladd Bay and the still deeper bay a mile to the south of this. There is probably also a Fish Bladder Island fault and another, with the trend of this system, just off the Vermont shore line. (See the Milton Sheet.)

These faults of the meridional system are accompanied by many minor step faults on either side of them. The Cumberland Head fault, where it passes Valcour Island, shows many such

PLATE VII

Step faults at Treadwell's Mills, Plattsburgh, N. Y.

minor parallels on the west side and the Woodruff Pond fault also shows many parallels on its east side.

These step faults are usually close together near the main fault line, as in Plate VII, where nine minor faults are shown to follow a line of fracture which is probably connected with the Tracy Brook fault. Some of the parallel faults in this locality present much greater displacements than those shown in the figure.

Farther from the fault line the step faults are not so closely placed, though the displacement may amount to several feet. By connecting up several different parallels, one may be led to draw a sinuous fault line where such does not exist.

In addition to these minor parallels, we may also have short branching faults or auxiliaries such as have been indicated for the Little Chazy fault near Chazy village and (by Brainerd and Seely) for the Cumberland Head fault at Cloak Island. These short branch faults, together with the covered nature of the territory, make the tracing out of any one line a difficult matter.

The difficulty is increased because of the presence of a superimposed *series of overthrust faults*. There is one fault plane of this nature that cuts the Grenville under Valcour Island, Plattsburgh and Cumberland Head. The monchiquite dikes cutting this long and wide territory have brought up millions of rounded and broken cobbles from this fault plane. At McMartin's Quarry, in the Chazy limestone (see Plate VIII), there has recently been uncovered a large area of quarry floor which has slickensides and calcite seam due to westerly movement of the mass over this floor. At Martin's Bay (Plate IX) there is a strong anticlinal fold which has been also cut across by an overthrust. This horizon is in the Cumberland Head shales. These New York State examples clearly indicate that Grand Isle and North Hero must also have been subjected to such overthrusts.

The meridional system was probably truly azoic in its youth and in its maturity had already formed a graben, locally covered by a sea arm in Cambrian time. The present multiplicity of the parallels in this system may be due in part to renewed activity of old faults covered by overthrust; or, as was suggested by Chadwick in a paper read before the Geological Society of America at Albany in 1916, such overthrust would induce parallel faulting both in the floor passed over and in the overriding mass.

In addition to the two faults systems already outlined there is a third which seems to have been developed in part through thrust. The fault lines of this system are more nearly straight. The slight curves they show seem to be due to unequal sag along fault planes which are not perpendicular.

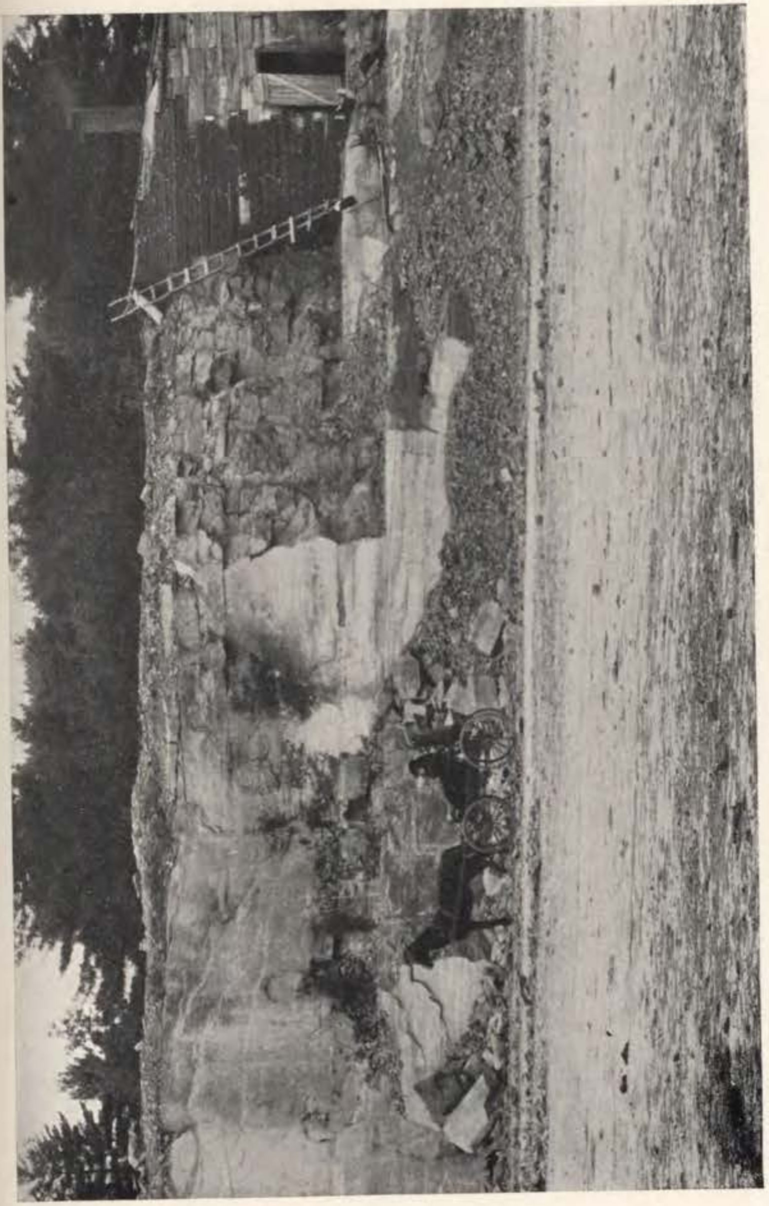
The first fault of this *tranverse system* to which we will call attention runs from Valcour, N. Y., in a practically straight line to the neck of Providence Island, which it cuts across at its narrowest part. This important fault, which we shall call the Valcour Cove fault, has never been described, but Brainerd and Seely drew one of its southern auxiliaries at Valcour, three of its northern auxiliaries at Valcour Island and four auxiliaries and one of its parallels at Providence Island. This tranverse fault thus completely crosses the lake basin and has Beekmantown on the south and Chazy on the north at Valcour, at Valcour Island and at Providence Island.

There seems to be at least ten more members of this system which cross the northern Champlain valley in lines running between N. 65° E. and N. 84° E. Not one of these faults has yet been shown to cross the lake basin, but doubtless all of them do so. For instance, the trend of the fault at Cliff Haven, N. Y., which brings down Trenton beds on the north side to the level of Middle Chazy beds on the south, would carry it to Rockwell Bay on Grand Isle, where we also find Trenton on the north and a strip of Chazy on the south. This fault is near the southern border of a sagging basin and if the dip of the fault plane was northerly, the line should show some northerly convexity. If a fault could be found crossing the strip of Trenton as an easterly extension of this line, we could determine whether or not it was in part responsible for the evident fault between the Chazy north of Keeler Bay and its fringe of Canajoharie shale or for the north shore of Keeler Bay itself. Apparently this fault has some close parallels.

Another important fault of this tranverse system; and one which, recognized in part, led Cushing to follow it for a short distance northeasterly with his Beekmantown fault of 1895; is the Mooney Bay fault which can be traced west-southwesterly from this bay to East Beekmantown. This fault line has a general trend which would carry it near North Hero station. On the New York side it has Beekmantown on the north and Cumberland Head shales on the south and, therefore, shows as profound a displacement as any fault in the valley. Has this fault been covered on North Hero by overthrust and, if so, has a subsequent slip allowed it to still manifest itself through the presence of the little cove at North Hero station on the west and the mouth of City Bay, the short line of coast at Hubbard Point with the same trend, and the channel between Hen and Diadama Island on the east. This fault is on the northern border of a sagging basin and the long east-west Beekmantown exposure is in the nature of a horst. If then this fault plane dips at all southerly, the fault line itself is likely to show a northerly convexity due to sag.

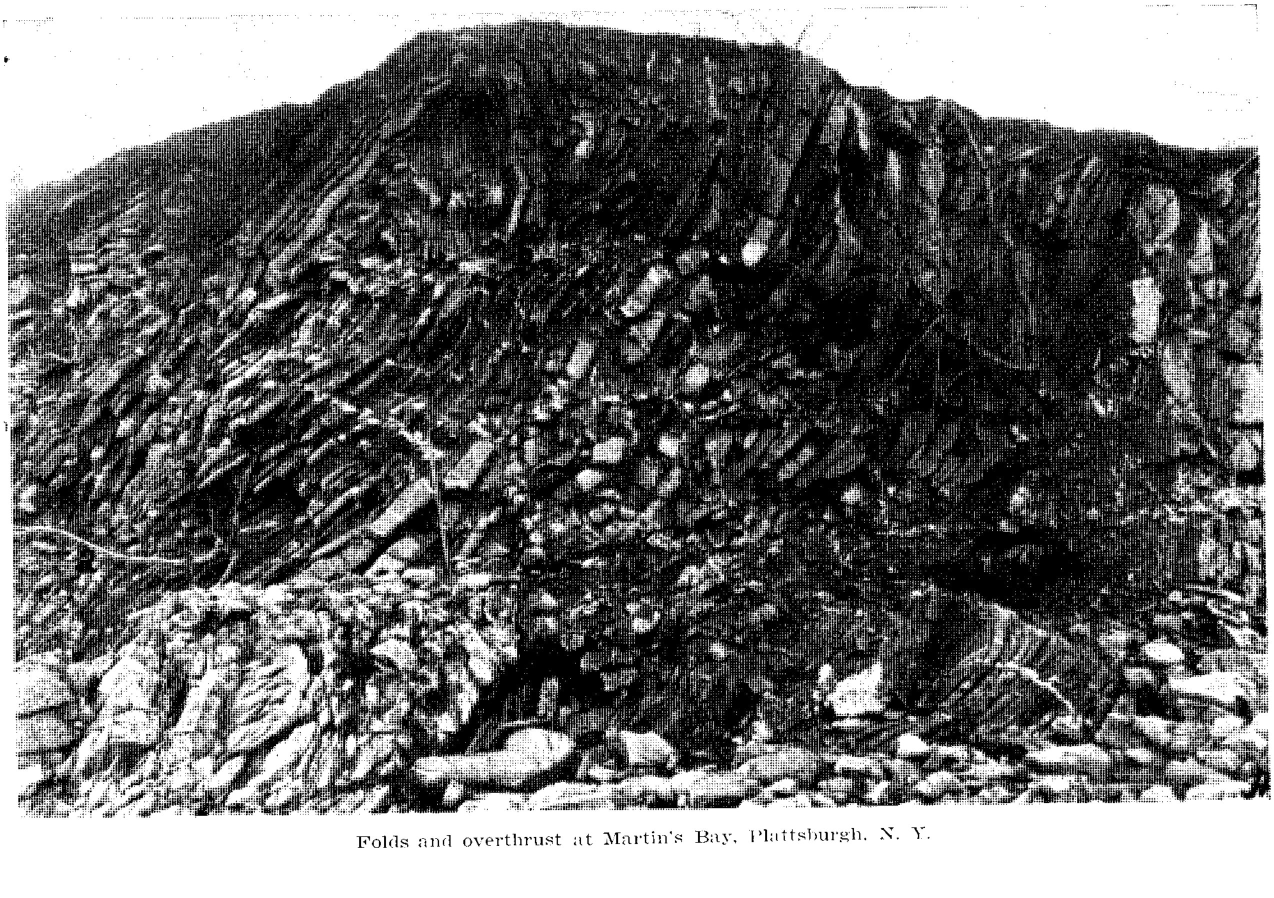
So far as we have been able to trace members of this transverse system, we have given them the names of bays or coves for which they appear to be responsible and not one of the meridional faults has been so named. The nomenclature will thus serve to distinguish two systems from each other. On our field map of

PLATE VIII



Slickensided floor of McMartin's Quarry, Plattsburgh, N. Y.

PLATE IX



Folds and overthrust at Martin's Bay, Plattsburgh, N. Y.

PLATE IX

Folds and overthrust at Martin's Bay, Plattsburgh, N. Y.

the region, we have also provisionally plotted this transverse system and carried most of the lines across the lake channel into Vermont territory. These lines, however, are intended to serve only as guides for field work. There is at present evidence enough to show the presence of a true transverse system, but whether or not its fault lines all have the extent of the Valcour Cove fault is yet to be demonstrated. And again, there can be but little doubt as to the exact position and direction of the Valcour Cove fault, but there is not the same certainty regarding the other members of this system.

A large field for more careful and exact work is here indicated. Take for instance the outcrop of Chazy shown in Perkins' Report of the Vermont State Geologist for 1901-1902—map opp. p. 102. The area of exposure as there drawn is in part conjectural, as must be the nature of the case in partly covered territory. The fault block itself without doubt has rectilinear boundaries and not curvilinear. Can any of these boundaries be found and connected up with the system to which it belongs? If we can find true curvilinear boundaries between the Canajoharie and the Chazy then we are dealing with the eroded edge of an overthrust whose plane cuts the Canajoharie beds themselves. We have already shown that the overthrusts of the region form a system of superimposed members. The problem in the locality cited may then be stated as follows: What portions of the boundary of this Chazy block are due to exposure of line of conformity of upper Chazy with Lowville or of unconformity between Chazy and Black River; what portions are due to exposed line of contact between the Chazy block and a mass of Canajoharie overthrust; if any; and what portions of this Chazy block are due to parallels or auxiliaries of the great meridional or transverse faults systems of the Champlain valley? The former class of boundaries of this Chazy exposure may be curvilinear, the latter boundaries will be rectilinear. Here is but one of a hundred similar problems that must be solved before the meridional and transverse systems can be accurately plotted.

The blocks cut by these systems, which make the mosaic floor of the Champlain valley, are seen to resemble a box of domino cut sugar that has been somewhat shaken up. All kinds of faulting are exemplified. We have normal, rotatory, bythrust, reverse, *reversed* (truly so), overthrust and possibly other types.

The comparative ages of the various systems is also open to study. The transverse system of faulting had its development, if not its origin as well, during the periods of great thrust from the east. Such details as have already been made out will be published in a more complete account now in the hands of Dr. John M. Clarke of the New York State Museum. This preliminary paper is published with his permission.

In the guide map, for field work which accompanies this paper, note the marked parallelism of the meridional faults designated as the Woodruff's Pond (line 6) and the Alburgh Passage (line 9) faults. The whole trend of this portion of the Champlain Valley is expressive of the meridional system as modified by thrust from the east. All broken lines are conjectural in position. Lines of cubical dots represent faults whose previous plotting was largely in error.

The names provisionally given the members of the transverse system, as we pass north from the Valcour Cove fault, are Sloop Bay, Beauty Bay (from bays on Valcour Island), Rockwell Bay, Cooper Bay (Grand Isle bays), Bay St. Amand, Mooney Bay, Monty Bay, Little Monty Bay (from New York State bays) Dillenbeck Bay and Ransoms Bay (Alburgh shore bays).

THE GEOLOGY OF WESTMORE, BROWNINGTON AND CHARLESTON

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In the Twelfth Report of the Vermont State Geologist, 1919-1920, the writer published his interpretation of the Geology of Lake Willoughby. In various Reports of the Geologist, extending from that of 1907-1908 to, and including, that of 1919-1920, Professor C. H. Richardson of Syracuse University, has worked out the geology of Troy, Coventry, and Newport, Irasburg, Albany, Craftsbury, Greensboro—in short, of the tier of townships extending southward as far as Braintree. It, therefore, seems a logical step to extend the scope of the Lake Willoughby work and begin a survey of the townships lying contiguous to and east of those of which Richardson has written. Accordingly, the present article deals with the geology of Westmore, Brownington, and Charleston; while the next will, it is hoped, include Morgan, Holland, and Derby, thus carrying the survey to the International Boundary. Subsequent work should then be directed at the geology of Barton, Sutton, Glover, etc.

It goes without saying that a necessary prerequisite to an accurate geological survey is an accurate map. This is at present, unfortunately, unobtainable. The United States Topographical Survey of the State is progressing slowly and it will probably be many years before this region is reached. Meanwhile, the most nearly complete map of the State is the Road Map, issued by the Secretary of State, in 1917, but this contains many inaccuracies, both in the location of country roads and of topographical features. Thus the long axis of Long Pond, in Westmore, is made to bear northwest and southeast, while as a matter of fact, it bears north, twenty degrees east. Then, too, the difficulties of exactly locating one's self on so small and generalized a map are many and, therefore, the exact positions of mountains, ridges, and other features of relief cannot be recorded without extensive surveying, for which the geologist's time cannot be taken. The only exact elevations are to be found in the railroad surveys and the few bench marks of the United States Coast and Geodetic Survey. Therefore, in order to give some idea of the topography of the region covered, the writer has carried an aneroid barometer and used it with as much care as possible. Several determinations of the elevation of Lake Willoughby above sea-level have been made, using the Boston and Maine Railroad elevation of its station at West Burke as a datum. The mean of these determinations gives the altitude of the lake as 1,155 feet above sea-level. The other elevations given on the map (Plate X) are based on this determination and are, obviously, only approximately correct —perhaps within fifty or seventy-five feet of the truth.

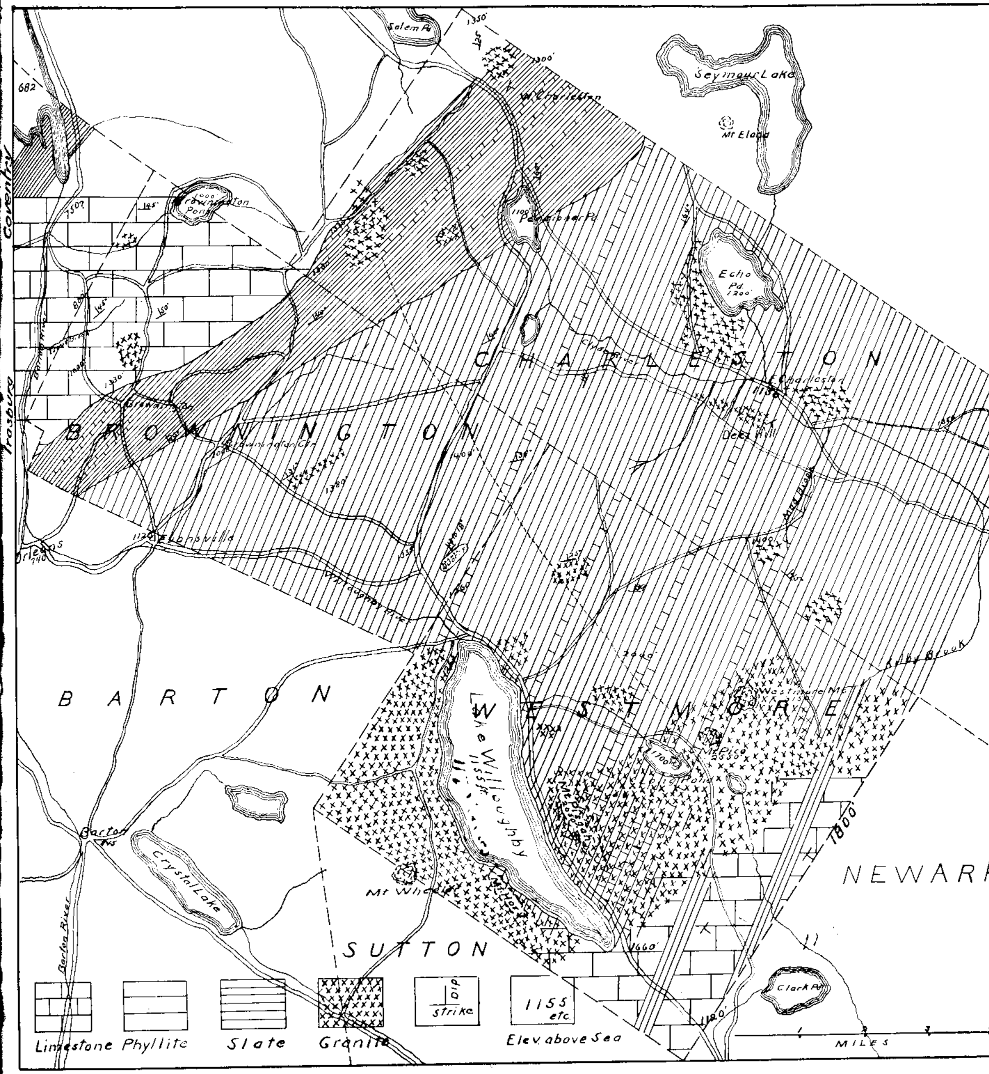
In the densely wooded and thickly mantled areas of eastern Westmore geological surveying is almost an impossibility. Many parts are practically inaccessible to the lone geologist, while outcrops are few and far between. Furthermore, nearly the whole region is covered with glacial drift which, of course, obscures the underlying formations. Hence this work can pretend at nothing more than a general geological survey of the region studied, with the rock systems, their approximate locations, and their petrographic and chemical composition, the general location of the topographical features and an approximate determination of elevations.

There is, among the inhabitants of the region, much confusion regarding even the names of the mountains and lakes. Thus, Westmore Mountain, the dominant elevation of the three townships studied, is also called Haystack and, again, Bald Mountain (although it is heavily wooded!), while the small sheet of water at its southeastern base is known as Bald Hill Pond. The small rock turret rising near Long Pond is called by some, Mount Pico; by others, Owl's Head. Pensioner Pond, in Charleston, is also known as Pumpkin Pond, etc., etc.

PREVIOUS WORK.

In the Eighth Report of the Geologist, 1911-1912, Professor Richardson discusses The Terranes of Irasburg. He shows that the western border of the town is flanked by Lowell Mountain (2,600 feet above sea-level) and Long Mountain (1,600 feet), both elevations trending northeast and southwest, and being made up of quartzite conglomerate, hydromica schist, and sericite schist. He judges that they are pre-Ordovician and probably Cambrian in age. These old metamorphics are bounded on the east by a limestone, a slate, and a phyllite member and these have been sculptured into ridges and valleys. In the central part of the township Richardson has located a limestone conglomerate and given it the name, Irasburg Conglomerate. This formation is exposed for a distance of four miles, striking north, forty degrees east, and is about half a mile wide at its maximum, near Irasburg village. He states that the enclosed material is all pre-Ordovician, while the enclosing limestone is Ordovician. Richardson claims that this conglomerate establishes an erosional unconformity between the pre-Ordovician terranes to the westward and the newer lands to the eastward—that this conglomerate, in other words, is the base of the Ordovician System in Vermont. Limestone makes up the greater part of the area discussed. It

PLATE X



Map of the region covered.

is bordered on the west by a bed of phyllite, while another, larger, belt strikes roughly north and south across the township and is interstratified with limestone. Several large areas of granite and some basic intrusives are noted.

To the limestone Richardson has given the name, Waits River Limestone, from the type locality in the town of Washington, in Orange County. He divides this member into three phases, based on lithological variations. The most westerly, the Coventry Phase, is "a dark gray, pyritiferous, siliceous limestone, with the coloring matter largely due to carbon." The strike is north, ten to twenty degrees east, while the dip is from 55 to 60 degrees, westerly. East of this phase, in the central part of the township, the limestone is described as being much more compact, and steel-gray in color. In this, pyrite is either lacking or else is present in very small amount, while large veins of secondary quartz traverse the rock. This member Richardson calls the Washington Phase. Still farther eastward and in contact with the Washington Phase, he finds a lighter colored, variegated limestone, to which he has given the name, Waits River Phase. Professor Richardson has noted the occurrence of this phase east of the Hor-Pisgah Range of mountains, in Westmore.

In his Geology of Newport, Troy, and Coventry,[1] Richardson finds the Washington Phase of the limestone to be the principal formation of the eastern part of Coventry.

The same writer has also located "three long, narrow, and parallel belts of slate, extending from Lake Memphremagog southwesterly across Newport and Coventry." The strike of these belts varies from north, 30 degrees east, to north, 40 degrees west, while the dip is invariably to the west, in amount from 75 to 80 degrees. All three of these belts lie in the Waits River Limestone. The most westerly is a "black, carbonaceous, highly fissile slate," which is thought to be well suited for commercial uses. The middle belt is "a black, clay slate, occasionally pyritiferous, yet with perfect cleavage * * * and well suited for roofing." The easterly belt "lies west of Barton River and is best seen along the height of land between Barton Landing (Orleans) and Coventry. Here the black, carbonaceous slate becomes shaly and unsuitable for roofing purposes. * * * It can be traced continuously through Coventry to Lake Memphremagog. It is flanked both upon the east and west by the Waits River Limestone." This limestone and the most easterly of the slate belts are shown on the map, Plate X, in Coventry and Derby.

Regarding the geological age of the limestone and slate (and also, of course, the interbedded phyllite) Richardson has found in Quebec, in Coventry, Brownington, and also in the other townships mapped by him, crushed graptolites, which establish all

[1] Sixth Report of the Vermont State Geologist.

three lithologic members as Ordovician in age, more specifically as Lower Trenton.

This important work of Professor Richardson is here quoted at length as it has a critical bearing on the geology of the areas mapped in the present work.

In the Twelfth Report,[1] 1919-20, the writer described in the eastern part of Westmore a short range of mountains, trending to the northeast and forming a water-shed between the Connecticut River drainage basin, on the east, and the Memphremagog drainage basin, on the west. Lake Willoughby was found to occupy a great U-shaped trough, in the mountain range, which had been gouged out by the ice sheet of the last glacial epoch. It was seen that the phyllite and limestone, which make up the sedimentary rocks of the region, had been upraised and injected by a granitic magma and that, later, the range had been cut through by the ice sheet and the trough formed. The writer was inclined to the opinion that the beginning of this trough (since it could not have been formed by fluviatile agencies) must have been caused by drop-faulting. More mature reflections, however, and discussions with other geologists have led him to the opinion that the trough was wholly glacial in its origin. The jointing in the phyllite and limestone and the rifts in the granite would have rendered them peculiarly vulnerable to the plucking action of the ice sheet, whose competence to erode such troughs is now generally admitted.

With the above information in mind, and the field notes, rock collections, and photographs at hand, the geology of the area chosen may now be attempted.

LOCATION, AREA, TOPOGRAPHY.

The townships of Westmore, Brownington, and Charleston lie in the southeastern part of Orleans County. The peculiar "lie" of the townships in this part of Vermont, not according with the cardinal points of the compass, but generally northwest and southeast, was probably influenced by the direction of the mountains and ridges, which trend northeast and southwest. The eastern boundaries of the townships are thus parallel to the trend. Westmore is, geometrically, a square, six and three-fourths miles on each side; Brownington which adjoins Westmore on the northwest, is a trapezium, five by seven and one-fourth miles in maximum dimensions; while Charleston, which is contiguous to these townships on the north, is a parallelogram, nine and three-fourths by four and three-fourths miles. The total "flat" area of the three is approximately 122 square miles. It may be mentioned here that parts of three summers were spent in this region. The monotonous character of the terrains and the use, where possible,

[1] 1919-20, The Geology of Lake Willoughby.

CANADA
NEW YORK
LAKE CHAMPLAIN
NEW HAMPSHIRE
MASSACHUSETTS
GRAND ISLE
FRANKLIN
ORLEANS
ESSEX
LAMOILLE
CALEDONIA
CHITTENDEN
WASHINGTON
ADDISON
ORANGE
RUTLAND
WINDSOR
BENNINGTON
WINDHAM
CONNECTICUT RIVER
860
715
670
890
500
788
BURLINGTON
MONTPELIER
RUTLAND
ST. ALBANS
NEWPORT
ST. JOHNSBURY
MIDDLEBURY
WOODSTOCK
MANCHESTER
BENNINGTON
45°
44°
43°
73°
72°
H. L. Fairchild. 1916

PLATE XI

The Westmore Range, from the northwest.

of an automobile, have made possible the covering of this large area in a fairly comprehensive manner. .

The dominant topographical feature of this area is the short mountain range (Plate XI), as yet unnamed, which lies in the eastern part of Westmore and trends to the northeast, separating the Connecticut River drainage basin, on the east, from the Memphremagog basin, on the west. The name, Westmore Range, is suggested and will be used in this article. As already mentioned, this range is broken by the glacial trough in which Lake Willoughly lies, and the road along the lake shore forms part of the state highway between St. Johnsbury and Newport. The principal peaks of the Westmore Range, from south to north, and their approximate elevations above sea-level are: Mount Wheeler, which lies on the line between Westmore and Sutton, and has not yet been measured, Mount Hor (unmeasured but perhaps 300 feet lower than Pisgah), Mount Pisgah (2,600 feet), Mount Pico (2,550 feet), and Westmore Mountain (3,150 feet). Westmore Mountain dominates the entire region and from the fire tower on its summit a superb view can be had, on a clear day, of the whole northern country, from the White Mountains, on the east, to the Canadian peaks, on the north, and Mansfield and Camels Hump, on the west.

From the Westmore Range a height of land extends northwesterly (shown by the dotted line on the map [Plate X]). It is about 2,000 feet above sea-level, in Westmore, but gradually descends to about 1,000 feet at the Charleston-Derby border. Westmore is practically all mountain land, which gradually descends to the valley of the Clyde River, in Charleston, and to the rolling land of Brownington. Brownington is made up of a series of low, parallel ridges and valleys, trending to the northeast and gradually losing elevation towards the western border of the township, where the land slopes sharply down to the valley of the Barton River, in Coventry. Charleston, in its southern, eastern, and northern parts, is hill country, but in its mid portions it is traversed by the broad valley of the Clyde River. This valley is bifurcated, south of East Charleston, by some small elevations, the highest of which is Deer Hill.

DRAINAGE.

Reference to the map (Plate XIa) illustrating the writer's Geology of Lake Willoughby,[1] will show that the entire area mapped in the present article, except the portion of Westmore east of the Westmore Range, lies in the Lake Memphremagog drainage basin, the western border of which is formed by Lowell Mountain, Long Mountain and their extension. The streams of eastern Westmore flow into the Passumpsic River. All other

[1] Twelfth Report of the Vermont State Geologist, 1919-1920, p. 282.

waters find their way into Lake Memphremagog and thence into the St. Lawrence. The area under discussion includes a number of lakes and ponds, the highest of which is Long Pond, 1,700 feet above sea-level (Plate XII), whose outlet is Mill Brook which discharges into Lake Willoughby. Willoughby is the largest body of water (five and two-tenths miles long, one and one-fifth miles in maximum width, and 296 feet, maximum depth). The writer has determined its elevation as 1,155 feet above sea-level. It is fed by several brooks and by springs. The lake is glacially dammed at its northern end, where it discharges through Willoughby River into Barton River and thence into Lake Memphremagog. An artificial dam serves to regulate its level. Lake Willoughby is perhaps the most strikingly beautiful sheet of water in Vermont.

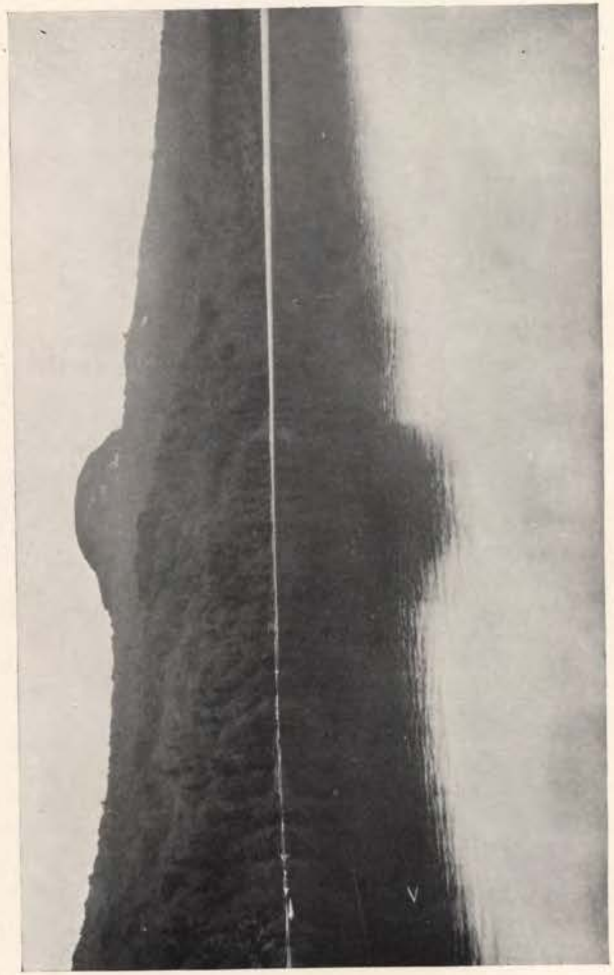
The height of land, before mentioned, which runs northwesterly from the Westmore Range, divides the drainage of the rest of the area under discussion between the Barton and the Clyde Rivers. Brownington Pond (1,000 feet elevation) lies in the northwestern part of Brownington and extends into the town of Derby. It is about three-tenths of a square mile in area and drains through a brook into Barton River. It furnishes a small water-power near the west border of the town. Farther south, Trout Brook flows swiftly down across the border of Brownington into Barton River. It will be again referred to under the caption of Geology.

The master stream in Charleston is the Clyde River, which rises in the high land of Brighton and flows northwesterly across the township, through Pensioner Pond and Salem Pond (the latter in Derby) and thence into Lake Memphremagog. On the south it drains the highlands which culminate in the Westmore Range, while from the north it receives the waters of Seymour Lake (in Holland) and Echo Pond. Echo Pond (Plate XIII) is about two miles long and somewhat less in width. It is said to be 150 feet deep. Pensioner Pond is four-fifths of a mile long by two-fifths of a mile wide. The village of West Charleston is located on the floor of the river valley. Above the village the waters of the river have been impounded by dams and furnish power for the Barton Electric Light Company and the Island Pond Electric Company, which furnish light and power for the towns of Barton, Orleans, Albany, Irasburg, Wheelock, Sheffield, Evansville, Westmore, and Island Pond.

GLACIATION.

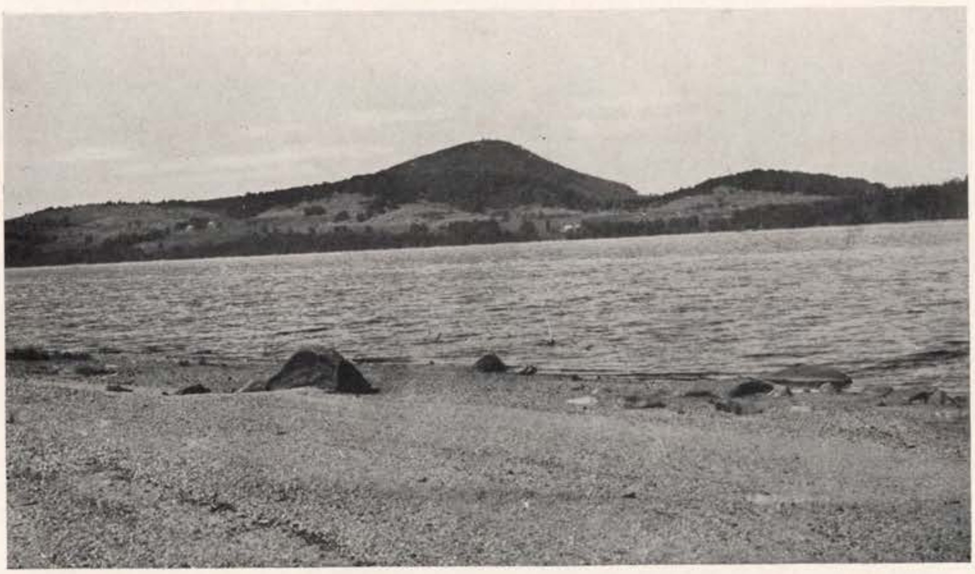
The whole region under discussion is heavily glaciated, displaying sand, gravel, boulder clay, erratics, kames, eskers, and other glacial forms. In West Charleston the Clyde River flows through a broad U-shaped valley, which has been cut through the north-east-trending ridges by combined stream and ice action.

PLATE XII



Long Pond, Westmore. Mt. Pico in the background.

PLATE XIII



Echo Pond, Charleston. Mt. Eland in the background.

There are the remains of small kames in West Charleston village, which are being used for road-metal; while west of the village long ridges of glacial till extend down from the valley walls, at right angles to the course of the river. Granite erratics are found on the great hills which form the valley walls. Following the State Road eastward, one finds hills and ridges of glacial till, which increase in size towards the eastern boundary of the township, and are accompanied by large granite erratics. Around Echo Pond one also sees abundant evidences of glaciation. The granite outcrops west and south of the pond are glacially smoothed and faintly striated, while just east of it are great banks of till. The pond itself (as well as all the other bodies of water in the region) is undoubtedly of glacial origin.

Brownington is thickly mantled with drift on its western border, and the Trout Brook has cuts its course through this material and down to bed-rock. The rest of the township is more thinly covered and fewer erratics are seen. The most interesting of these erratics is found on the east side of the road from Brownington village to Brownington Pond, just beyond the E. J. Carron farm. This is a boulder (Plate XIV) fourteen feet long, twelve feet wide, and five and one-half feet above ground. It is rounded and consists of a dark green matrix, in which are set a mosaic of small granite masses, the largest of which is nineteen by thirteen inches. There is another boulder of similar rock, but without the granitic inclusions, on the road from Brownington village to Coventry station, not far from J. E. Young's farm. In the eastern part of Brownington, on the country road from the "Center" to the County Road, there is a fine kame, a conical hill, some fifty feet high, composed of rather fine sand (Plate XV). The eastern border of Brownington, between the above point and Evansville, is a sandy plain, which continues to the northern shore of Lake Willoughby and forms the glacial dam. It deeply covers the underlying rock.

But in Westmore are found by far the most impressive evidences of past glacial action. The great trough, in which Willoughby partly lies, is probably due entirely to glacial gouging. The cutting which the ice sheet has done, here, is measured by the height of Mt. Pisgah above the lake and the bottom of the gorge which runs through the lake, some 2,900 feet. The lake basin is rock-rimmed on all sides, save the northern, where, as before stated, is dammed by glacial sand and gravel. At the southern end a moraine rises to a height of 120 feet, in the space of six-tenths of a mile, but granitic bed-rock is found a short distance farther south, emerging from the detrital material. Mount Hor rises precipitously from the west shore, while farther north the granite outcrops on the lake shore have been glacially smoothed. Above these, the granite on the promontory, rising 110 feet above the lake, and on which is located the girls' camp, "Songadeewin" (formerly Camp Westmore), is not only smoothed but is distinctly striated. These glacial scratches bear north, twelve degrees west. On the northeast shore, immediately north of the "Den," are also to be found glacial striations, bearing north, three degrees west. Glacial scratches were not found on the cliffs of either Mt. Pisgah or Mt. Hor, on account of the active erosion; but the granite outcroppings on the summit of Pisgah bear abundant evidence of ice action. South of the lake, on the road to West Burke, are found mounds of glacial till and several long, sinuous eskers. Glacial boulders, or erratics, are most numerous in the Willoughby region. They are mostly of granite, although a few are composed of green diabase. The largest erratic, the so-called Balanced Rock, is found on the old county road (not shown on the map) which formerly ran south, between Pisgah and Long Pond, before the lake-shore road was built. Balanced Rock is an enormous mass of granite, thirty-three feet high. Other large boulders, of undoubted glacial character, are found along the road to West Burke, while several occur on the summit of Pisgah. Running through Long Pond, there is said to be a channel, forty-five feet deep, bearing about north and south, which strongly suggests glacial deepening. Mount Wheeler, which lies on the border of Westmore and Sutton, is a great granite boss, whose northern profile is probably due to glacial "snubbing." Taken altogether, the lake region is an impressive example of past glacial action.

GEOLOGY.

The geology of the area embraced in this report is very simple. In West Brownington we have a continuation of the limestone which Richardson has described in his work on Irasburg and Coventry. In southeastern Westmore limestone is the dominant sedimentary and it extends up to the summit of Mt. Pisgah and Mt. Pico and is also found on the cliffs of Mt. Hor. East of the Brownington limestone, noted above, there is a broad belt of slate (Plate X) interbedded with limestone and, to some extent, with phyllite, which strikes northeasterly across Brownington and Charleston. Between this slate belt and the Westmore limestone there is a great area of phyllite, which makes up eastern Brownington, the greater part of Westmore, and nearly the whole of Charleston. Underlying these sedimentaries, according to the interpretation of the writer, there is an enormous bathylith of granite, which is responsible for the Westmore Range and outcrops here and there over the three townships, forming considerable hills, in places, and injecting the bedding-panes of the sedimentaries. The strike and dip symbols, shown on the map, around the Westmore Range, indicate how the strata have been warped and upraised by the granitic magma.

PLATE XIV

Erratic, Brownington.

THE LIMESTONE.

The limestone which makes up western Brownington and which is found interstratified with the slate and phyllite, in many more places than the map shows, is a fine grained, dark steel-blue rock, which corresponds perfectly to Richardson's "Washington Phase." Furthermore, the Brownington limestone and the Coventry limestone are contiguous and the writer has found crushed graptolites in the bed of Trout Brook, identical with those found by Richardson elsewhere in the State; so that there is no doubt but that we have here Ordovician limestone. The general strike of this sedimentary is east of north and the dip is northwesterly, both varying considerably as is to be expected where great igneous masses intrude sedimentaries.

In Westmore a few strata of limestone are found on the northeastern lake-shore, interbedded with phyllite and injected by granite. There is a good exposure, showing all three members, near Mr. J. G. Justis's house. As shown on the map, the country southeast of the Westmore Range is also made up predominatingly of limestone, with a few interbedded strata of phyllite, and this limestone extends eastward through Newark, Sutton, and Burke. The Westmore Range seems to have been raised up at about the junction of the limestone and phyllite, so that we have the eastern slopes of Pisgah preponderating in limestone, and the western in phyllite, both upraised and injected by granite. The same condition obtains on Mt. Hor, which was formerly continuous, across the great glacial trough, with Pisgah. All three lithologic members are found on Mt. Pico, the small, turret-like mass lying a short distance north of Long Pond, but only phyllite and granite were noted on Westmore Mountain, although the heavy forest mantle made anything like a careful examination impossible. Most of the limestone of the Westmore Range is made up of the "Washington Phase," but rock-falls of the lighter, variegated limestone show that the "Waits River Phase" exists in the range. Furthermore, the latter phase is found in the fields east of the range (in Stoddard's pasture, for instance) and also north of Westmore Mountain by Mad Brook, in southeastern Charleston.

But little limestone was found in Charleston aside from that noted above. The Charleston-Derby boundary is thickly mantled with glacial débris, so that rock exposures were not found. A more careful examination will be in order when the survey of Derby is undertaken.

THE SLATE.

This member forms a more or less continuous belt across western Brownington and Charleston, extends through Morgan and Holland and, no doubt, into Canada. It is much interbedded with limestone and phyllite—much more so than is shown on the map.

The slate is found well developed in the railroad cut just north of the Orleans station, where it is interbedded with dark blue limestone. Here we have a very dark gray rock, shot through with minute fragments of pyrite. Slaty cleavage is well developed but the fissility is slight and the slate has no commercial importance. A thin section of the slate shows a mass of well oriented, minute grains of quartz, orthoclase, sericite, and bleached biotite, with biotite predominating over the sericite. Some garnet grains, pyrite, iron oxide (from the weathering of the pyrite) and a little carbonate are noted. On a reconnaissance trip into Derby and Holland, slate of the same description was seen.

The slate in the area covered in this report is a mongrel, even poorer in quality than that just described, although the fissility is often more pronounced. It is much interbedded with limestone and phyllite, and in places, grades into the latter. And yet, it is to be distinguished from the phyllite and was not found, to any extent, east of the boundary shown on the map. Its dip is generally westerly and its strike, about north, 70 degrees east, roughly parallel to the most easterly belt of Richardson's Memphremagog Slate, which is shown in the northwest corner of the map.

East of Pensioner Pond, in Charleston, just north of the State Road, there is a peculiar sedimentary rock. It is dark, bluish gray, very fine grained, has no fissility but is so well jointed that it seems to possess slaty cleavage. Microscopically, it is seen to be made up, predominatingly, of fine shreds of a pyroxene and a chloratoid mineral, with quartz and orthoclase (the quartz predominating) and a good deal of carbonate. No sericite or biotite is noted. It is undoubtedly sedimentary and is nearer a phyllite than a slate.

THE PHYLLITE.

The dominant rock of the region under discussion is phyllite, which Kemp[1] defines as a rock intermediate between mica schists and slates. As shown on the map (Plate X) this phyllite makes up the sedimentary country rock in the area lying between the slate belt, on the west, and the limestone area lying east of the Westmore Range. It is interbedded with a limestone stratum or two and it has been intruded and upraised by the great granite batholith which underlies the whole area studied. Its strike is generally northeast and its dip, west of the Westmore Range, is generally northwesterly, but both strike and dip have been modified by the upthrust of the granitic magma, as shown by the strike and dip symbols on the map.

[1] Handbook of Rocks.

PLATE XV

Sand Kame, Brownington.

Around Lake Willoughby the phyllite is found above the northwest shore of the lake, on the plateau on which is located Camp Keewaydin (formerly Camp Westmore), as well as around the eastern shore, where it is interbedded in places with limestone and intruded by granite. All three rock members, in their typical association, are found just below the house of Mr. J. G. Justus, in Westmore village.

In the vertical rock face, by the watering trough, on the Willoughby shore road, phyllite strata, interbedded with limestone, and with granite intruded along the bed and joint planes, are found tipped up nearly vertically in the mountain mass and metamorphosed to a hard, dense rock, called "hornfels." hornfels

Phyllite is the dominant sedimentary member of the western half of the Mt. Pisgah ridge (limestone replaces it in the eastern half) and is also found on the cliffs of Mt. Hor.

On the high land west of the Westmore Range small masses of phyllite were broken off by the granitic magma, as it rose, and now appear as inclusions in the granite, forming "horses." Fine examples of such horses are also found on Burke Mountain. Phyllite also appears on Mt. Pico, where rock relations are similar to those on Pisgah, and on Westmore Mountain. None of it was found in southwestern Westmore, where granite forms the country rock. The phyllite is nonfossiliferous.

The best exposure of the phyllite is found in southeastern Brownington, where it is quarried by the Pike Manufacturing Company of Haverhill, N. H., and cut, at the mill in Evanston, into whetstones. The quarry has been worked for over fifty years, with the result that there has been excavated an opening, 150 feet long, 30 feet wide, and about 30 feet deep. The axis of the quarry is along the strike of the phyllite, which is here north, 30 degrees east. The dip is 13 to 18 degrees, westerly. On the east wall of the quarry a series of joint planes divides the rock into great blocks, some 28 feet wide. A sheet of granite, four or five inches wide, has been intruded along the bedding planes and its coarseness of texture beautifully illustrates the effect of slow cooling. The "baking" effect of this and of other sheets of the intrusive on the sedimentary rock is shown by the relatively greater hardness of the latter when in contact with the igneous member. The harder phyllite does not saw well and so has to be discarded as whetstone material. G sills hornfels

The phyllite is a medium gray, very dense, tough rock, whose bedding planes are covered with a very thin sheet of biotite and pyrite grains, which present a brilliant appearance. Oxidation of the pyrite gives rise to much iron stain on the rock. Near the quarry a beautiful example of rock disintegration was found, the phyllite weathering to soil, while still preserving its bed and joint planes.

PETROGRAPHIC DESCRIPTION OF THE PHYLLITE.

Thin sections of the whetstone phyllite, when examined under the polarizing microscope, reveal a mass of fine grains of quartz and feldspar (the quartz predominating) .35 by .18 millimeters maximum diameters, with short, stubby, basal sections of biotite and long, narrow laths of sericite, .30 by .04 millimeters, maximum dimensions, well oriented and giving the rock a strongly schistose structure. The biotite is the more abundant mica. The sections are thickly sprinkled with fine, graphitic dust. There is some chlorite present, suggesting the former presence of ferromagnesian minerals. A few short, stubby tourmaline crystals, .14 by .05 millimeters maximum dimensions, some wedge-shaped titanite crystals, and some pyrrhotite are also noted.

A chemical analysis of this interesting rock gave the following composition:

SiO_2	61.63%
Al_2O_3	18.79
Fe_2O_3	.97
FeO	6.14
MgO	1.94
CaO	.45
TiO_2	.78
K_2O	3.26
Na_2O	2.87
H_2O+	2.88
H_2O-	.02
	99.73

S & C, not determined.

The minerals present have too many elements in common to make recasting for percentage mineral composition possible, but the chemical composition clearly indicates a sedimentary origin for the phyllite.

It is not known how far this whetstone quality of the phyllite extends, since to the north it becomes lost in the heavy woods and glacial mantle, while to the south it is covered by the sandy plain which extends across southern Brownington to Evansville. To the west it is more intruded by granite and is unfit for cutting. Some of the same quality of the rock was found on the cliffs of Mt. Hor, but in no other part of the area studied.

A particularly interesting phase of the phyllite was found in Westmore, near the road leading across the height of land to Charleston, on the farm of Mr. John Hinton. We have here a light gray, schistose rock with minute, elongated crystal plates, whose long axes are parallel to the schistosity but whose short axes lie across it.

The thin section reveals a fine, meta porphyritic texture and a strongly schistose structure. In a ground mass of fine shreds of sericite and minute grains of quartz are set, at varying angles, metacrysts of chloratoid crystals and intergrowths of chloratoid

13th Rep

Phyllite

Westmore

155

156

157

159

161

164

fine dust

garnet?

over

and sericite, the largest, 1.1 by .9 millimeters. Small, elongated crystals of ottrellite and a few tourmaline sections are seen. Iron sulphide was evidently introduced and crystallized into pyrite and pyrrhotite, previous to the consolidation of the sediments, for they now appear as elongated grains, conforming to the schistosity. The whole section is shot through with fine, graphitic dust. Strain shadows in the chloratoid, seen near extinction, bear witness to the compressive forces which consolidated the rock. This phyllite is a fine example of the regional metamorphism of a fine sediment and the complete recrystallization of its mineral constituents.

On the western slope of Westmore Mountain, phyllite strata were found, nearly black in color and with fine, glittering scales of black mica. The section shows a ground mass of quartz grains (with a few of orthoclase), sericite and biotite, metacrysts of biotite and sericite (1.5 by .65 millimeters, maximum dimensions), and a few patches of chlorite. There are much graphitic dust and pyrrhotite.

In the slate belt, in Brownington, there are phyllite strata of a mixed type. The sections show much biotite and quartz and small intergrowths of them, graphitic dust and introduced sulphides as usual, and the appearance of carbonate. The biotite occurs often as metacrysts, set transverse to the schistosity. The rock is more nearly a slate than a phyllite, texturally, but possesses no fissility and no slaty cleavage.

Farther west in Brownington, on the Chabot farm, we have a calcareous phase of the phyllite: a nearly black, fine-grained, glistening rock, which freely effervesces with acid. The sections show a fine ground-mass of much quartz (.05 by .05 mm.), a little feldspar and fine shreds of sericite, in which occur metacrysts of bleached biotite set across the schistosity, and laths of sericite. Some ottrellite crystals, much graphitic dust, and elongated grains of pyrrhotite were also noted. Considerable carbonate (probably dolomite) is scattered through the slide, but this is decidedly a minor constituent.

The phyllites of Charleston also present interesting phases. The continuation of the whetstone quality of Brownington was not found, but in the southwestern part of the township there is a very fine-grained, gray variety, which lacks the glittering appearance of the whetstone rock, but resembles it texturally. A thin section of this Charleston rock shows the common constituents of phyllite: a fine ground-mass of quartz, sericite and a little feldspar, with metacrysts of biotite, tourmaline and ottrellite crystals, much mineral dust and considerable pyrrhotite. Grossularite is present and large sections (.8 by .4 mm.) of staurolite are seen.

In the eastern part of Charleston, along Mad Brook, there is found a grayish-black, fine-grained, schistose rock, which one hesitates to classify. The sections show a strongly schistose structure and a meta-porphyritic texture. The groundmass is made of up quartz, orthoclase, microline, microperthite, and plagioclase, shot through with graphitic dust. In this groundmass are set well-oriented laths of sericite and irregular, basal sections of biotite, which produce the schistose structure. There are garnets and a considerable development of titanite. Pyrrhotite is present, as usual, but no chlorite or ferro-magnesian minerals is seen. The rock is more nearly a mica schist than a phyllite, but it is far from typical in general appearance.

SUMMARY OF THE PHYLLITES, AND NAME SUGGESTED FOR THEM.

The phyllites studied are gray, highly schistose rocks, which have been formed from fine sediments by metamorphic processes. A more or less complete recrystallization of the original material has taken place, producing secondary muscovite (sericite) bleached mica (also probably secondary), garnet, chloratoid, ottrellite, tourmaline, staurolite, etc. The constant presence of graphitic dust is noteworthy. This rock has been shown by the writer through his field studies and reconnaissance, to extend north and south across the eastern part of Orleans County, while Richardson mentions belts of it in the western part. It, therefore, constitutes a distinct rock formation in the State and is entitled to a name. Richardson's rather inclusive term, Bradford Schists, perhaps embraces it. It is not a typical schist, however, but a phyllite, which the writer has studied at length in all its aspects. He, therefore, suggests for it a name, the Orleans Phyllite.

THE GRANITE.

The whole area covered by this report is probably underlain by a great batholyth of granite, which is largely responsible for the present topography. It has injected and upraised the phyllite and limestone in eastern Westmore, forming the Westmore Range. It underlies most of Lake Willoughby's bed, forms the country rock in southwestern Westmore and, it may be stated, almost the whole of the township of Barton. Around Echo Pond (Plate XIII) considerable areas of granite are exposed and outcrops of it are noted, in smaller masses or as intrusions, in the sedimentaries throughout the whole area studied, as shown on the map. Wheeler Mountain and the neighboring Kimball Hill (the latter not shown on the map) are great bosses of solid granite, with no sedimentary strata included. Mr. Hor, Mt. Pisgah, and Mt. Pico, are made up of granite, limestone and phyllite, with the granite decreasing in proportion from Hor to Pico. Granite crops out around Long Pond (Plate XII) and forms the tiny island in its waters. Westmore Mountain (Plate XVI), the dominating

PLATE XVI

Westmore Mountain.

topographical feature of the region, is a cone-shaped eminence, 3,150 feet above sea-level, and is made up of granite and phyllite, but in what proportions it is difficult to say, because of the heavy woods and glacial mantle. The photograph shows faintly granite cliffs on its southeast side. Probably at some time, when these were more prominent, because of the lighter growth of timber, the other name, Bald Mountain, was given it.

Very interesting effects of the assimilating action of the granitic magma on the country phyllites are to be noted in this region. On John Hinton's farm, west of the Westmore Range, small inclusions, or "horses," of phyllite in the granite occur and it is probable that, were the granite on this neighborhood analyzed, it would be found to have been modified by the sedimentary rock assimilated by it. On the summit of Burke Mountain these horses are much larger and the included and assimlated sedimentary rock produces a mongrel and worthless granite.

PETROGRAPHY.

The granite of the region studied is a light colored quartz-monzonite, by which is meant one in which "the amount of soda-lime feldspar about equals or exceeds that of the potash feldspar."[1] The texture of the granite varies widely. On the cliff of Wheeler Mountain it is so coarse that feldspar masses five or six inches in diameter are found. On the cliffs of Hor and Pisgah very coarse, crumbly granite occurs. Cutting the coarse rock are found dikes of fine-grained aplite. Around Echo Pond, in Charleston, and on the farm of Mr. F. E. Hitchins, in western Brownington, the granite is finer textured, sound, and fit for building material. In other places, where the granite has intruded the sedimentaries, along their bedding planes, it is coarsely crystalline and muscovite flakes, 0.3 to .4 mm. in diameter are found.

Sections of the granite from the cliffs of Mts. Hor. and Pisgah show, in decreasing order of abundance: (1) quartz, much cracked and strained, with fluidal cavities in linear arrangement, maximum size of grain, 1.6 by 1 mm.; (2) milk-white plagioclase (oligoclase) a little saussuritized; (3) microcline and microperthite; (4) orthoclase, very little altered; (5) biotite and muscovite in about equal proportions, maximum size, 1.5 by .4 mm.; (6) accessories, apatite needles, titanite, very little saussurite and kaolin, very little pyrite and a slight amount of carbonate.

The Charleston granite, around Echo Pond, is practically the same as that just described. It has been quarried and used for building purposes.

In western Brownington, northwest of the village, granite is exposed on the flank of a large hill. This may, indeed, be a granite boss. On the Hitchins farm the granite is studded to

[1] T. Nelson Dale, The Granites of Vermont. Report of the Vermont State Geologist, 1907-08.

Xenoliths

some extent with nodules of biotite, about 1¼ inches in diameter, somewhat resembling the orbicular granite of Craftsbury. The mineral constituents are quartz, containing no fluidal cavities but many fine shreds of muscovite; palgioclase (albite rather than oligoclase), microperthite, orthoclase, more altered than that of the Westmore Range; microcline; muscovite, in prismatic sections, as well as fine shreds; feldspar, and very little biotite. The accessory minerals are: apatite in fine needles; considerable rutile in well-bounded crystal sections, and in irregular grains; kaolin and saussurite. The granite is considerably more kaolinized than that of the Westmore Range. The biotite has evidently been segregated into the nodules and so is present in much smaller quantity in the sections.

ECONOMICS.

The economic wealth of the townships studied lies in the soil rather than in the rocks. As already noted, granite of commercial grade occurs in western Brownington and eastern Charleston, but transportation difficulties prevent its use for other than local purposes. But parts of Brownington and Charleston are well adapted to agriculture and many fine farms and dairies dot the landscape. The cause of the fertility of the soil is the decomposing phyllite, whose content of potash (3.26% in the sample analyzed) furnishes this constituent of plant food in considerable quantity.

THE GEOLOGY AND PETROGRAPHY OF RANDOLPH, VERMONT

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INTRODUCTION

The report upon the Geology and Petrography of Randolph, Vermont, is of necessity brief. It may best be considered as one of progress in the solution of the many intricate geological problems of the eastern half of the State. Its purpose is to present in concise form new work done on the microscopic examination of the rocks from Randolph, Vermont, and to draw therefrom conclusions as to their origin and mineralogical composition.

The township of Randolph, Vermont, is located near the central part of State, approximately 30 miles south of Montpelier, the Capital of the State. It is further situated in the western part of Orange County. It lies between north latitude 40 degrees and 0 minutes, and 43 degrees and 52 minutes, and west longitude 72 degrees and 31 minutes and 72 degrees and 42 minutes. Randolph is bounded on the north by Brookfield, on the east by Tunbridge, on the south by Bethel and on the west by Braintree.

There were four reasons for the selection of this area. (1) It lies to the southeast of Braintree, Vermont, which area was described by the above named authors in the "Geology and Mineralogy of Braintree, Vermont," published in the Biennial Report of the State Geologist for 1919-1920. It, therefore, makes the work continuous in a southeasterly direction in the eastern half of the State. It falls in the line of the erosional unconformity between the Upper Cambrian and the Ordovician formations on the eastern side of the Green Mountains. (3) The presence of a large number of basic intrusives which invited a careful petrographic study of both the sedimentary and intrusive rocks. (4) The fact that no detailed petrographic work had ever been done upon the sedimentaries and basic intrusives.

The first named author traversed this area in reconnaissance work in 1895. Some of the results of this investigation were published under the title, "The Terranes of Orange County, Vermont," in the Biennial Report of the Vermont Geological Survey for 1901-1902. In the summer of 1919 both authors, together with W. D. Macumber, took up a detailed study of the geology and mineralogy of the township. The field relations were found intricate and difficult. Some of the rocks were so highly metamorphosed that it was impossible in the field to tell with definiteness whether they were of sedimentary or of igneous origin. The township is hilly and a part of it is densely wooded and difficult to work in an east and west direction across the strike of the different formations. The intrusives were found to be far more abundant than was formerly supposed, for this area has always been mapped as purely sedimentary with a single limited granitic intrusive.

An areal map showing the general distribution of the terranes in Randolph accompanies this report as Plate XVII. A cross-section is drawn practically at right angles across the strike of the formations and through the center of the township. It is regretted that no topographic map was available, so that the intrusives might be located with greater definiteness.

Many new samples were collected in the field. These were trimmed to regulation size, 3 by 4 inches, and placed in the museum at Montpelier. From 37 of the duplicate samples, microscopic slides were prepared for the detailed petrographic study.

The authors recognize their indebtedness to T. Nelson Dale of the United States Geological Survey in the study of the quartz monzonite of Randolph, to Prof. Louis Wade Currier of Syracuse University for his kindly assistance in checking up unexpected minerals in the slides and to W. D. Macumber for his assistance in the field.

DRAINAGE.

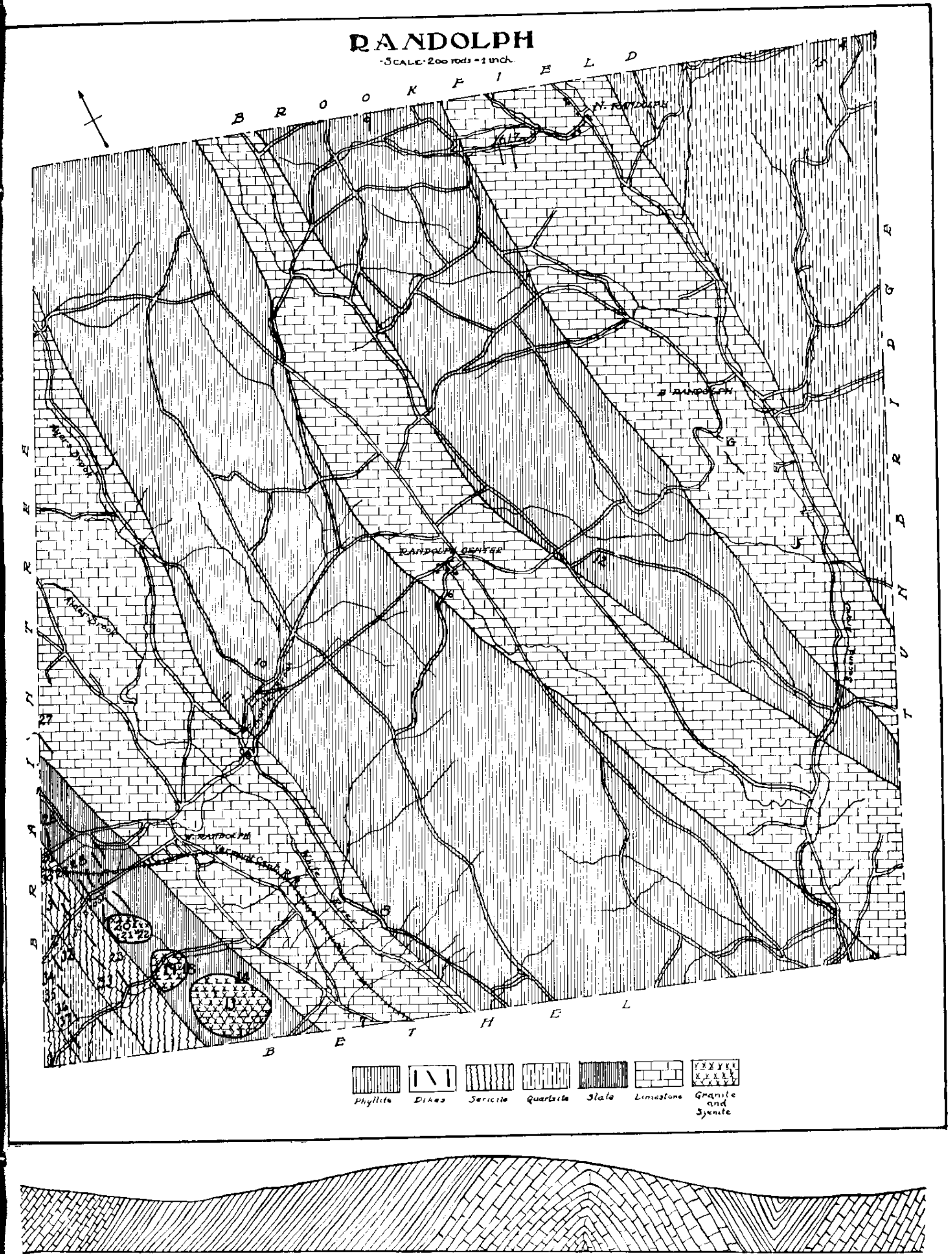
The main drainage of Randolph is received by the White River which flows in a southeasterly direction into the Connecticut River at White River Junction. The three major streams forming the White River are the Third Branch of the White River which flows in a southeasterly direction through the valley of the Central Vermont Railroad, Alder Brook which flows southerly from East Braintree into Randolph and Chandler Brook which rises in the northern part of Randolph and flows in a southwesterly direction into White River. There are numerous small tributaries to each of these streams.

The eastern part of Randolph is drained by the Second Branch of the White River. This stream flows from Brookfield in a general southerly direction through Randolph and empties into the White River in Bethel. The Second Branch also has numerous tributaries.

TOPOGRAPHY.

The main valley is the one which the Central Vermont Railroad traverses. It extends in a somewhat semicircular form across the southwestern corner of the township. It is a broad U-shaped, fertile valley. The valley through which Ayers Brook flows in the western part of Randolph is also a U-shaped valley.

PLATE XVII



The eastern part of the township is traversed by the broad U-shaped valley of the Second Branch of the White River. This valley is roughly parallel with Alder Brook valley. The White River valley, the Third Branch of the White River, Alder Brook and the Second Branch valleys are all pre-Glacial.

There are numerous transverse valleys that are V-shaped and in part at least post-Glacial. This would hold particularly true of Thayer Brook in the southwestern part of the township, Gifford Brook in the eastern part and Randolph Gulf Brook in the northeastern part.

The altitude of the village of Randolph is 691 feet. Braintree to the northwest is 777 feet, and Bethel to the southeast is 569 feet. To the east and the west of the broad U-shaped valleys the altitudes rise rapidly and steep ridges that are now pasture lands are common. An excellent illustration of this fact can be found on Crompton Hill near the village of Randolph and to the east of the Ayers Brook valley in the northwest part of the township. It can also be observed both to the east and the west of the village of East Randolph. Altitudes of 1,000 to 1,200 feet were not uncommon on the highest ridges.

GLACIATION.

The township of Randolph is mantled with morainic material to such an extent that the geologist is seriously hampered in the study of the field relations of the different geological formations. This holds especially true in the southwest corner of Randolph, where the area is in part densely wooded and where the basic intrusives are the most abundant. Often the continuous outcrop of a given dike can be followed only for a short distance on account of the heavy overburden of glacial drift.

Evidences of glaciation and the general direction of the ice movement can be found in the striations still remaining on the more resistant rocks. The well-exposed outcrops of nearly pure white, secondary, vein quartz are particularly prone to retain this evidence. The resistant phyllites and the Cambrian quartzites occasionally afford excellent illustrations of glacial grooves. Three different sets of striations were recorded in Randolph. These were due south, south 20 degrees east, and south 30 degrees west. These directions were all found on a well exposed outcrop of garnetiferous phyllite schist, either on or near the Moulton farm on the east side of the White River. A direction of south 25 degrees west was also recorded in the White River valley.

The terminal moraine of recession has left boulder trains in its course and often by following in the direction of the boulder train the intrusive rock was discovered which gave rise to these erratics. Sometimes an intrusive that appears as a dike only a few feet in width has given rise to many erratics. The numerous sand and gravel deposits in the valleys represent the outwash of the terminal moraine of recession that traverses the adjacent area to the north of Randolph.

GEOLOGY AND PETROGRAPHY.

The geology of Randolph, like the geology of other townships in eastern Vermont is intricate and complex. The terranes consist of a series of highly folded and faulted metamorphic rocks. These sedimentaries always dip at a high angle and are are often cut by intrusives. These intrusives are both acidic and basic in character, but the basic members predominate. The sediments, as well as the intrusives, differ widely in age and in their mineralogical composition. A careful study of their field relations has been necessary to avoid the introduction of errors in their interpretation. Thirty-seven microscopic slides have been prepared from Randolph alone. The detailed study of these slides, together with study of forty-two slides from Braintree, has brought out some new facts that are exceedingly interesting. These facts will be discussed together with the intrusives.

In the southwestern part of the township the stratigraphy has been determined largely by apparent field relations and the study of the microscopic slides. In the remainder of the area the stratigraphy has largely been determined by the discovery of new beds of graptolites in both the impure slates and the shaly limestones. The graptolites, however, are not as numerous or as well preserved as they are in the slates of Braintree, Roxbury, Northfield, Berlin and Montpelier. They are less abundant also in the shaly limestones in Randolph than they are in the limestones in the more northern townships.

ALGONKIAN.

The Algonkian terranes do not appear in Randolph. Apparently they occur in the southwestern part of Braintree, which township joins Randolph on the northwest. They are present in the extreme western part of Northfield as a highly feldspathic mica schist or else as Algonkian gneiss.

CAMBRIAN.

The term Cambrian as here used signifies a group of highly metamorphosed sedimentary rocks which lie between the eastern foothills of the Green Mountains and the erosional unconformity that separates the pre-Ordovician from the Ordovician. These formations consist of hydromica schists (present in Braintree but wanting in Randolph), sericite schists, chlorite schists and quartzites. These formations occupy only a limited area in southwestern part of Randolph. They are considered to have been derived from the erosion of the Algonkian terranes to the west.

The verd antique marble beds and the talcose schists or talc schists are all within the Cambrian terranes.

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

HYDROMICA SCHISTS.

The hydromica schists which form a prominent terrane in Braintree and continue northward for more than 100 miles are wanting in Randolph. This does not imply that their southern limit has been reached, but rather that their normal position falls to the west of Randolph. The hydromica schists are fine grained, greenish, schistose, sedimentary rocks which are more or less associated with chlorite. If the original mica of these schists was biotite, it has in many instances been largely altered to chlorite. Whether the typical hydromica schists will be encountered in the western part of Bethel, which township joins Randolph on the south is a matter of conjecture. Chloritic rocks are known to be well represented and it will require careful field work and petrographic study to determine their origin.

MISSISQUOI GROUP.

The term Missisquoi Group as here used is made to include the sericite schists, quartzite and the chlorite schists that are of sedimentary origin. The quartzite is always sericitic and is simply a highly quartzose phase of the sericite schist. The chlorite schists that cut the sericite schists and the sericitic quartzite at a high angle cannot be regarded as of sedimentary origin, but some of the chlorite schists in eastern Vermont are parallel with rocks of unquestioned sedimentary origin and are probably themselves highly metamorphosed sediments. All the terranes of the Missisquoi Group are of Cambrian age or, at least, they are pre-Ordovician.

SERICITE SCHISTS.

The sericite schists of the Missisquoi Group have been continuous from the international boundary on the north southward for more than 100 miles. Throughout the entire distance they everywhere flank the Ordovician terranes on the west and become the easternmost member of the Cambrian group. In Braintree the sericite schists occupied a greater area than all other formations combined, but in Randolph they are limited to a rather small area in the southwestern part of the township. These schists stretch across this corner in a southerly direction. They form two belts which are separated from each other by a narrow belt of sericitic quartzite. Perhaps this should have been mapped as sericite schist. Where the sericite predominates the rock is classified as a sericite schist. Where the well rounded quartz grains are in large excess over the mica the rock is classified as a quartzite. In some instances the sericite schist becomes decidedly talcose as in limited areas in the southwestern corner of Randolph near the southeastern corner of Braintrée and here the narrow bands are catalogued as talcose schist.

The general strike of the sericite schists is north and south but outcrops were recorded with strike north 10 degrees east and north 10 degrees west. In Braintree to the northwest of Randolph the average strike was north 30 degrees east.

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

The sericite schists of eastern Vermont are thinly laminated, metamorphic rocks, which split more or less readily along certain planes approximately parallel.

Two different modes of presentation of the petrographic data are possible. (1) To list all the slides at the close of the general discussion. (2) To list them as far as possible under the discussion of each particular group. The latter method has been chosen. The numbers refer to the numbers on the areal map which accompanies this report.

No. 1. Megascopically this rock is fine to medium grained, somewhat greenish, schistose and metamorphic. Microscopically its texture is fine grained and granular. The essential constituents are sericite and quartz. The accessory minerals are magnetite, apatite, garnet and pyrite.

Among the secondary minerals there is quartz which has been secondarily introduced, for it is found in sharp, angular grains surrounding well water-worn grains, and occasionally in narrow bands. Limonite also occurs as a secondary mineral derived from the oxidation and hydration of pyrite. The staining of the rock by limonite follows in the direction of schistosity.

According to J. P. Iddings, sericite is an aggregate of microscopic crystals with anhedral shapes, usually in scale-like plates, either in diverse positions or in clusters of curved or radiating scales. It has a silky luster.

According to N. H. and A. N. Winchell, sericite is a fine, scaly or fibrous damourite. The name is sometimes applied to unaltered muscovite. The cleavage laminæ are flexible but lose their elasticity as the change progresses. At the same time the angle of the optic axes decreases from 70 degrees to nearly uniaxial.

In slide No. 1 the sericite appears in very small flakes of a fibrous and silky appearance and is banded with fine grained, rounded crystals of quartz, thereby indicating the sedimentary origin of the rock. The quartz is slightly in excess of the sericite. The presence of good crystals of pyrite, the abundance of accessory magnetite and the absence of feldspars are noteworthy features of this slide.

No. 2. Sericite schist. Megascopically this rock is fine to medium grained, silvery white, schistose and granular. The essential minerals are sericite and quartz. The accessories are apatite, magnetite and pyrite.

The secondary minerals are limonite and what appears to be zoisite. The zoisite has extinction parallel to the long axis which was shown to be the direction of the Alpha ray. The mineral is embedded in sericite which has an index of refraction of 1.564 to 1.619. The zoisite exhibits high relief against this background, for it has an index of refraction of 1.699 to 1.720. The fragments were too small to give a satisfactory interference figure, so that the optical character of the mineral was not determined.

The rock is predominantly sericite with quartz grains filling the spaces about the sericite scales. The paucity of free quartz and the banded arrangement of the sericite in needles and scales are noteworthy features.

In origin the rock was probably derived from the metamorphism of an argillaceous sediment. The abundance of corroded apatite crystals supports this theory, although this is not regarded by some authors as absolute proof.

According to E. T. Wherry, the abundance of rounded quartz grains in certain slides and the higher silica and alumina content of slides richer in sericite are more commonly associated with sedimentary than with igneous formations. Large, round garnets with pale colors are characteristic of metamorphosed sediments. The presence of well rounded grains of zircon is strong presumptive evidence of sedimentary origin. Corroded apatite crystals are characteristic of metamorphosed sediments rather than igneous rocks.

QUARTZITE.

The Cambrian quartzites have appeared in every township southward from the international boundary through which the erosional unconformity between the Cambrian and Ordovician terranes has been traced. This distance is more than 100 miles. In some instances the outcrops appear fairly uniform in width, while in others the formation is quite lenticular. In Randolph it is very narrow and micaceous. The quartzite is flanked both upon the east and the west by a band of sericite schist.

In Randolph the Cambrian quartzite is found only in the southwest corner. Its strike is nearly north and south and its prevailing dips are at a high angle to the west. It graduates insensibly by the increase of sericite and the decrease of quartz grains into the sericite schist which is of the same age. The quartzite represents the more arenaceous sediments of the Upper Cambrian.

No. 3. Sericitic quartzite. Megascopically this rock is fine to medium grained, silvery white and metamorphic. The essential minerals are quartz and sericite in about the ratio of 7 to 5. The accessory minerals are magnetite, corroded apatite, oligoclase, biotite and pyrite.

The secondary minerals are some of the quartz, limonite derived from pyrite, and chlorite derived from biotite.

The quartz grains are much larger than they are in Nos. 1 and 2. They are angular in form and arranged with the sericite in schistose banding. In the field the rock is pronouncedly schistose. From the arrangement of the quartz grains and the fact of their angularity and the way they fill all the spaces in and around the sericite it is assumed that the quartz has recrystallized since its original deposition. This is in accordance with the definition of Arthur Holmes that a quartzite is a granular metamorphic rock, representing a recrystallized sandstone, consisting predominantly of quartz. The name is also used for sandstones and grits cemented by silica, which has grown in optical continuity around each fragment.

In the Missisquoi Group in eastern Vermont all gradations can be found from rocks consisting almost wholly of fibrous or scaly sericite to those equally rich in quartz grains.

CHLORITE SCHISTS.

If any of the chloritic rocks of Randolph are of sedimentary origin, then these schists belong here in the Missisquoi Group. If they are igneous in origin, as many of them are definitely known to be, then their discussion belongs under the caption of intrusives. Under this caption, evidence will be presented to prove an igneous origin of many of these chloritic outcrops.

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

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

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

ORDOVICIAN.

The term Ordovician as here used embraces a group of metamorphic sediments that lies to the east of the Cambrian terranes already described. These two groups are separated from each other by an erosional unconformity that has been traced in a northeasterly and southwesterly direction for more than 150 miles. It extends northward into Canada for a considerable distance and southward from Randolph through Bethel and Barnard. The Ordovician terranes consist of limestones, marbles, calcareous quartzites, phyllites and slates.

IRASBURG CONGLOMERATE.

No outcrops were found in Randolph that presented the striking characteristics of this conglomerate as seen in Irasburg, Albany and Northfield. Apparently erosion has not been carried as low in the Ordovician formations in Randolph as it has in Albany and Irasburg. However, the erosional unconformity between the Cambrian and the Ordovician extends southward through Randolph.

QUARTZITE.

In the extreme northeastern part of Randolph there occurs a belt of quartzite. Its strike is nearly north and south and its dip is always at a high angle. Its greatest width as represented in Randolph is in the extreme northeastern part of the township. It narrows rapidly to the southward and soon disappears from the township. In certain sections calcium carbonate is wanting, while in others this quartzite is strongly calcareous. It must not be confused with the sericitic quartzite which is of Cambrian age.

No. 4. Megascopically this rock is fine grained, granular, schistose and metamorphic. In color it is silvery white. Megascopically it is finely granular. The only essential mineral is quartz, usually in fine grains but with a few larger grains intermixed. As accessory minerals there are garnet in the form of a large corroded crystal, an appreciable amount of a green amphibole, actinolite, a few scattered crystals of apatite, a few crystals of chlorite and a little magnetite.

The secondary minerals consist of a few crystals of biotite, muscovite, chlorite, calcite, limonite and some of the quartz.

The well rounded quartz grains indicate a sedimentary origin of this rock. This conclusion is substantiated by the corroded crystals of apatite and garnet. The quartz grains have been cemented together by a secondary deposition of silica, which brings this rock well within the range of the quartzites.

WAITS RIVER LIMESTONE.

The Waits River limestone traverses Randolph in three belts separated from each other by belts of phyllite. The series includes limestones, quartzose marbles, calcareous quartzites, or calcareous quartz schists. No attempt has been made in the mapping to distinguish one phase of these calcareous rocks from another. In general the western belt is finer grained and darker colored. This holds especially true in the northwestern part of the township. Here the limestone becomes quite shaly. The eastern portion of the western belt carries the quartzose marbles. Some of the beds around Randolph Center are true quartzose marbles. The eastern belt is the more highly quartzose. Some of the beds should be catalogued as calcareous quartz schists. Other beds in the same belt are quartzose marbles. A good outcrop of the calcareous quartz schist is found up Gifford Brook in the eastern part of the township.

The strike of these calcareous beds is nearly north and south. The dip is at a high angle, usually to the west, but easterly dips were recorded. Along Gifford Brook there are some very sharp anticlines and synclines of small breadth.

No. 5. Calcareous quartz schist. Megascopically this rock is fine grained to medium grained, grayish, schistose and metamorphic. Microscopically its texture is granular. The essential constituents are quartz and calcite in approximately equal amounts. The quartz grains are somewhat rounded but appear to have been recrystallized. The accessory minerals are magnetite in parallel bands, muscovite and biotite. There is present a little carbonaceous matter which may be regarded as of secondary origin. It imparts a grayish color to the rock.

The name quartzite could not be used for this rock with justification, as that requires that the major part of the cementing material should be quartz itself, deposited around the original quartz sand. In the present instance, the cement is neither quartz entirely, nor is it calcite entirely. The calcite is in grains of about the same size as the average quartz grains. The calcite appears to be recrystallized from the calcareous sediments of the original rock rather than as cementing material binding the sand grains together. The lack of siliceous cement in large amount prevents the use of the term quartzite for this rock. The presence of 50 per cent. of quartz prevents the use of the term quartzose marble.

No. 6. Waits River marble. Megascopically this rock is fine grained, banded gray and white, plicated and metamorphic. Under

the microscope it is granular, but with the grains much larger than in the preceding slide.

The essential minerals are calcite and quartz, which is rounded and granular. As accessories there are garnet and muscovite, the former being very small and the latter arranged in parallel lines.

A marble may be defined as a metamorphosed and recrystallized limestone. In many cases, however, there are various amounts of other substances such as clay, sand, and organic matter, depending on the type of limestone which has been metamorphosed and in some measure on the amount and type of metamorphism, also on materials introduced during metamorphism.

In the marble of this slide there are large amounts of quartz which may have been derived from a quartz vein secondarily introduced into the marble. In the field many quartz veins are encountered. The calcite is well crystallized and twinned in some cases, while in others it is fibrous and mixed with a considerable amount of organic matter. The organic matter imparts the grayish color to the rock.

This slide conforms closely with the type locality, Waits River, in the township of Topsham. This slide shows no pyrite as do some slides of the same formation from other localities. A noteworthy feature is the absence of biotite, which is so often recognized in the Washington phase.

No. 7. Quartzose marble. Megascopically this is a fine grained, compact, metamorphic rock. Microscopically it is granular. The essential minerals are calcite and quartz. The accessory minerals are apatite, magnetite and carbonaceous material.

Muscovite is the only secondary mineral present. It occurs in small, narrow crystals which show blue intereference colors and straight extinction.

The quartz grains are somewhat rounded. There is little or no evidence of the sorting of calcite and quartz, thereby producing schistosity. Some of the quartz grains suggest the replacement of calcite, for some of them are partly idiomorphic and an occasional grain of quartz is completely surrounded by calcite.

This marble is about 60 per cent. calcite and about 40 per cent. quartz. The two are intimately mixed, not banded or segregated. Therefore it represents the Washington phase. The angularity of the quartz grains suggests that the calcareous and siliceous muds from which the rock was derived were not subjected to long-continued water action.

MEMPHREMAGOG SLATES.

The Memphremagog slates of Newport, Montpelier and Northfield appear also in Randolph. These slates flank the eastern belt of the Cambrian sericite schists on the east. Furthermore they lie west of the westernmost belt of the Waits River limestone. The slates appear only as a narrow belt in the southwestern part of the township. Perhaps they should all have been mapped in as phyllite, yet some narrow beds still retain the characteristic ring and cleavage of slate. However, there are many beds of phyllite in the area mapped in as slate, and none of the slate is a commercial possibility.

These slates constitute a series of fine grained, dark bluish-gray to black, schistose, metamorphic rocks. In a slide from this formation in Braintree the slate appears scaly and fibrous. The essential constituents are mica, mostly muscovite but with some sericite, and quartz. The accessory minerals are magnetite, pyrite, garnet and graphite. An iron stain results form the oxidation of the pyrite and the leaching out of the oxides formed gives rise to small cubical holes in the loose slabs of the slate. Calcareous bands are often found in the area mapped in as slate.

PHYLLITE.

Randolph is traversed by two belts of phyllite. These belts are flanked both upon the east and west by belts of limestone. The eastern belt extends southeasterly into Tunbridge and the western belt southerly into Bethel. The eastern belt narrows to the southward and the western belt widens. Even these beds of phyllite may be intercallated with beds of limestone and in the area mapped as marble small beds of phyllite were present. Without topographic maps the mapping is only an approximation. These phyllites are more resistant to erosion than the associated limestones and marbles and, therefore, they form the more prominent ridges in this township. They have apeared in every township southward from the international boundary for more than 100 miles. Sometimes they occur as lens-shaped outcrops, and sometimes they have traversed the entire township. They are of the same age as the Memphremagog slates and belong to the Mempremagog group. This is clearly evident in Newport, and is everywhere apparent as these formations are traversed to the southward.

These phyllites are foliated metamorphic rocks of sedimentary origin and argillaceous composition, intermediate between the slates and the true mica schists. They are more micaceous than the slates and more finely crystalline than the mica schists. Their fracture is intermediate between the smooth even cleavage of the slates and the rather splintery fissility of the schists.

No. 8. Phyllite. Megascopically this rock is fine grained, even textured, bluish-gray and metamorphic. Microscopically it is finely granular. The essential minerals are muscovite, variety sericite, and quartz. As accessory minerals there are magnetite, pyrite, garnet and graphite.

The muscovite is in very fine scales or fibers and the original quartz grains are small and well rounded, therefore, schistosity is very fine. The rounded garnets are small and show the optical anomaly of double refraction. The magnetite is fairly abundant and arranged somewhat in parallel lines. A part of the pyrite is surrounded by quartz. A part of the silica is in large angular grains filling the interstices in the muscovite. These quartz grains were secondarily introduced for they contain crystals of pyrite. The carbonaceous matter is very abundant and evenly distributed. Limonite stain appears as a secondary product. The rock might be called a graphitic phyllite. It was derived from the metamorphism of argillaceous sediments containing much organic matter.

No. 9. Biotite schist. Megascopically this rock is fine grained and grayish. Microscopically it is granular.

The essential minerals are quartz and mica, variety biotite. The biotite in part is in plates set transverse to the planes of foliation of the rock. The accessory minerals are magnetite, muscovite and garnet.

The quartz grains are small, fairly well rounded and arranged with muscovite in parallel bands. The muscovite shows blue interference colors. The biotite is in large flakes showing strong pleochroism and parallel extinction. The magnetite is in zones showing the effect of metamorphism. There are several small garnets. One is much corroded with its irregular fracture cracks not in the same direction as the schistosity of the rock.

The secondary minerals are limonite and garnet. The limonite was derived from pyrite. The garnet may possibly have been derived by replacement of the original material. The origin of the rock is the metamorphism of siliceous and argillaceous sediments.

No. 10. Quartzite. Megascopically this rock is fine grained, dark gray, schistose, and metamorphic. The only essential constituents are quartz and muscovite, in part the variety sericite. The accessories are pyrite, magnetite, apatite and garnet. The little grains of magnetite follow the lines of schistosity. Some of the rounded quartz grains are surrounded by angular quartz showing the evidence of recrystallization.

The secondary minerals are limonite, which appears as a yellow stain, a little chlorite possibly derived from biotite, and one large garnet which appears to have pushed aside the mica and quartz during its formation.

The quartz content exceeds 90 per cent. of the rock mass. Therefore there is sufficient reason for naming this slide, a quartzite. In origin the rock was derived from a siliceous sediment and the quartz grains recemented by silica.

No. 11. Quartzite from fault zone. Megascopically this rock is fine grained, dark gray, schistose, and metamorphic. Microscopically it is fine grained and granular.

The only essential mineral is quartz. The accessory minerals are muscovite, a few small flakes of biotite, magnetite, garnet and pyrite.

Limonite from the alteration of pyrite is very abundant, staining the slide yellow. This is a secondary mineral product. A part of the quartz is derived from the recrystallization of the silica and is also secondary.

This slide contains a large fractured and corroded garnet whose cracks are filled with quartz. The garnet has thrust aside both mica and quartz in its formation, showing that it crystallized subsequent to the formation of the quartzite. The quartz comprises more than 90 per cent. of the entire rock. The muscovite is second in abundance. It occurs in more or less parallel scales and fibers. The few scales or plates of biotite are cut parallel with the base, for they show no cleavage lines. They are small and of much lighter color than normal biotite, as if bleached by weathering. The magnetite is not abundant nor is it drawn into parallel lines. The pyrite has been much decomposed as is evidenced by the great abundance of limonite stain. The rock was derived from siliceous sediments which were cemented together by silica.

No. 12. Slaty phyllite. Megascopically this rock is fine grained, dark bluish-gray, schistose and metamorphic. Microscopically it is scaly, fibrous and banded.

The essential minerals are quartz and the white mica, muscovite. The accessory minerals are pyrite, magnetite, garnet and graphite.

The secondary minerals are limonite derived from the oxidation of the pyrite, carbonaceous matter derived from organic matter in the original sediments, and garnet which appears as a later development than the chief constituents. The garnet cuts the flow structure, which proves that it is secondary. There appears to have been a slight movement of the rock since the garnet was formed. The original quartz grains are fine and well rounded. Some of the quartz occurs in narrow veinlets composed of sharp angular grains. This quartz was secondarily introduced. The magnetite is drawn more or less into parallel bands.

This rock might be considered as intermediate between a true slate and a true mica schist. It is more highly metamorphosed than a slate since there is a large development of the mica. It is not as highly metamorphosed as some of the phyllites observed in the field. Slates and certain schists may have originated in deposits of nearly identical character but they have undergone different processes.

ACID INTRUSIVES.

GRANITE.

The largest and best known granite outcrop in Randolph occurs on the farm of Mr. A. H. Beadle about one mile south by southwest of the village of Randolph, formerly called West Randolph. It is furthermore situated in the southwest corner of the township. It has been quarried and used for monumental work. It would make an excellent constructional stone if it could be secured in sufficient quantities for building purposes. It is an ideal monumental and sculptural stone. It is fine grained, works easily, susceptible of a good polish, cuts to sharp edge and is one of the three whitest granites of the State. It is not as white as the Bethel granite nor does it contain the same light gray to white color as the West Dummerston granite. There is a silghtly greenish tinge in the polished samples and the polished specimens are exceedingly beautiful.

Granite dikes occur in the eastern belt of limestone but they are not commercial propositions. They range in width from four to ten feet. One of these occurs about one mile southwest of the village of East Randolph and another occurs in the northern part of the township along the Gulf road leading west from the village of North Randolph. Only a few rods from it there is a dike of mica syenite.

No. 13. Quartz monzonite. Quartz monzonites are igneous rocks of granular texture containing quartz with potash feldspar and plagioclase in approximately equal amounts.

Megascopically the quartz monzonite of Randolph is fine grained, light gray in color and igneous. Microscopically it is subhedral and granular.

The essential constituents are quartz, orthoclase, albite to oligoclase-albite and in a less amount microcline which shows the characteristic grating structure. Some of the microcline is intergrown with albite. All of the feldspars are slightly kaolinized and contain small crystals of mica, probably sericite. Epidote, leucoxene and zoisite are also present.

Quartz is very abundant and microcline is sparingly present. Plagioclase is present in equal or slightly greater amounts than the orthoclase, hence the name quartz monzonite. The muscovite occurs in scales up to 0.037 mm. Epidote is the fifth mineral in abundance and accounts for the greenish tinge which is reinforced by chlorite. The quartz is clear and colorless, with fluidal cavities and with rare inclusions of rutile. Its compression test is 20,860 pounds.

The following chemical analysis has been furnished by the Rockport Granite Company of Rockport, Mass.

Silica, SiO^2	71.80
Alumina, Al^2O^3	20.78
Ferrous oxide, FeO	Trace
Ferric oxide, Fe^2O^3	None
Lime, CaO	Trace
Soda, Na^2O	4.40
Potassa, K^2O	2.99
Manganese dioxide, MnO^2	None
	99.97

No. 15. Contact rock. This is one of the most interesting slides studied and represents the contact between the quartz monzonite described in slide No. 13 and a metamorphic sedimentary. The contact zone is very narrow and almost no alteration has taken place between the two formations. For distinction the two parts will be discussed separately. The contrast between the dark sedimentary and the light colored granite is very sharp and the zone of alteration is so limited that good examples of each type can be brought into the field of the microscope at the same time.

Microscopically the sedimentary rock is dark gray and granular. The parallel arrangement of the mica gives the rock a schistose appearance and so the rock has been given the name of quartz schist. The essential minerals are quartz and muscovite, with the quartz in large excess over the mica. The accessory minerals are calcite, which is sparingly present, magnetite and pyrite.

The secondary minerals are limonite derived from pyrite, secondary quartz, and organic matter which imparts the dark color to the rock.

The mica, muscovite, is developed along the lines of schistosity. Some of the quartz is in fine rounded grains of undoubted sedimentary character. Some of the quartz is angular but of primary origin. It owes its form to recrystallization. In lesser amounts there is secondary quartz surrounding the other grains.

The characteristics of the igneous portion of this slide have been discussed under slide No. 13. It differs in no way in the essential, accessory and secondary minerals except that there is a small amount of very finely crushed quartz and oligoclase-albite along the actual contact.

No. 15. Granite dike. The granite dike from which this slide was cut occurs in the extreme northeastern corner of the township. It is only a few feet in width and its general strike is north and south.

Megascopically this rock is fine grained to moderately porphyritic. It is of light gray color. Microscopically it is anhedral granular with orthoclase phenocrysts. The ground mass is microgranitic with moderately large crystals of feldspar and quartz embedded in it.

The essential minerals are quartz, orthoclase, muscovite and biotite. It is, therefore, a true granite. The accessory minerals are apatite, magnetite and ilmenite.

The secondary minerals are kaolinite derived from the feldspars, sericite also derived from the feldspars, chlorite in small amounts derived from the biotite, limonite derived in part from pyrite and leucoxene derived from the ilmenite.

The quartz is angular in outline. Some of the feldspar shows albite twining. This plagioclase is an acid oligoclase with extinction angles around 7 degrees measured on the longitudinal section of the crystal. The presence of one crystal which may be twinned according to the Baveno law is noteworthy. The muscovite is far in excess of the biotite. The few biotite crystals appear in part as plates and in part as long, narrow crystals. The crystals of biotite are strongly pleochroic and have parallel extinction. With the exception of the apatite the accessory minerals are sparingly present.

No. 16. Mica syenite. Strictly speaking this slide should be described with the intermediate intrusives. It is placed here in this report because of its high biotite content and its quartz content of approximately 5 per cent. Furthermore it occurs in close proximity to a granite dike in the northern part of the township along the Randolph Gulf road. It is of entirely different type from the normal intermediate intrusives of the township.

Megascopically this rock is much weathered and presents a variety of interesting and well developed secondary minerals. In hand specimen the rock is fine grained and gray. Microscopically it is anhedral to subhedral granular.

The essential minerals are feldspars and mica. The former consists largely of albite with some orthoclase. All of the feldspars are weathered with indistinct outlines and the spaces around them are filled with saussurite. The saussurite appears as a mass of indistinguishable feldspars, chlorite and other alteration minerals. Many of the feldspar crystals have small flakes of sericite developed in the cracks. The predominant micas are biotite and muscovite, the former showing strong pleochroism and the latter appearing as fibrous masses surrounding the feldspar crystals.

The accessory minerals are apatite with fairly well preserved outlines, a few sporadic grains of quartz, abundant magnetite which is not arranged in zones, many large, fractured and corroded garnets, zircon and calcite. Quartz, calcite and mica are present in the fractured planes of the garnets. The zircon is sparingly present.

The secondary minerals are kaolinite derived from the feldspars, calcite in some cases surrounding the magnetite, and green chlorite in intimate association with the biotite, from which it was derived.

The calcite is quite abundant and may have been absorbed from the limestone which this rock cuts. The rock is very rich in biotite for a syenite. The quartz comprises approximately 5 per cent. The amphiboles and pyroxenes are wanting.

No. 17. Granite dike. This dike occurs in the extreme northern part of the township along the Randolph Gulf road. As will be seen on the areal map it outcrops only a few rods distant from the dike described in slide No. 16. The two dikes are roughly parallel with each other. They apparently belong to the same magma.

Megascopically this rock is fine grained and of light gray color. Microscpocially it is anhedral granular. The essential minerals are quartz, feldspars and micas. The feldspars are orthoclase and the plagioclase, albite-oligoclase. The micas are muscovite and biotite. The biotite is in excess of the muscovite. The plagioclase feldspars exhibit extinction angles around 22 degrees and 78 degrees.

The principal accessory mineral is garnet, probably andradite, of which there are many. All of the garnets are fractured and, in some cases, shattered. They all exhibit slight double refraction and are much pitted. The fractures are filled with quartz. Apatite and magnetite are fairly abundant. Ilmenite and zircon are sparingly present.

The secondary minerals present some interesting features. The biotite is partly altered to green, fibrous chlorite and magnetite which is scattered through the chlorite. Small amounts of calcite appear at the edges of the feldspar crystals, as if derived from a soda-lime plagioclase. Kaolinite is present derived from feldspars. This slide is more noteworthy for the development of the secondary minerals than it is for unusual features in the primary minerals.

The quartz is fairly abundant but in very small grains filling the spaces among the other minerals. The orthoclase is in excess of the plagioclase. The biotite is in excess of the muscovite.

INTERMEDIATE INTRUSIVES.

Among the rocks in eastern Vermont that were formerly supposed to be acid intrusives there are nepheline syenites, alkaline syenites, and light colored diorites, at least some of the diorites that appear light colored on their weathered surfaces. A searching petrographic study of the intrusives of other sections of the State will ultimately lead to a change in the names so far ascribed to many of these rocks. The discovery of syenites in Braintree was unexpected. Their presence and mineral composition are noteworthy. The discovery of unexpected syenites in Randolph is especially interesting. What Bethel to the southward may reveal in the way of new intermediate intrusives is only a matter of conjecture. Randolph has apparently furnished the State a new rock.

SYENITE.

No. 18. Amphibole syenite. This rock is a most unusual one for the area under consideration and appears to be a new rock. Locally this intrusive is known as the Beadle Green Granite. It occurs on Crompton Hill in the southwestern corner of Randolph. It also occurs a little to the northwest of the Randolph granite, which is described in this report as a quartz monzonite. Megascopically this syenite is of greenish color, fine to medium grained and granular. Microscopically it is subhedral granular.

The essential constituents are feldspar, largely orthoclase, and amphibole, probably both pargasite and hornblende. The accessory minerals are sporadic quartz, pyrite and ilmenite.

The secondary minerals are abundant. They consist of leucoxene derived from ilmenite, kaolinite and zoisite from the feldspars, chlorite from amphibole and a yellow iron stain from an iron bearing amphibole. In some cases the feldspars are very much altered and form an indistinguishable mass among the other crystals. Except for a few grains those feldspars which are recognizable show extinction angles around 21 degrees, no polysynthetic twinning and are, therefore, classified as orthoclase. Small amounts of the feldspars, however, appear to be the more acid plagloclase, albite-oligoclase.

A part of the amphibole was determined to be pargasite from the following facts: The index of refraction was about 1.63, resulting in high relief and rough appearance of the surface. The crystals are prismatic in general form and some are stout. Many are bent and some are broken. The larger cleavage angle is nearly 124 degrees and many cleavage cracks are present. Below are listed for comparison the indices of refraction for hornblende and pargasite.

	Hornblende.	Pargasite.
n alpha	1.680	1.613
n beta	1.725	1.620
n gamma	1.752	1.632

The extinction angles vary from 16 degrees to 25 degrees, but in general are low. There is slight pleochroism but the darker varieties of amphibole display this characteristic. In convergent polarized light a good biaxial interference figure was obtained and on testing with the mica and gypsum plates showed the character of the mineral to be positive. Common hornblende is optically negative. The optically positive crystals are in far greater abundance than the optically negative crystals. From these facts and because the chemical analysis made by Mr. Samuel Wilson shows the mineral to correspond more closely to pargasite than hornblende, the conclusion is drawn that the green amphibole in the Beadle Green Granite is pargasite. The thickness of this section is 0.041 and the birefringence is 0.045 to 0.015.

The analysis of a carefully selected sample of the green amphibole was made by Mr. Samuel Wilson, instructor in chemistry at Syracuse University. The results are here given.

Pargasite, Randolph, Vermont.

Silica, SiO^2	42.97%
Alumina, Al^2O^3	5.13
Ferric oxide, Fe^2O^3	6.54
Ferrous oxide, FeO	16.52
Lime, CaO	12.04
Magnesia, MgO	5.52
Potassa, K^2O	2.16
Soda, Na^2O	1.54
Water, H^2O, combined	0.30
Water, H^2O, minus 110 deg.	1.68
Total	100.63

No. 19. Amphibole syenite. Megascopically this rock is fine to medium grained, green in color and of igneous origin. Microscopically it is subhedral granular. The essential minerals are orthoclase, and an amphibole, largely pargasite. The accessory minerals are quartz and pyrite.

The accessory minerals are leucoxene derived from ilmenite, chlorite derived from amphibole, and kaolinite and zoisite derived from feldspars.

Fairly distinct interference figures were obtained from the pargasite and the optical character was positive. The angle of the optic axis, the angle 2V, was 59 degrees. Common hornblende has 2V equal to 84 degrees.

No. 20. Acmite syenite gneiss. A gneiss is a coarsely crystalline, foliated, metamorphic rock which may be of sedimentary or metamorphic origin and is usually high in feldspar content. In the acmite syenite gneiss, quartz is wanting and the ferromagnesian mineral present is the pyroxene acmite. Megascopically this rock is fine to medium grained, greenish in color, gneissoid, and metamorphic. Microscopically it is subhedral granular.

The essential minerals are acmite, hornblende, oligoclase and orthoclase. The accessory minerals are sporadic quartz, apatite, pyrite, magnetite, ilmenite, garnet and biotite.

The secondary minerals are leucoxene derived from the alteration of ilmenite, epidote from the interaction of the acmite and feldspars, limonite derived in part at least from pyrite, and chlorite from biotite.

The crystals of acmite are arranged in somewhat parallel lines. The crystals are often shattered and bent. The ilmenite is almost wholly altered to leucoxene. The magnetite shows zonal structure. Only small fragments of the feldspars are left and these show much decomposition. The ferromagnesian minerals are present in somewhat smaller amount than the feldspars. Most of the quartz is either secondary or secondarily introduced, for it appears as a few sharp, angular fragments in vein-like forms.

The acmite was identified by means of the following facts: The mineral was light green in color and possessed the characteristic cleavage angles of 87 and 93 degrees, approximately, for the pyroxenes. The acmite is anisotropic and has a high index of refraction. The crystals are long and prismatic with inclined extinction, the angle of extinction being about 8 degrees. Optically the crystals are negative. The interference colors are green of the second order. The pleochroism is distinct. Arfvedsonite differs from acmite in being blue to black in color, in having a maximum extinction angle of 14 degrees, and shows strong pleochroism in blue-black tints. The index of refraction is high and the optical character probably positive.

The rock may have been derived from an arfvedsonite syenite through the alteration of the arfvedsonite to acmite and the arrangement of the ferromagnesian minerals in more or less parallel lines. The acmite may have crystallized directly from molten solution.

No. 21. Acmite syenite gneiss. More of the feldspar is visible in this slide than in slide No. 20. However, the feldspars are weathered in the same general manner. Biotite is more abundant than it is in No. 20 and the quartz is present in smaller amounts. The grains of ilmenite are arranged along the lines of gneissoid structure. The magnetite is also banded. Secondary hornblende is present which shows parting parallel to the base. Some of the amphibole is uralitic.

No. 22. Acmite syenite gneiss. This slide bears a closer resemblance to No. 20 than to No. 21. It has an appreciable amount of quartz either of secondary origin or secondarily introduced. If secondary, then this quartz may have been derived in part from the alteration of the feldspars. The magnetite is sparingly present but not distinctly banded.

No. 23. Acmite syenite. A syenite may consist entirely of feldspar but usually more or less hornblende, mica or pyroxene is present in subordinate amounts to the feldspars. Megascopically this rock is fine to medium grained, gray to greenish, dense and igneous. Microscopically it is subhedral granular.

The essential minerals are orthoclase and to a less amount oligoclase and the pyroxene acmite. The accessory minerals are hornblende, biotite, ilmenite, apatite, magnetite, pyrite, garnet and quartz.

The secondary minerals are present in considerable abundance and consist of leucoxene derived from ilmenite, limonite from pyrite, epidote from the interaction of the feldspars and the ferromagnesian minerals. The epidote exhibits high relief and strong interference colors under crossed nicols. Sericite, chlorite and kaolinite are present. Leucoxene is present and appears as a thick, semi-transparent mineral under the microscope when the light is cut off from the mirror. It stands up in high relief from the surrounding feldspar which has an index of refraction of about 1.54.

The maximum extinction angle of the plagioclase is 15 degrees. The acmite has extinction angles of 7 degrees and is pleochroic. The hornblende is fairly abundant and shows good cleavage. The quartz comprises less than 5 per cent. of the minerals.

There is no trace of a gneissoid structure in this slide, but from the similarity in composition the inference may be drawn that this rock came from the same original source as those discussed in the three preceding slides. The gneissoid structure may be due to flowage near the margin of the syenite during the process of cooling. This condition has often been observed in the granite outcrops of eastern Vermont.

No. 24. Syenite contact. This slide represents the contact between an alkali syenite and a metamorphic sedimentary rock. Megascopically the rock is fine to medium grained, sometimes moderately porphyritic, greenish and dense. Microscopically it is subhedral granular. The line of contact is fairly distinct.

The essential minerals in the syenite are microcline, albite, orthoclase, in the ratio of 3:2:1 respectively and hornblende. The accessory minerals are magnetite, apatite, zircon, garnet, ilmenite, biotite and sporadic quartz.

The secondary minerals are abundant epidote which shows high relief and bright interference colors, kaolinite derived from the feldspars, calcite fairly abundant perhaps derived in part from the alteration of lime-bearing minerals, sericite which is formed in the cleavage cracks of the feldspars, leucoxene derived from ilmenite and associated with altered hornblende. The hornblende has become somewhat chloritized and even uralitized. The uralitic mineral in this case appears to be hornblende rather than actinolite. The epidote is found in or near the altered hornblende.

The sedimentary part of this slide appears to be a recrystallized lime-silica sediment. The essential minerals are calcite, quartz and biotite. The calcite shows good cleavage and occurs in angular grains which occasionally include one or more of the rounded quartz grains. The calcite forms slightly less than half of the total sedimentary area. The quartz grains are mostly angular and some show wavy extinction, which is an indication of recrystallization and secondary deposition. The biotite is pleochroic and arranged in parallel lines. The accessory minerals are apatite, magnetite and garnet.

The secondary minerals appear to have been derived from the intrusive. They are epidote, chlorite and leucoxene. The sedimentary portion of the slide may be a part of some sedimentary rock which was included in the igneous mass and not completely absorbed by the magma.

BASIC INTRUSIVES.

Basic intrusives are very abundant in the eastern half of Vermont. They are especially pronounced along the western side of the contact between the Cambrian and Ordovician terranes. Some of them appear as dikes, while others are rounded masses suggestive of stocks. They consist of diorites, gabbros, diabases, camptonites, amphibolites, etc., and some metamorphic rocks derived from them. The basic intrusives of Randolph are confined to the southwestern corner of the township.

DIORITES.

The diorites are plutonic rocks of medium to coarse texture, consisting essentially of a soda-lime feldspar and hornblende, with less important constituents. The normal diorite covers a series of rocks consisting of the feldspar oligoclase, andesine or labradorite, and the amphibole hornblende. However, other types are recognized as quartz diorites which contain a small amount of free quartz, mica diorites, quartz-mica diorites and olivine diorites.

No. 25. Diorite. Megascopically this rock is fine to medium grained, greenish gray, dense and igneous. Microscopically the texture is bostonitic, that is the crystals have an irregular outline as if corroded.

The essential minerals are andesine, a little orthoclase, chloritized hornblende and a small amount of biotite. The feldspars predominate over the ferromagnesian minerals. The andesine is present in much larger amount than the orthoclase. The hornblende is abundant and occurs in greenish black crystals. The biotite is rare.

The accessory minerals are apatite, magnetite, ilmenite and garnet, all of which are only sparingly present.

The secondary minerals are calcite, epidote, chlorite, leucoxene and a few grains of quartz. The calcite is by far the most abundant secondary mineral present. It is well crystallized and shows good cleavages. The presence of so much calcite would indicate some decomposition of soda-lime feldspars, but it is not impossible that a large amount of the calcite has been derived from the calcareous rocks intruded by the diorite. The chlorite has been derived from the hornblende and shows distinctly fibrous forms. The epidote derived from the interaction of the feldspars and ferromagnesian minerals shows high relief and bright interference colors. Leucoxene derived from ilmenite is fairly abundant. An occasional grain of quartz is present and is probably of secondary origin. The quartz grains are sharp and angular and comprise less than 5 per cent. of the rock mass.

No. 26. Diorite. Megascopically this rock is fine grained, greenish gray, dense and igneous. Microscopically it is subhedral granular.

The essential minerals are plagioclase, variety andesine in poorly outlined crystals, orthoclase in small amount, and a dark green variety of hornblende showing marked pleochroism and parallel extinction. The hornblende is partly chloritized. The feldspars are in slight excess of the hornblende.

The accessory minerals are apatite, magnetite, abundant ilmenite and garnet.

The secondary minerals consist of kaolinite derived from the feldspars, an occasional grain of quartz, a little chlorite, and a few grains of epidote derived from the interaction of the feldspars and ferromagnesian minerals, and leucoxene from ilmenite. The ilmenite occurs in all stages of alteration to leucoxene.

No. 27. Diorite. Megascopically this rock is dark gray, medium grained and dense. Microscopically it is anhedral granular.

The essential minerals are feldspars, both plagioclase and orthoclase, and hornblende. The plagioclase shows extinction angles of about 15 degrees and is albite to andesine. The feldspars are in small crystals. The hornblende shows marked pleochroism and appears to be common hornblende.

The accessory minerals are magnetite, ilmenite, pyrite and sporadic quartz. The magnetite is not arranged in zones. The pyrite shows one large square section while the other sections are small.

The secondary minerals are abundant. The chlorite was derived from hornblende, limonite from pyrite, sericite and kaolinite from the feldspars. The epidote appears as a decomposition product of the feldspars and the hornblende. The leucoxene was derived from the ilmenite. A part of the sporadic quartz is in large angular grains as if secondary in origin. Chlorite occurs in long needles arranged in somewhat parallel bands. The secondary minerals appear as products of rock weathering rather than of folding.

No. 28. Epidosite. The epidosites are rocks formed largely of epidote. The epidote seems to be generally produced by the action of feldspars and bi-silicates upon each other during alteration.

Megascopically this rock is fine grained, pistachio green, and dense. Microscopically it is anhedral granular and much weathered. The essential minerals are epidote, augite, biotite. The accessory minerals are altered feldspars, olivine, apatite, magnetite and pyrite.

The feldspar content is rather low and almost completely altered to saussurite which consists of a feldspar mass more or less completely altered to a mixture of new feldspars, zoisite, actinolite, chlorite, etc. The biotite crystals are large and fairly fresh. The epidote crystals are very abundant and constitute the major part of the slide. The crystals are both large and small and somewhat shattered.

The secondary minerals consist of epidote, chlorite, calcite, saussurite, leucoxene, quartz and limonite. The quartz grains act as fillings for the fissures in the epidote. From their angularity and position they are regarded as secondary. The limonite appears as a brown stain.

No. 29. Epidote schist. This slide is similar in mineral content to slide No. 28 but different in the amount of metamorphism. Megascopically the rock is fine grained, greenish and schistose. Microscopically it is anhedral granular.

The essential constituents are epidote, albite-oligoclase, hornblende and quartz. The accessory minerals are magnetite, apatite, indeterminable feldspars and quartz.

The secondary minerals are epidote, chlorite, antigorite and magnetite. The epidote which is very abundant was derived from the interaction of the feldspars and ferromagnesian minerals. Chlorite which is sparingly present may have been derived from the hornblende. The antigorite was derived from olivine. This change gave rise to secondary magnetite, for some of the olivine grains are completely surrounded by magnetite as if derived therefrom. A part of the magnetite is in partial zones which indicates some schistosity. The leucoxene which has been so abundant in the basic intrusives of both Braintree and Randolph appears to be wanting in this slide. This, however, does not prove that ilmenite is wanting in the dike from which this slide happened to cut.

If the original feldspar had been labradorite the rock would have been a diabase. But the feldspars are more acidic than labradorite and are near andesine if not actually andesine, therefore, the original rock was probably a diorite. The presence of uncorroded crystals of apatite suggests an igneous origin.

No. 30. Epidosite. This rock is by far the richest in epidote of any examined. Practically the whole microscopic field is covered with epidote. Megascopically this rock is fine grained and pistachio green. Microscopically it is anhedral granular. The only essential constituent is epidote. The accessory minerals are magnetite, augite, olivine, and biotite. It is only by calling the rock an epidosite that the augite, olivine, biotite and indeterminable feldspars may be called accessories.

The secondary minerals are sporadic quartz, chlorite from augite, probably through hornblende, leucoxene from ilmenite. There were no feldspars on which extinction angles could be measured as the original feldspars were well saussuritized. Much of the epidote is in small grains forming the ground mass for the larger grains of the same mineral.

No. 31. Epidotic amphibole schist. This rock appears very complex. Megascopically it is fine grained, greenish, schistose and metamorphic. Microscopically it is anhedral granular.

The essential minerals are epidote, acmite, hornblende and andesine. The accessory minerals are biotite, garnet, magnetite, ilmenite and olivine.

The secondary minerals are numerous and consist of epidote, chlorite, uralite, calcite, leucoxene and quartz. The epidote is fairly abundant and arranged in parallel lines. It is not as pronouncedly parallel as the chlorite. The calcite is very abundant. The acmite is green and fibrous. The uralite is fibrous and has frayed ends. Small amounts of secondary quartz are present. The leucoxene shows as a mineral of high relief with no pleochoism or extinction angle, and white in reflected light.

The original rock was probably a normal diorite which has been rendered schistose by regional metamorphism and in which epidote has been abundantly developed by the interaction of the feldspars and the ferromagnesian minerals.

No. 32. Epidotic chlorite schist. Megascopically this rock is greenish, dense, schistose and metamorphic. Microscopically it is subhedral granular. The essential minerals are epidote, chlorite and quartz. The accessory minerals are pyrite, amphibole, biotite and magnetite which is in zones following the structure of the rock.

The secondary minerals are limonite from pyrite, chlorite from amphibole and some of the quartz. Grains of quartz are found completely enclosed by epidote which suggests that a part of the quartz has been derived through the epidotization of original ferromagnesian minerals. The fine granular quartz grains may have been derived in this manner. The sharp angular grains which are arranged in parallel bands were secondarily introduced.

The schistose character of the rock is evident for the chlorite and some of the epidote is in parallel bands. In the absence of crystals of plagioclase proof is not positive that this rock was derived from an intrusive rich in ferromagnesian minerals. If feldspars were originally present then they have become completely saussuritized and are now indeterminable. The original rock may have been a quartz diabase. Such diabases have been found in eastern Vermont in the townships north of Randolph.

CHLORITE SCHISTS.

The chlorite schists of Randolph are marked by the presence of green micaceous chlorite in large amounts. More or less quartz is usually present and not infrequently plagioclase, talc, epidote and magnesite. The strike at times will conform to that of the sedimentaries but more often it cuts across the sedimentaries at high angles. In Roxbury one angle was recorded of 85 degrees. Such chlorite schists can not be of sedimentary origin.

No. 33. Chlorite schist. Megascopically this rock is fine grained, greenish and schistose. Microscopically it is anhedral granular. The essential mineral is chlorite. The accessory minerals are augite, an amphibole which is optically positive and probably pargasite, ilmenite, magnetite, quartz, apatite in small amounts, and plagioclase approaching andesine and having extinction angles from 8 to 10 degrees.

The secondary minerals are leucoxene derived from ilmenite and sparingly present, chlorite which, although an essential mineral, is of secondary origin. The rock is much weathered. The ferromagnesian minerals are much chloritized and in some cases completely surrounded by chlorite. The feldspars are much weathered but still show plagioclase twinning.

The original rock may have been a diorite but the texture is now schistose and the ferromagnesian minerals largely altered to chlorite. It may have been a diabase. Altered diabases particularly rich in chlorite are common in the townships north of Randolph. The parent rock was some basic intrusive rich in its ferromagnesian minerals.

PERIDOTITE AND PYROXENITE.

The peridotites and pyroxenites of Randolph are confined to narrow outcrops in the southwest corner of the township. It is not certain that the outcrops are continuous with those in southeastern part of Braintree for the area is heavily drift covered and wooded. Their strike is the same and they are in the same general belt. This belt is known to extend southward into Bethel where several outcrops have been discovered. The peridotite phases gave rise to verd antique marble in comparatively narrow beds. The pyroxenite phase has given rise to some lenses of talc but more often to a talcose schist.

No. 34. Talc schist. Megascopically this rock is fine grained, greenish, foliated, schistose and metamorphic. Microscopically it is anhedral granular. The essential minerals are talc in scales, plates and fibres, and quartz in somewhat mosaic arrangement. The accessory minerals are magnetite, pyrite, muscovite, phlogopite, chlorite and garnet. The chlorite is in green, pleochroic aggregates which are anisotropic and show peculiar interference colors. The magnetite is drawn more or less into parallel bands. There are a few scales of phlogopite showing brown interference colors, low relief and a biaxial interference figure.

The secondary mineral is limonite, which appears as a brown stain that follows the lines of schistosity in the rock.

Talc schists have resulted from the alteration of some rock with one or more of the anhydrous magnesium silicates that lacked iron. Tremolite and enstatite are the most available but the original sources of these are obscure. In this case the original rock was probably a pyroxenite, there are no siliceous dolomites in central or eastern Vermont known to be the source of these talc deposits, but the proxenites are definitely proven to have produced talc.

No. 35. Talc. This rock is fine grained, greenish, slightly schistose and metamorphic. Microscopically it is anhedral granular. The essential constituent is talc. The accessory minerals are calcite, magnetite and pyrite.

The secondary minerals are limonite and dolomite.

The magnetite is drawn out somewhat into parallel lines. The dolomite is in close proximity to the calcite and shows a slightly higher relief. The limonite stain follows the contact of the carbonates and the silicates in the rock. A few grains of serpentine are present.

No. 36. Verd antique marble. Serpentines are green and red aggregates of scales, fibres or massive individuals of the mineral serpentine. Other minerals are not especially prominent. Veinlets of calcite, or dolomite, or magnesite, ramify through the rock in many exposures.

Megascopically this rock is fine to medium grained, fibrous, foliated, banded, dark green and metamorphic. Microscopically it is fibrous and silky with the exception of some crystals that are anhedral granular.

The essential mineral is the fibrous variety of serpentine, antigorite. The accessory minerals are calcite, magnetite and pyrite.

The secondary minerals are talc derived from enstatite, dolomite from the action of carbonated waters on the calcium and magnesium silicates, and breunnerite. A little limonite stain is present.

The serpentine and calcite are in alternate bands, with the magnetite following the banding and occurring abundantly in both minerals. Dolomite is present showing two cleavages at an angle of 70 degrees with each other and showing strong absorption. The presence of a mineral taken to be breunnerite is determined because of its high relief, dark gray color, lack of polysynthetic twinning, and very strong birefringence. Breunnerite is fairly abundant in the peridotite belt in northern Vermont and southern Quebec. A chemical analysis of closely related crystals from Roxbury shows them to conform more closely in composition to ankerite than to breunnerite.

The presence in this slide of a crystal with two good cleavages of approximately 87 and 93 degrees, extinction angles of 40 to 45 degrees, slight pleochrism, suggests augite. The extinction angles correspond more closely to fassaite.

The entire absence of olivine or any evidence in this section of the origin of the serpentine, variety antigorite, is noteworthy. However, there was abundant olivine found in the peridotites of Braintree. A peridotite consisting essentially of olivine with a very little plagioclase was found on the farm of George Farrington, Braintree, Vermont. Olivine has been found in this peridotite belt in other townships to the north of Randolph. Almost all serpentines have been formed by the alteration of basic igneous rocks among which pyroxenites and peridotites are the chief contributors.

No. 37. Verd antique marble. Megascopically this rock is fine grained, even textured, greenish, massive and metamorphic. Microscopically it is anhedral to fibrous. The mineral composition is essentially the same as that in slide No. 36. The serpentine is fibrous and silky. The magnetite is in zones. The calcite and dolomite are abundant.

The antigorite which comprises by far the greater amount of this slide is fibrous to silky and shows blue interference colors. Talc is quite abundant and drawn out into parallel bands with a part of the antigorite. The calcite and dolomite fill the fracture planes as if introduced subsequently to the fracturing due to serpentinization. A mineral taken to be Breunnerite is present with dull gray color, lower interference colors than calcite, slightly higher relief, strong birefringence, and a tendency to break up into cube-like rhombohedrons. These are uniaxial and optically positive. The magnetite is quite abundant and in part disseminated through the antigorite, and in part drawn out into parallel bands. A few crystals of muscovite showing blue interference colors are present. The origin of this verd antique marble is from the alteration of a peridotite which extends in broken outcrops in a northeasterly direction into Roxbury, Vermont, where verd antique marble has been extensively quarried for many years.

PALEONTOLOGY.

No fossils have yet been found in the hydromica schists, sericite schists and non-calcareous quartzites which lie to the west of the erosional unconformity between the Cambrian and Ordovician terranes. The relative age has been determined by continuity, lithological characteristics, stratigraphical position. They are unquestionably pre-Ordovician for they furnish the pebbles in the Irasburg conglomerate in Irasburg, Albany and Northfield which lies at the base of the Ordovician series in eastern Vermont.

The discovery of new beds of graptolites in Randolph is significant. Graptolites well preserved were found in Braintree in the shaly limestone beds to the west of Snowsville and Pethville. The graptolites in Randolph are the best preserved in the northwestern part of the township near the Braintree town line. The phyllites interstratified with the limestones sometimes carry a few carbonaceous patches that are strikingly suggestive of graptolites. The occurrence of these graptolites proves the limestones to be of Ordovician age.

CONCLUSIONS.

1. The sericite schists contain silvery white muscovite (variety sericite) in minute scales and fibres. All slides show a marked parallelism of the sericite plates. Wherever the sericite appears as scales in altered feldspars in slides examined from Randolph, Vermont, it is regarded as being derived from the feldspars by the process known as sericitization.

2. The sericite schists often contain fresh, uncorroded crystals of feldspars which prove that the sericite schists are of different age than the hydromica schists to the southwest of Randolph, for these contain no feldspar phenocrysts. The fresh character of the feldspar phenocrysts, when present, proves that the sericite was not derived to any great extent from feldspar and the conclusion is that it was derived directly from siliceous and argillaceous sediments.

3. The Cambrian quartzite with small amount of scaly and fibrous sericite leads to the conclusion that the quartzite was derived from sand sediments, low in clay, rather than from the decomposition of feldspars. The fine rounded quartz grains also support this conclusion.

4. The absence of calcite in the sericite schists and quartzites over large areas suggests that the sediments were all non-calcareous. Calcite in the area of the sericite schists and sericitic quartzites is found only in the altered intrusives.

5. The Waits River marble with its calcite showing perfect cleavage and the well rounded quartz grains often associated with angular secondary quartz proves that this formation consists of a quartzite combined with a calcite marble. The rock may be catalogued either as a calcitic quartzite or as a quartzose marble. Where the percentage of calcite is greater than 50 it is called a quartzose marble. If less than 50 percent it may be called a calcitic quartzite. This term is open to criticism for it is not found in the standard petrologic text-books.

6. The lack of calcite other than sporadic in the quarzite from the extreme northeast corner of the township suggests that the siliceous muds which made up this formation were either low in, or entirely free from, lime. The presence of secondary muscovite, biotite and actinolite proves the formation to be different from the Cambrian quartzite and must not be confused with that non-calcareous member of the Missisquoi Group.

7. The fineness of the quartz grains and the mica scales in the phyllites proves them to be the final stage in the metamorphism of the clay-bearing sediments of the Ordovician period. All these rocks have passed through the slate stage of metamorphism and are classed as phyllites. These rocks are all more fissile than slate. The banding of the biotite crystals indicates that there has been a crustal movement subsequent to their formation.

8. The granite of Randolph is a quartz monzonite with plagioclase approximately equal to the orthoclase in abundance. The similarity in composition with the white granite of Bethel, Vermont, suggests that these two intrusions may be of the same age.

9. The Beadle green granite, so-called, is lacking in primary quartz and, therefore, cannot be considered as a granite. Since the essential feldspar is orthoclase and the ferromagnesian mineral is an amphibole the rock is classified as a syenite. The amphibole appears to be pargasite, therefore the rock is a pargasite syenite. As pargasite syenites have not hitherto been reported in the United States the rock is named Randolphite for the township of Randolph in which it occurs.

10. The diorites are all rich in ilmenite and its alteration product, leucoxene. This would imply that these diorite dikes were intruded at the same time as the similar dikes in Braintree, Roxbury and Northfield to the north of Randolph.

11. The epidote dikes invariably have their epidote derived from the interaction of the feldspars and the ferromagnesian minerals. They all belong to the same period of intrusion as the regular diorite dikes, but they have been subjected to greater alteration.

12. The chlorite schists result from the alteration of basic dikes rather than from the metamorphism of sediments. The chlorite is almost entirely derived from hornblende, and quartz other than sporadic is almost wholly wanting. They cut the sericite schists and quartzites at angles ranging from zero to nearly 90 degrees.

13. The talc deposits were derived from the alteration of a basic intrusive consisting essentially of pyroxene. While no enstatite was found in the Randolph slide, yet crystals of enstatite were found in slides from Braintree and Roxbury. Augite is fairly abundant in the intrusives of Randolph as well as in Braintree and Roxbury. The absence of water-worn quartz grains suggests that the talc deposits did not result from the metamorphism of sediments. These are no calcareous sediments in the Cambrian rocks in which the veins of talc occur. The talc, therefore, is not associated with the crystalline limestones as it is in New York, nor is it associated with any marble other than the verd antique marble of central Vermont.

14. The verd antique marble was derived from the alteration of a peridotite rich in olivine. Olivine was found abundantly in slides from Braintree and Roxbury and the belt is probably continuous into Randolph. Serpentine may be derived from pyroxenites, amphibolites, garnets or condrodites. It is not impossible that pyroxenites have contributed somewhat to the serpentines of central Vermont, for the serpentine rocks sometimes contain quartz and calcite. These are common minerals formed in the transition of pyroxenes to serpentine. There is no evidence that amphiboles furnished the serpentine in this district. The belt extends interruptedly in a northeasterly direction into the Province of Quebec, where peridotites are definitely recognized as the parent source of the massive serpentine.

15. The age of the introduction of the pyroxenites and the peridotites antedates that of the diorites and diabases for the basic igneous dikes cut the pyroxenites and peridotites in northern Vermont. In Roxbury also basic dikes appear to cut the peridotite belt. These basic intrusives are now largely altered to chlorite and epidote and these rocks cut the verd antique marble formation at angles varying from zero to nearly 90 degrees. The peridotites in Vermont are not known to cut any rocks of Ordovician age, therefore they are regarded as pre-Ordovician.

16. The syenites are not definitely proven to be either older or younger than the Randolph granites. They may represent the more basic phase of the same magma. If derived from the same magma their solidification and crystallization would precede that of the more acid quartz monzonite. Actual contact of the two was not found. If the interpretation of slide No. 24 is correct, namely, that this dike represents an alkali syenite and a calcitic quarzite, then the introduction of the syenites was post-Ordovician and probably Devonian.

BIBLIOGRAPHY.

Chamberlin, T. C. and Salisbury, R. D.
A College Text-book of Geology. Henry Holt & Co., New York.

Clarke, F. W.
The Data of Geochemistry. U. S. G. S. Bul. 616.

Cross, Iddings, Pirsson, Washington.
University of Chicago Press, 1903.

Dale, T. N.
Calcite Marbles of Eastern Vermont. Rept. of the Vermont State Geologist, 1913-14.
The Granites of Vermont. Rept. of the Vermont State Geologist, 1907-08.

Dana, J. D.
System of Mineralogy. 6th Edition. John Wiley & Sons, New York.

Doelter, C.
Handbuch Der Mineralchemie. Band. 2. Theodore Steinkopff, 1910.

Dresser, J. A.
A Note on the Varieties of Serpentine in Southeastern Quebec. Vol. 8, 1905.

Eckel, E. C.
Building Stones and Clays. John Wiley & Sons, New York, 1912.

Emmerson, B. K.
Monograph U. S. G. S. Vol. 29, 1898.

Finlay, G. I.
Introduction to the Study of Igneous Books. McGraw-Hill Book Co., 1913.

Harker, Alfred.
Petrology for Students. Cambridge University Press, 1902-1920.

Holmes, Arthur.
The Nomenclature of Petrology. D. Van Nostrand Co., 1920.

Iddings, J. P.
Igneous Rocks. Vols. I and II. John Wiley & Sons, 1913.
Rock Minerals. John Wiley & Sons, 1911.

Jacobs, E. C.
Talc and Talc Deposits of Vermont. Rept. of Vermont State Geologist, 1913-1914.

Johannsen, Albert.
Petrographic Methods. McGraw-Hill Book Co., N. Y., 1914.
Determination of Rock Forming Minerals. John Wiley & Sons, 1908.

Kemp, J. F.
Handbook of Rocks. D. Van Nostrand Co., N. Y., 1904.

Kraus, E. H. and Hunt, F. W.
Mineralogy. McGraw-Hill Book Co., N. Y., 1920.

Larsen, E. S.
Microscopic Determination of the Non-opaque Minerals. U. S. G. S. Bul. 679.

Luquer, L. M.
Minerals in Rock Section. D. Van Nostrand Co., N. Y., 1913.

Marsters, V. F.
Origin of Serpentine. Rept. of the Vermont State Geologist, 1903-04.

Moses, A. J. and Parsons, C. L.
Elements of Mineralogy, Crystalography and Blowpipe Analysis. D. Van Nostrand Co., 1911.

Pirrson, L. V. and Schuchert, Chas.
Text-book of Geology. John Wiley & Sons, N. Y., 1915.

Richardson, C. H.
Building Stones and Clays. Orange Pub. Co., Syracuse, N. Y., 1914.
The Terranes of Roxbury. Rept. of the Vermont State Geologist, 1917-18.
The Terranes of Northfield. Rept. of the Vermont State Geologist, 1917-18.
Geology of Newport, Troy and Coventry. Rept. of the Vermont State Geologist, 1907-08.
The Terranes of Orange County. Rept. of the Vermont State Geologist, 1901-02.

Richardson, C. H. and Conway, E. F.
The Terranes of Irasburg. Rept. of the Vermont State Geologist, 1911-12.

Van Hise, C. R.
Treatise on Metamorphism. Vol. XLVII. Monograph U. S. G. S., 1904.

Washington, H. S.
U. S. G. S. Professional Paper 99.

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WEINSCHENK, E. and JOHANNSEN, A.
Fundamental Principles of Petrography. McGraw-Hill Book Co., 1916.
WHERRY, E. T.
Pre-Cambrian Sedimentary Rocks in the Highlands of Eastern Pennsylvania. Bul. Geol. Soc. Am. Vol. 29.
WIGGLESWORTH, E.
Serpentines of Vermont. Rept. of the Vermont State Geologist, 1915-16.
WINCHELL, N. H. and A. N.
Optical Mineralogy. D. Van Nostrand Co., 1909.

STUDIES IN THE GEOLOGY OF WESTERN VERMONT

Second Paper.

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INTRODUCTION.

A description of the principal physiographic divisions of western Vermont and a general statement of the characters distribution and certain other features of the various rock formations found in those divisions may be found in the first paper under this title, published in the Twelfth Report of the State Geologist. These were intended to serve for guidance in following the description and discussion, offered in the same paper, of a number of observations made in certain parts of western Vermont which dealt chiefly with the deformations of the different rocks. For the present paper, which gives an account of studies of the field relations of the rocks in other parts of western Vermont, the general statement made in the preceding report is considered sufficient and need not be repeated nor amplified in this one.

The physiographic divisions mentioned are the prominent ones of the present surface of this part of the state. Each, of course, shows many minor topographic variations incident to, the character and structure of the underlying rock and the modifying effects of erosion and other agencies, such as glaciation. Except for a quarry here and there the average observer is probably impressed only by the grander features of the surface; it is their charm that invites the tourist to motor through this part of Vermont or impels the summer resident to build his camp on some hill or mountain side.

So conspicuous indeed are these larger divisions of the landscape they may easily impress the geological student as possessing a significance beyond that which they really have. Geological accounts of different parts of the region often accentuate these more or less modern features and it seems as though in a provincial treatment of them their true geological history and connections have been more or less obscured. The more ancient secondary structural features of the rocks bear no necessary relation to the present physiography of the region, which is due in part to later deformations or disturbances and in part to repeated erosion.

Over the present surface of western Vermont there is shown a confusion in the arrangement of the rocks that is very baffling. This confusion is very clearly due in large measure to the various deformational and metamorphic changes which the rocks have suffered and to certain primary features, such as lateral variations in certain members. Added to these are the effects of erosion and glaciation. Over large areas correlation may not be made by direct aid of fossils, and one must rely upon other criteria of various sorts. Particular mention should be made of the extensive mantle of surface material, either bowlder drift, sand or clay, which conceals large areas and imposes great difficulties in working out the structural details of most localities.

The student who confines his studies to a small portion of the region may gain a glimpse of the nature of the structure of the rocks in some cases; in others he may be quite confused. It is necessary to carry one's studies over a wide area to see into the plan that apparently prevails over the region as a whole.

The studies described in this paper and the earlier one were undertaken in the hope that it would eventually prove possible to examine in a somewhat critical way a large number of outcrops in all four of the different divisions of the region, which the writer has defined, with the purpose of getting light on the general plan of structure of the rocks and in order to discover if any marked degree of unity prevails throughout. For reasons that will generally be understood it has been necessary to publish accounts of the work at various stages of its progress. At this writing there still remains the larger portion of the mass of rocks contained within what is known as the Taconic range, which is a territory which the writer had reserved in his mind for future study. From studies already made in parts of the range it seems likely that in its main features it may finally be reduced to a plan of structure like that of other divisions which now bear little physiographic resemblance to it. Finally, it seemed probable that a more careful inspection than has yet been possible could be given to the western ranges and other masses of the Green Mountain plateau to see to what extent the rocks now lying west of the plateau could be traced into it and whether the deformations present in it are similar in plan to those found among the rocks now lying west of it. Experience has served to show that apparently only by a broad survey of the region as a whole is it likely that one may grasp the true significance of the relations within and among its different parts.

The general similarity shown by the field relations in widely separated areas indicates a fundamental unity of structure in all of them. Moreover, excursions into areas contiguous to Vermont, such as western Massachusetts and southern Quebec, as well as published descriptions for other adjoining territory and for districts still more remote suggest that a common plan of structure may prevail over a much wider region than western Vermont.

The work and writings of Professor J. D. Dana,[1] in which he aimed to show the relations (general similarity or unity of plan) between the geological features of western Vermont and those of Berkshire County, Massachusetts, and other areas as well, are well known. The writer's conception of the similarity that exists in the areas described by Dana follows him in maintaining that

[1] On the relations of the Geology of Vermont and that of Berkshire, A. J. S., Vol. XIV, July, 1877.

the "western half of the whole Green Mountain region is eminently a natural area," and that in many primary features, such as general age and general original interrelations, the rocks throughout are similar. The purpose of this paper is to indicate, if possible, the *kind of structure* in which western Vermont possesses unity and to show the apparent nature of the chief deformations which have disturbed the rocks. Numerous descriptions of field relations, in addition to those given in the first paper, will be offered to show the dominant influence of thrust displacements of various magnitudes and of kindred phenomena due to pressure acting upon highly elastic and resistant rock formations associated with weaker and less "competent" strata.

Extent and certain other features of the region described in this paper. A rough estimate of the dimensions of the irregular territory which has been surveyed gives about 900 or 950 square miles. It includes either the whole or large portions of the following-named topographic sheets of the U. S. G. S.:—Rouses Point, St. Albans, Plattsburg, Milton, Willsboro, Burlington, Port Henry, Middlebury, Ticonderoga and Brandon. In a north to south direction it extends from the Canada line approximately to the southern boundary of Leicester in Addison County, and west to east from the New York State boundary to the western margin of the Green Mountain plateau.

The ground gone over has not, of course, all been studied in minute detail; but much of it has been examined with more thoroughness than will appear in the descriptions, in the search made for clues of different sorts, especially for fossils in the more altered rocks found in the eastern portions of the region.

Some parts of the territory have been described more or less fully in the first paper; but in most cases these areas have been reexamined.

The lake region proper, which is included within the physiographic division called the Champlain lowland, seems to call for some sort of specific definition, as it will be frequently mentioned in the following pages. In addition to the lake with its islands there are along its border many areas of various dimensions, often small but again of considerable size, which are underlain by rocks similar to those which form the islands and the lake bottom. Many of these areas are now covered with Champlain clays, or sands brought in by streams entering the lake. In many places outcrops are few, especially where the underlying rock is clearly or apparently the soft shale formation, but at many places limestone beds like those found on the islands project above the surface deposits, forming knolls and ridges. It seems likely that if the clay which is so plentiful over portions of the mainland near the lake were removed these areas would be more or less inundated by the lake waters, even at their lower levels, and that

there would be produced a very different shore line, more numerous islands and a larger water body. A similar operation on the islands would in some cases partition them into smaller units.

Some of the streams which enter Lake Champlain, such as Lewis, Little Otter and Otter Creeks, are for greater or less distances from their mouths hardly more than inundations by the lake waters of narrow channels in the clays, with hardly head enough at the present time to give them perceptible currents; and Dead Creek, a tributary of the Otter, is practically all its way a sluggish stream of this sort. In the case of the Otter the inundation extends from its mouth to the city of Vergennes, where the stream tumbles over a scarp in massive dolomite to the graptolite shales below. For a large part of its course below Vergennes the river flows through a sand plain of its own making and at its mouth it has formed delta levees by which it has tied Fort Cassin to the mainland.

Hog Island, so-called, in the township of Swanton, is a land-tied island, accomplished in this case by the delta deposits of the Missisquoi River.

It thus appears that some islands have become secondarily attached to the mainland and that large areas of the mainland differ from the lake only in the fact that clay takes the place of water. Such considerations may prove helpful to the reader when in the succeeding pages different areas are described and compared with one another.

The studies which were described in previous papers were scattered rather generally over the western half of the state and were conducted in much more detailed and systematic manner in some places than in others. This resulted from the way in which the general problem was from time to time approached.

The rocks first examined were those in the difficult region around Bennington, in the southwestern portion of the state. Six years later (1918) a trip was made through the Vermont valley and parts of the Champlain lowland, Taconic range, and Green Mountain plateau with the definite purpose of searching for a general plan of structure among the rocks over a wide region which might serve as a key to the relations around Bennington. Much that was planned for this trip had to be abandoned on account of illness. In the seasons of 1919 and 1920 a somewhat systematic study was made of a wide surface section from the Green Mountains to Lake Champlain, in the towns of Brandon, Sudbury and Orwell.

From these several studies, especially from those made in Brandon, Sudbury and Orwell, various inferences were drawn, some of which were given a broad application in the interpretation of the structure of the region. The views expressed were based on personal work. Some found support in the writings of other workers while others were apparently new and clearly called for such substantiation as further study might give.

The brief studies which it had been possible to make in various parts of the Champlain lowland, up to the season of 1921, had tended to strengthen the belief that the whole of western Vermont is "eminently a natural area" and had suggested that the lowland would probably afford the field relations that would serve best in testing certain views regarding structure.

The Champlain lowland makes up a large portion of western Vermont. It merges quite imperceptibly with the Vermont valley, both physiographically and geologically, and except as disguised by certain primary differences of the rocks and by faulting may reasonably be shown to merge with the Taconic range, whose foothills as well as the main range itself still show vestiges of the features that are now best preserved over the lowland. The lowland then seems to be only a physiographic subdivision of a large region whose genetic features are essentially identical throughout. Even in its relation to the Green Mountain plateau the designation of lowland should not be understood to convey the idea of strong contrast between the two, for over long distances there is a most gradual transition topographically and almost complete identity or unity geologically between adjacent portions of them.

Notwithstanding these recognizable transitions between the lowland and the higher lands of the Taconic range and the Green Mountain plateau and the presence of high hills at many places in the lowland this division is structurally a sunken region with respect to surrounding higher surfaces. The Vermont valley may be viewed as the southward extension of the lowland between the plateau and the Taconic range. Since in its breadth from west to east the lowland therefore comprises counterparts of the marginal portion of the plateau, of the Vermont valley and of the Taconic range one finds within it relations that are often preserved only in much more fragmentary conditions in the other divisions, for one reason or other.

The meaning of the comparisons which have just been made of parts of the region with each other really comes out only after careful field study; but it is hoped that the discussions which will follow, taken with those which were given in the first paper, will enable the reader to see the force of the contention that different parts of western Vermont possess strong similarities in a number of ways.

A survey of the lowland was carried on during the seasons of 1921 and 1922, together with some study of the marginal portions of the plateau. The territory covers many square miles. It was necessary to confine attention to those field relations that bear particularly upon structure, simply in order to get over the ground and not leave untouched any large number of places that

Township map of Vermont.

might throw light on the main problem. Naturally during the work many other fascinating problems appeared which it was necessary to pass by.

DESCRIPTIONS AND DISCUSSIONS OF OBSERVATIONS MADE BY THE WRITER WITHIN THE CHAMPLAIN LOWLAND AND ADJACENT PORTIONS OF THE GREEN MOUNTAIN PLATEAU.

General plan of discussion. As the field studies described herein were the continuation of those discussed in the first paper it has seemed best to make no marked change in mode of treatment. General reference will be given by counties and townships which are shown on the accompanying township map of Vermont. Citations of localities are based chiefly on the topographic quadrangle sheets of the United States Geological Survey.

It may prove useful in some cases to cite observations or interpretations of others in order to develop the writer's viewpoint in respect of relations and structure, and in this paper this will be done along with the discussions of different areas rather than in the form of a general preliminary review, such as was given in the first report.

Because there is often a close relation between topography and geology the topographic features that are of interest in regard to structure will be mentioned at appropriate places.

GRAND ISLE COUNTY.

Townships of South Hero and Grand Isle.

(Plattsburg and Rouses Point topographic sheets.)

General remarks. From observations made in the season of 1920 on the island which includes the townships of South Hero and Grand Isle, suggestions were offered as to how the relations among the formations there present might possibly be explained. These suggestions were made not only on the basis of conditions on the island, but also in the light of careful studies of the field relations at other places in the lake region, particularly in Shoreham and Orwell.

While camping on the island in the summer of 1921, parts of it which had not been personally visited before were inspected and excursions were made to the New York side of the lake.

Principal geological features of the island. The geology of the island has been described in detail by Professor Perkins.[1]

[1] Third Report of the State Geologist, 1901-02, pp. 102-173.

The formations of the island may be briefly described as follows:

1. Limestones, mostly gray or gray-weathering, generally in rather thick beds, frequently very massive, more or less altered by granulation and, perhaps, somewhat in certain cases by dynamic agencies; but generally not marked by clearly visible internal deformation due to shearing. These rocks include a small portion of Brainerd and Seely's "Beekmantown," which is more fully developed on Providence Island just to the south of Grand Isle and parts at least of the same authors' divisions A, B, and C of the Chazy. These rocks occur in somewhat disconnected masses, chiefly in the central and southwestern portions of the island. The Chazy shows much variation in color and the different divisions are recognizable on the basis of fossils. The small area of Beekmantown at the south end of the island was considered by Seely and Perkins to belong to division E of Brainerd and Seely's classification.

2. Other limestones, generally in contrast with those of 1 in being composed of prevailingly much thinner beds, but including somewhat massive blackish rocks of Black River age. All belong to a series which is apparently marked at the base by heavy Black River beds and overlying fairly pure limestones of Trenton age and which ascends through a sequence of mud rocks, all more or less limy, but including fairly pure limestone beds. The members vary in color from gray to bluish-black, the latter usually weathering to a gray. In these rocks granulation is not at all marked. The sequence from base to top is interrupted by displacements so that it is not as well shown on this island as at some other places in the lake region which will be mentioned beyond. The alternations from one kind of rock to another, from fairly pure limestone to more argillaceous material, suggest oscillations of level and other conditions which operated to cause changes in the character of the deposits from time to time and changes in the character of the fauna as well. As would be supposed, there are also shown lateral gradations or variations in the same beds. Frequently limestone apparently takes the form of small lenses in more argillaceous rocks. All the conditions indicate that during the times of deposition of this series, muds were contending with limestones, over which they finally gained ascendency. Some portions of this mud-limestone series are barren of fossils. In others they are scarce. There is an interesting recurrence in low horizons within the shales of forms marking the basal beds which have a typical Trenton fauna ("Glens Falls".)

This formation of limestones and irregularly repeated muddy limestones and limy muds passes upward into the rocks described under 3.

3. Prevailingly blackish, shaly mud rocks, still often if not usually limy, effervescing with cold dilute acid, but characterized by persistently finer grain. In their bedded features they are not, however, uniformly thinly-bedded shales. The beds can be seen to vary in thickness from a fraction of an inch to an inch or more and are interbedded with siliceous bands of tougher texture which break with subconchoidal fracture and are often from six to eight or more inches thick. These various shaly rocks have over wide areas a splintery character due to pronounced shearing across the bedding, giving a kind of slaty structure.

Contacts of the members given under 1 with those of 2 and 3 are mostly wanting and their structural relations are, therefore, more or less problematical and open to such interpretation as the general structural features of the region might suggest. The higher members of 2 probably pass upward into the lower beds of 3, but there are present well-defined displacements which actual contacts do not seem necessary to demonstrate.

Attention has been directed by different observers to the differences shown at the present time among the formations of the island with regard to the extent to which or the manner in which they have been respectively affected by dynamic agencies.

The rocks belonging to group 3, as defined above, perhaps make up the larger part of the island. They are generally characterized by pronounced deformation. Folding and tilting are common; but even in places where neither of these is marked, they are when only slightly buckled or lying nearly flat distinguished by a strongly developed cleavage. But this shearing structure is not confined to the members of group 3 alone; it is found in much of fine grained limestone of category 2.

This shearing structure has undoubtedly led to confusion in the field among different horizons of the younger members of the Ordovician series. In surface outcrops, particularly small ones projecting through the clay or drift, all that may be visible is an irregular erosion surface of apparently more or less flattish beds which have been sheared into slates which do not differ much in appearance, whether they belong to group 2 or group 3. This circumstance is of importance because without appreciation of it the real character of a rock in its present surface exposure may not be recognized.

From the conditions shown on Grand Isle, Perkins[1] was early led to regard a considerable portion of the limestones with interbedded muds as forming a transitional series between the Trenton and the "Utica." The probable occurrence of such a "transitional series" in the Champlain basin has also been suggested by other observers.[2] From a study of fossils from the younger limestones and shales of the Champlain region, Ruedemann[3] came to

[1] Perkins, Third Report, 1902, The Geology of Grand Isle.
[2] White, Bull. Geol. Soc. Amer., No. 10, 1899, pp. 452-462.
[3] Ruedemann, Twelfth Report Vt. State Geol., 1920, pp. 90-100.

the conclusion that the "Ordovician series ends in Vermont with beds no younger than the Trenton group." The thinly-bedded limestones of the basal beds are true Trenton ("Glens Falls horizon"). The black mud rocks of the Champlain basin in the south (for example, around Panton) consist entirely of Canajoharie shale; in the north they are "prevailingly of the 'Stony Point' shale. In the middle they meet, the 'Stony Point' shale resting upon the Canajoharie shales on Grand Isle and in the Vermont portion of the northern part of the basin."

Most of the rather barren black shale in the northern part of the basin, carrying *Triarthrus becki* and *Glossograptus quadrimucronatus* as its prominent fossils, which extends from the Canadian line southward over the islands of the lake and along the mainland of Vermont, is thought by Ruedemann to be the equivalent of his "Stony Point" shale and to be homotaxial with late Trenton and, therefore, older than true Utica. Ulrich concurs with Ruedemann in the opinion that no true Utica exists in the Champlain basin.

On Grand Isle the thinly-bedded basal Trenton rocks form a ridge about a mile east of the west shore of the island, running from a point southeast of Sawyer's Bay, where they are in proximity to Chazy beds, northward to the latitude of Gordon Landing. At numerous places they yield characteristic basal Trenton fossils. For the most part these beds are not crushed nor sheared, although at some places they have buckled and sheared somewhat, showing clearly that they have experienced lateral pressure. Except where buckled into small folds these rocks appear to lie in a flattish position, dipping gently easterly. They do not appear to form a part of a true anticlinal fold. The western outcrop of the beds forms a slope of variable inclination as now eroded. This slope east of Sawyer's Bay clearly marks a former shore of the Champlain water body. There is a topographic breach in this Trenton ridge northeast of Rockwell Bay. It seems probable that these rocks formerly had an extension west of their present western margin.

The muddy limestones with included shaly layers which occur along shore north of Rockwell Bay appear to be younger than the beds forming the ridge just described. They also lie in flattish position, but take on a slight northerly pitch about one-fourth of a mile north of Rockwell Bay. These rocks have strong resemblance to beds which lie above the basal Trenton near Crane Point in Addison County, which will be described more fully later. Around Gordon Landing the rocks are of more muddy texture than are those southward and are even more thickly-bedded. Near Gordon Landing, although bedding is distinct, the rocks are sheared with easterly dipping cleavage, so that surface exposures away from shore have the appearance of slates.

A little way north of Rockwell Bay, in a layer near the water, *Isotelus* occurs with *Prasopora,* paralleling the conditions near Crane Point where *Prasopora,* which sometimes makes up almost an entire bed in the basal series, as it does also on Grand Isle, recurs occasionally in certain layers of the muddy rocks which lie above the basal series.

Between the west shore of the island at Gordon Landing and the slope of the ridge of basal beds east of it there is much surface covering; but from the general field relations and the attitude of the layers along shore and in the ridge there is nothing that suggests an anticlinal fold so that the so-called younger beds along shore could be interpreted as lying above the basal beds on the western limb of such fold.

North of Gordon Landing the rocks in some places have resemblance to the basal Trenton and at others to the beds north of Rockwell Bay. At the Grand Isle landing of the Cumberland Head ferry in a thick layer near the water-level there were found specimens of *Sinuites cancellatus,* fragments of *Calymene,* and small orthocerata. The thick layer just referred to is succeeded northward and upward by an imperfectly alternating series of layers, some of which are dark colored and sheared, while others are lighter colored, as weathered and usually non-sheared. It is somewhat surprising to observe these rather strongly sheared layers lying between others which show no marked cleavage. Among the mud rocks this condition not infrequently occurs within a considerable thickness of beds which do not show any prominent mass deformation and which often lie nearly flat.

Although the beds near the ferry landing are not greatly deformed, in general there is more evidence of disturbance from pressure in the rocks between Gordon Landing and Camp Vermont than in the shore section south of the landing. This disturbance is shown in the form of minor buckling and occasional ruptures, as well as by mashing and by the shearing which has been mentioned.

There is acceptable suggestion of an east-west fault at Rockwell Bay, the "transition beds" lying against the Chazy, although the contact is not visible. There is also suggestion of a break at Gordon Landing, with the beds at the north occupying the upthrow side.

The ridge that has been described above as composed of the basal Trenton beds can be followed only a short distance north of the latitude of Gordon Landing. Northward over areas that have been mapped as "Utica" the surface outcrops are few and usually not clear as to horizon. In some places the rock might without much hesitation be correlated with the "transitional series" of limestones and shales rather than with the higher black shale beds; but extensive shearing and absence of fossils make it difficult to decide the matter, particularly in low surface outcrops, such as these rocks usually present.

From Wilcox Cove northward the shore section displays a series of beds which are predominantly shaly, with some bands of siliceous rock, the whole lying nearly flat. While there is some crushing these rocks are not much tilted.

The formation of black shale on this island, and in most of its exposures among the islands to the north, as well as on the mainland, has primary structures which serve to distinguish it from the more limy rocks that are thought to be transitional from the basal Trenton beds into it. Even when strongly sheared the black shale formation may be seen to comprise members of variable thickness, as has been mentioned above, some of which are distinctly shaly, while others are of firmer character and more siliceous. These different members are separated by distinct parting planes which come out most sharply when the rocks have been folded or tilted. But the more shaly or muddy beds are marked in addition by fine laminations which often give an appearance of fine-grained wood. These laminations show most clearly when the rock has been weathered, the weathering process having the effect of emphasizing the slight differences in the composition of the laminae. One is tempted to speculate on the conditions that could have produced these laminations which have so much resemblance to seasonal accumulations.

The "primary" shaly character of these muds is due to these laminations, but there is often shown an imperfect separation under impact which may be an expression of a tendency to minor lenticular segregation of the more limy from the less limy portions of mud in a sea in which limy deposits were contending with argillaceous material, but in which there was always more or less admixture of the two. Many of the laminations in the beds so distinguished are of rusty brown color, in which they resemble the more siliceous bands interbedded with the shales.

Over the eastern part of the island the rocks which have been mapped as "Utica" probably include some beds which belong to the "transitional series." The rocks at Allen Point may be such.

North of South Hero station, in the railway cut near the overhead bridge, are outcrops of rock much like that north of Rockwell Bay, and similar rock occurs just east of the station along the main highway. The beds in these outcrops have not been much disturbed from the horizontal and in the railway cut on both sides the dip may be plainly observed at an angle of about 15 degrees easterly. The rock is sheared, giving a splintery structure.

Again, along the road from South Hero station to Sandbar Bridge, a mile east of the station, some of the low-lying ledges seem to be sheared limy rocks like those of the cut just mentioned.

Towards Sandbar Bridge the rocks are blacker and more shaly. It would, therefore, seem that there is a gradation eastward from the basal Trenton through a "transitional series" to blacker, more shaly rocks like that which with some interruptions may be traced along the west shore of the island from Rockwell Bay northward.

Cedar and Fish Bladder Islands. These islands were visited with a suspicion that they would be found to be made up of the shale formation; but as they would serve to carry the inspection of the lake rocks eastward towards the Vermont mainland it was kept in mind that possibly some overthrust rocks might be found. There was seen no evidence of any kind to indicate that at the present time the slates of these islands have any traces of older rocks lying on them.

On these small islands the rocks which are shales are exposed in high cliffs around their shores, but are concealed by clay over their central portions. Savage Island was not visited. The Vermont Report shows it to be composed of the shale.

The rocks of Cedar and Fish Bladder Islands are entirely similar, and are laminated muds with firmer layers, such as have been described. Recognizing in these laminations a primary character it is clear that the beds of these islands have been terribly jammed and mashed, and distorted in the most amazing manner. The deformation is largely that of fracture; once continuous layers have been broken into chunks which have been separated from each other and mashed together, producing a sort of brecciation. Cleavage is also pronounced. At some places it appears that small blocks have moved over other parts of the formation, but such displacements were never very extended.

Kibbie Point. At Kibbie Point on the main island are rocks similar in their several structural features to those south of Sandbar Bridge and those of the islands just described. Distortion and shearing are plainly manifest. At this place a minor thrust was noted which did not appear to pass beyond the immediate exposure involved.

Robinson Point. At Robinson Point, four miles north of Kibbie Point, in the northeastern part of the island, the laminated shales are apparently not so badly mashed as in the southeastern part. They are disposed in rather gentle folds as can be determined from the laminations, which are usually the only means of identifying the stratification. The bedding is very often obscured by cleavage. This cuts the bedding at different angles as a consequence of buckling which preceded the shearing. At Robinson Point the stratification dip is about 15 degrees westerly, while that of the cleavage is 60 degrees easterly. Shearing has often produced a rough jointing which might be mistaken for bedding.

It is, however, uneven, giving a ragged, splintery structure. In many places bedding and cleavage dip in the same direction, although the two dips do not coincide in most cases.

In common with all the areas in the lake region the northeastern part of this island shows at some places local disturbances of the slate by folding and minor crushing, but these particular features are not so marked in present exposures in this part of the island as at other places.

Occasionally in these rocks one of the firmer siliceous beds will be seen to have buckled into gentle, wavy folds, while the laminated muds above and below show no apparent folding, but instead a more or less prominent cleavage induced by the same pressure that folded the firmer band. This is but one instance of the ease with which the shales accommodated themselves to pressure by shearing.

Calcite veining is very common among the shales in the eastern part of this island and sometimes indicates mashing when such is not very apparent from any other structures.

As well seen in cliff exposures the way a mass has behaved under shearing stress, even when bedding structure is largely destroyed, affords a means of telling whether the rocks were originally shaly or somewhat more massive. The more thinly-bedded rocks will give a slaty or finely splintered rock, while the thicker beds will be coarsely splintered, or sometimes roughly jointed.

A rather careful inspection of Grand Isle, joined with an examination of the rocks of North Hero, Alburgh peninsula, Isle La Motte, some of the smaller islands, and the Vermont mainland, shows that the Ordovician rocks of the Champlain basin, above the Beekmantown, are well represented on Grand Isle, and that some of the shales belong in the higher portions of the shale formation. On Grand Isle fossils from these higher horizons are rare, probably largely because of shearing; but in lithological characters the rocks are closely comparable to and seem susceptible of indentification with similar rocks in the upper part of the shale formation in many of the other parts of the region as named above.

The shore sections of the islands and the rocks along the mainland from the Canada line to the southern limit of the lake show that the various submerged channels, passages and bays that now form the basin known as Lake Champlain are practically throughout excavated in the softer rocks belonging to the transitional series of limestones and shales or to the higher black shales of the basin. But on both the islands and the mainland, sometimes forming parts of the present lake shore, are areas of older and very different kind of rock whose relations to the shales form some of the problems of the region.

Structure of Grand Isle. Certain apparently possible interpretations of the structural relations of the rocks of Grand Isle were discussed in the writer's first paper in the light of such studies as it had been possible to make up to the time of its publication. Attention was directed to the secondary structural differences shown by the rocks of the island. It was pointed out that a large portion of the formation including the transitional series and overlying black shales might be somewhat sharply differentiated from the massive strata of Beekmantown and Chazy ages. The deformational features shown by much of the transitional and shale series were noted and it was indicated that in the crushed condition of these rocks, now manifested by minor folding and tilting, minor reverse faulting, mashing and coarse brecciation, and different modes of shearing, they stand in contrast to the more massive strata of the island. The Beekmantown and Chazy beds were shown to have a generally flattish position in most of their exposures, particularly in the western half of the island, and not to be notably sheared, although somewhat deformed by pressure along or near their eastern margins. The Black River and the basal Trenton beds making up the ridge that has been described above, were also shown to lie rather flat, although the latter were described as showing minor buckling and shearing at some places.

Before passing to the discussion of the possible significance of the structural differences shown by these Grand Isle rocks as the result of differences in behavior under dynamic stresses it may be worth while to consider other differences of secondary character which some of them show.

The Beekmantown and Chazy rocks give an impression of having suffered certain alterations before the formation of the younger beds. The features referred to do not seem to represent on a minor scale or to be in the same class with those which in similar rocks of the region have more or less clearly been due to dynamic pressure, which in addition to producing metamorphism by crystallization also caused flowage and cleavage in different degrees, with the formation of marble or marbly rocks. The particular alterations mentioned appear to be due rather to static metamorphism of the rocks. As has been mentioned, they are apparently largely of the nature of granulation which has more or less completely changed the original material and produced a tough rock from which fossils are extracted with much difficulty. In some parts of the Champlain region rocks which have thus been altered have also been changed further by dynamic metamorphism and in such cases, of course, the earlier alteration features are blended with those of later date or are quite concealed. Gradations occur. In those rocks not much affected by dynamic agencies the fossils retain their outlines more or less perfectly, although crystallization may have destroyed details. In other rocks the features resulting from static metamorphism are very evident, but other characters resulting from shearing stress appear in the shape of distortion of fossils and flowage or cleavage. In still other rocks, pressure has more completely obscured the older static features with the destruction or almost complete obliteration of fossil remains.

On Grand Isle the metamorphic characters of the Beekmantown and Chazy rocks appear to be due chiefly, if not wholly, to static changes. Absence of shearing, lack of distortion of fossils, apparent absence of mass deformation by folding and other features all point to such conclusion. If these rocks generally had suffered any internal deformation they should give more evidence of it, comparable with such as is found in other and similar rocks of the region, some of which are clearly of similar age while others probably are. Such deformation as these rocks may have experienced probably involved extensive mass dislocation, rather than what might be called internal adjustment, except as the latter was locally developed at some places.

The static alteration features of these massive, granular limestones give them an appearance of antiquity in contrast with the rocks with which they are associated. In the Black River and basal Trenton beds there is not present apparently the same degree of alteration by granulation as the Beekmantown and Chazy beds show. In these differences there is offered an indication quite distinct from that which fossils show of a hiatus between the Canadian and Mohawkian of the Champlain region. One is tempted somewhat to speculate on what the conditions were which led to the induration of the older rocks.

As was discussed in the first paper it has usually been assumed that there has been no great amount of lateral disturbance of any of the formations now found on Grand Isle, that the various rocks, including the masive limestones of the Beekmantown and Chazy formations, rest now substantially where they were formed. Unfortunately, the conditions on the island at the present time do not allow of positive determination of the relations between the massive limestones and the younger rocks. It was not possible to find any contacts of the former on the latter anywhere on the island. The idea that there has been displacement of the rocks of the island rests upon the considerations that such kind of deformation is widely prevalent in and characteristic of the region and that the rocks of the island show the effects of profound pressure.

It was first supposed that the shale formation of the whole region had undergone more severe folding as a whole, than now appears to have been the case, even in the eastern portion of the basin where the pressures might reasonably be assumed to have been more powerful. The comparatively small number of

exposures which it had been possible to inspect when such a view was formulated seemed to indicate that the shales were usually disposed in rather large close folds with overturning and consequent isoclinal structure. For places where the shales had clearly been overridden by older rocks along thrust planes they were discussed and pictured as having a prevailingly easterly dip, which was attributed to overturning. The conditions noted in a more extensive study of the region and from an examination of the shale formation in widely separated localities contradict such a view and have afforded data for a revision of ideas.

Any severe buckling or folding which the shales show now seem to be more or less local corrugations which pass along the strike into crush zones or fault fractures, or perhaps eventually into relatively gentle flexures marked only by a profound cleavage. Across the strike also these localized zones of severe folding, fracturing and mashing will apparently pass into gently undulating folds. Eastward toward the areas of the region marked by overthrust of older rocks on the shales the latter are more generally crushed and tilted, but at some places not far from the present margin of overthrust rocks they are notably flat, as indicated by bedding and laminations, although when flat they are always strongly sheared with the development of fracture cleavage.

What then are some of the conclusions to be drawn from the flat position or, generally speaking, open folds which these different rocks show, perhaps having Grand Isle principally in mind at this point? These rocks have clearly been acted upon by powerful compressive forces. This is shown on Grand Isle, but more clearly at other places. In the absence of any folding of large dimensions, or even universal close folding of small dimensions, the inference is strong that these rocks yielded to pressure chiefly through shearing of one kind or other. In this particular the massive limestones behaved like the shales; but in the former the shearing did not always manifest itself as an internal deformation with the development of fracture cleavage or other pronounced internal structure attributable to pressure, even when the associated shales often developed such structures to a high degree. On Grand Isle the massive strata have clearly effectively resisted any appreciable internal deformation for the most part. If this is not the correct interpretation it is not only difficult to understand their own characters but also why the much less massive, thinly-bedded, basal Trenton beds in west part of the island have not been more severely deformed in all ways. The massive beds have acted as a buffer for the younger rocks.

What then has probably been the behavior of the massive strata under pressure if they have not buckled or sheared with any visible flow or fracture structures? They are probably to be thought of as having moved as a great block or as blocks fragmented from the main mass with which they were once joined. They have resisted internal deformation in some places, as on Grand Isle, without, however, being able to prevail completely against the pressure. They were competent against such deformation as the shales exhibit, but not resistant enough to remain in place. From a consideration of the very different primary characters of the heavy limestones and the shales it is not difficult to see how forces competent to crush the shales might leave the massive limestones practically free of such features, but since it is apparent that the shales could hardly have been so generally crushed or sheared without diminishing their original breadth from east to west to a marked extent, it naturally becomes a question of how the massive rocks accommodated themselves to the simultaneous action of the same forces. That accommodation was reached in some places in the lake region by shearing even in the massive limestones is shown in numerous cases, but on Grand Isle it was effected chiefly by mass dislocation.

In the writer's first discussion of the probable structure of Grand Isle (see first paper) some of the considerations developed above were dwelt upon, but a good deal of stress was put upon present conditions among similar rocks in other parts of the Champlain region, particularly along the lake shore farther south. In Shoreham and Orwell the present field relations leave no doubt that older formations have ridden over the shales along thrust planes, and while at many places the massive beds have been somewhat folded and fractured and sometimes internally deformed, there are other places where the massive beds lie nearly flat with little evidence of internal changes resulting from pressure, although the rocks may be altered by other processes as is the case on Grand Isle. The so-called "Potsdam" and "Beekmantown" at Mt. Independence in Orwell and at Mutton Hill in Shoreham are cases in point. The conditions in other parts of the Champlain basin also give support of very positive character to the conclusion that massive Lower Ordovician beds similar to those on Grand Isle have been moved by thrusts and are not now in their original places.

In some studies which the writer made in the Hudson valley region near Poughkeepsie, New York, among rocks which in spite of their apparent remoteness from the Champlain basin have much resemblance to certain strata of the basin, not only in respect to age and general lithology, but in character of deformation as well, there seemed to be acceptable evidence for the conclusion that massive limestones of Lower Ordovician age had been thrust through younger shales by reverse faulting, often with a horizontal component powerful enough to drive the massive rocks in a lateral direction over the younger beds for a considerable but usually indeterminable distance.

While reverse faulting was recognized as probably playing a part in the disturbance of the rocks of Grand Isle, so that they are probably to be regarded as crowded somewhat by blocks riding against other blocks, the view was rather favored (see first paper) that the Beekmantown and Chazy beds, and some of the younger rocks as well, had been moved along a "major" thrust plane that had sheared beneath them after they had been broken by earlier reverse faulting and had transported them, perhaps for a long distance, from the east. They were thought of as having ridden over the shales that form the eastern part of the island, as well as others which intervene between the island and the Vermont mainland. Largely on account of normal faulting that probably occurred subsequent to the action of pressure on these rocks it is not now possible to decide whether this view is correct, or whether the massive rocks have simply broken through the younger beds and perhaps have travelled only a short distance over the shales which are now concealed beneath them. In this connection it should perhaps be remembered that we are dealing with an eroded and a sunken region.

From relations which are present in the Taconic hills of Sudbury and Orwell it was conjectured that a major thrust, like that referred to above, might have cut in such way as to carry early Cambrian strata at one place and early Ordovician at another over the shale formation. The conjecture rested in part on the assumption that early Ordovician beds lay unconformably upon eroded Cambrian rocks. The conditions in the Taconic hills are very puzzling and require further detailed study with reference to this point, but there remains little doubt of the existence of thrusting in the Taconic range. In the range the difficulty is to account definitely for the remarkable present distribution and contiguity of what appear to be Lower Cambrian terrigenous rocks and certain limestones including probably lower and middle Ordovician rocks.

The absence of large folds in the various rocks of the Champlain basin does not seem to fall in with a view that these formations were at any time elevated into mountain masses by huge and extensive plications of the crust. But the absence of large folds does not militate against an idea that there may well have been a considerable elevation of the rocks at some time in their history. That much elevation was possible seems to follow from consideration of the result of integrating a large number of thrusts of all dimensions, including those which now find expression in cleavage. The statement that there has not been extensive folding on a large scale is in accord with facts observed in the field. Lack of such folds in the shales seems to have been the direct result of failure to fold on the part of the massive beds which underlay them. But if the latter were thrust into the shales in varying degrees, sometimes into them, sometimes through them and sometimes even over them, the effect apparently would have been to produce the crushed characters which they now show and to give a prominent fracture cleavage, whether the shales remained practically flat or were previously buckled into small folds or jammed into crush zones. The massive rocks are in the position of overthrust with reference to the shales that lie on one side of them, and of underthrust with respect to shales that lie on the other side and above them. Either relation seems sufficient to account for crushing and shearing of the shales.

On Grand Isle then different masses of rocks are probably to be thought of as now in more or less displaced relations with respect to one another as the result of compression. But the evidence on Grand Isle itself is inconclusive. Features elsewhere in the region that show what the actual behavior has been and what the tendency obviously was must be invoked and the probable presence of a common plan of structure for the region must be recognized in explaining the structure of Grand Isle.

It may as well be stated at this place as elsewhere that so far as observations have gone on the Vermont side of Lake Champlain, there is no evidence to show a thrust plane cutting beneath all the rocks now exposed in the Champlain basin. If such plane exists, perhaps evidence for it would hardly be sought on the Vermont side. There may be such a plane cutting at considerable but unknown depth and having its line of emergence in older rocks on the New York side of the lake. On the Vermont side the thrusts of various magnitudes which cut the rocks along the general strike and which are repeated across it may be the surface expression of a deep-seated shear, but the major thrusts on the Vermont side cut above the weak shales of the region, and are themselves apparently modified by antecedent faults and thrusts of minor dimensions.

North Hero Township.

(Rouses Point topographic sheet.)

The township of North Hero comprises several small islands of varying dimensions and two larger ones which are joined by a narrow neck, a portion of which, known as the "carrying place," is flooded at high water. These various insular areas are all of low relief and are made up of the shale formation. As in the case of Grand Isle the most satisfactory exposures are found along shore.

While there are some minor variations in the bedded characters of the rocks of the North Hero islands they are prevailingly black, limy shales with occasional firmer bands and much like those of the northern end of Grand Isle, showing beds of different thicknesses with the more muddy ones distinctly marked by laminations, accentuated by weathering, which appear in rocks

that have been strongly sheared, as well as in those which have not. The firmer beds are composed of tougher, more siliceous material than the associated muds. On these low islands with visibly limited vertical range of beds the firmer usually rusty beds do not so frequently appear and are not such conspicuous members as on the Vermont mainland, where they serve as useful features for correlation. On North Hero, as elsewhere, these rocks are of monotonous aspect, although with respect to the degree in which they are now sheared and cut by cleavage they show conspicuous differences among their outcrops.

The rocks were examined primarily for their secondary structural characters. In their primary lithological features they form a fairly homogeneous mass of deposits of apparently uninterrupted sequence.

Professor Perkins in his description of these islands has given an accurate account of the distribution and other general characters which it is hardly necessary to repeat, except as it may be desirable to emphasize certain aspects that belong to a discussion of the geology of the whole region.

The prominently argillaceous nature of the shale formation comes out strongly from the manner in which its surface portions have weathered. In many places the shale may be seen to grade upward into clay which retains the primary laminated character of the original rock. While the surface material of the islands is apparently to a considerable extent of glacial origin, much of the clay is purely residual material which has probably been largely formed since the glaciation of the region. Such material is apparently nowhere very thick.

While the shales have clearly buckled locally under pressure and almost always show cleavage well developed, they are apparently more commonly disposed in gentle swells of moderate lateral extent and comparatively small vertical displacement so that the bedding has low easterly or westerly dip and the axes of the folds lie horizontally or more often have slight northerly or southerly pitch. Such features are of interest with respect to the deformational history of the region, particularly with reference to the question of the extent of the region involved in the folding which is supposed to have occurred at the close of Ordovician time.

Studies made on North Hero seemed to show that the shales are more severely jammed along certain north-south belts than along others and that even shearing as expressed by fracture cleavage shows similar geographical segregation and is more marked in some places than at others even on the same meridians. Fossils are not uncommon in parts least sheared, so far as fossils are apparently present in these rocks; but where shearing has been severe, as might be expected, fossils are hard to find.

Some of the outcrops of the shore sections may now be briefly described.

On the island that lies just north of Grand Isle the rocks along shore between Grand Isle bridge and City Bay lie generally in a flattish position, from the bridge northward for a distance of about two miles, pitching gently to the north and then changing to an equally gentle southerly pitch. Whether the rock throughout the distance mentioned all belongs to the eastern limb of a common anticlinal fold is not certain. The dip is predominantly easterly, but where the pitch changes to southerly, about a mile south of City Bay, the rocks appear to be more broken by rough compression "joints" and shearing planes than farther south. At several places graptolites, probably *G. quadrimucronatus*, and heads of *T. becki* were found.

Along the west shore of this island similar variations in direction of pitch were noted; at Hazen Point the shales pitch southerly, less than a mile to the north they pitch in the opposite direction. In traversing the west shore one walks diagonally over small, gentle anticlinal and synclinal folds. At Hazen Point the dip is westerly, a mile north and nearly on the same meridian the dip is easterly. Farther north, about midway of the shore, the dip changes to westerly. Cleavage is usually well developed along the west shore. It did not appear that one type of fold was more marked in this regard than the other. In some places the folds are quite symmetrical, but in others they are less so and sharper and the beds are tilted to a high angle or even to a vertical position, and are sometimes overturned. Mashing and fracturing of beds are common in the sharper folds and most of the anticlinal buckles show some modification from crushing. Usually these crush zones are further marked by veinlets and streaks of calcite. Differences with respect to the expression of shearing may be correlated definitely with primary differences in the characters of the beds. In both easterly and westerly dipping beds a sort of jointing practically perpendicular to the bedding and parallel or diagonal with the strike was occasionally noted, especially along the shore of Pelot Point peninsula. This type of fracture is probably also an expression of shearing strain. Plates XIX and XX serve to convey ideas of the nature of some of the structures more clearly than verbal descriptions could. It seems as though folding and fracture sometimes preceded the formation of cleavage, as though the latter were the final expression in such cases of the shearing stress. Probably, however, these respective deformations were sequential in the same episode.

If it were assumed that there was considerable lateral variation in the characters of the beds of this shale formation, it is not difficult to understand that at some places along the same general meridian the rocks were mashed or broken by faults of small displacement and that at others sufficient relief came from frac-

PLATE XIX

Strongly folded thinly-bedded, argillaceous limestones of so-called "Utica" age, on west shore of North Hero island, about one-half mile north of North Hero station. View looking north.

PLATE XX

Sheared thinly-bedded laminated shales on west shore of North Hero island, about one-half mile south of North Hero station, showing nearly horizontal bedding cut by easterly-dipping cleavage and illustrating characters very frequent in the shales among the islands of the lake and on the Vermont mainland. The hammer marks the bedding planes and the log the cleavage dip. View looking north.

ture cleavage or compression jointing. These different types of deformation clearly belong to the same class or category and, probably, to the same general episode of disturbance.

Along the west shore of the island in many places where the rocks were not too badly sheared, graptolites and glabellas of *Triarthrus becki* were found. They were seen most abundantly just north of Hazen Point and along the shore of Pelot Point peninsula. Exceptionally low water in the season of 1921 allowed an inspection of practically the entire west shore section. South of Pelot Point the shales form bold cliffs which on foot are impassable except at low water. Possibly the rocks contain other fossils, but such were not seen.

The shale formation continues from the island just described to the one just north of it; but on this northern island much of the shore is very low and bowlder strewn, with no outcrops of the shale now visible. Good outcrops occur along the east shore in the southern part and on the west shore north of Blockhouse Point. These sections show the same kinds of rocks and fossils and the same structures as those found on the island just south.

Alburgh Peninsula.

(Rouses Point topographic sheet.)

The topographic and geologic features of Alburgh are quite like those of the North Hero islands. The peninsula is everywhere of low relief, only in two or three small areas rising above 200 feet. Several swampy tracts occur and some of these probably mark nearly or quite complete separation of the hard rock formation at the present water-level, so that if the surface material which now fills them were removed the peninsula would be resolved into insular or smaller peninsular fragments of the shale formation.

The rocks of Alburgh were examined over the interior of the peninsula at many places and for long distances where exposed along shore, but on the shore and inland there are many stretches and areas where the shales are not exposed.

Along the east shore bordering Alburgh Passage there is an almost continuous outcrop of the shale. At many places between Wagner Point and Point of the Tongue the shales dip easterly at low angle with easterly dipping cleavage. On the west shore of the Point of the Tongue the rocks are much disturbed, like those on the west shore of Pelot Point farther south on North Hero. Near the point the rocks are folded into a fairly sharp anticline. Northward the beds of the western limb stand at a high angle of dip and still farther north are overturned with high easterly dip, with shearing in the direction of the bedding.

After a stretch of sandy beach the rocks outcrop again at Coon Point, whence, with a slight interruption at Palmer Cove, they continue practically without break along the shore of Isle

La Motte Passage, to within two-thirds of a mile of the toll bridge.

At the western end of "Sand Beach," at Coon Point, the shales form a gentle open syncline. This is followed westward by a smaller, unsymmetrical anticlinal fold and this by a small, irregular synclinal flexure, which is succeeded by a broader anticlinal swell and this in turn by a broken syncline whose western limb is crushed against an anticlinal buckle. All the deformational features appear to have been the result of compression. Some portions of the rock had apparently become wedged between others and confined, so that under continued compression there occurred some differential movement and offsetting giving a structure simulating step faulting as produced by gravitational tensional stress. The beds are not distinguished by strong cleavage.

At Coon Point, in fact, the rocks for the most part do not show pronounced shearing and the locality is an excellent collecting ground for fossils, particularly fragments of the trilobite, *Triarthrus becki,* which were seen here in abundance. Graptolites were also found.

In the section along the west shore north of Coon Point there are no especially noteworthy structures different from those which have been described. About two miles north of the point the rocks show prevailingly low westerly dip and carry fossils like those at Coon Point; a series of vertical joints with strike N. about 52 degrees east cuts the shales at this place.

Just north of the Alburgh end of the Isle La Motte toll bridge is a high cliff in the shales and the shore road cuts through these rocks. At this place the rocks are severely jammed and the laminated beds much distorted and broken, showing great disorder. The rocks are filled with veins and bunches of calcite. North of these outcrops the shore is low and bowlder strewn with few outcrops as far as Windmill Point. Between Windmill Point and Rouses Point ferry landing the shales carry graptolites and fragments of trilobites and dip westerly at a low angle without conspicuous cleavage.

Ruedemann[1] reports a list of fossils from alternating black, calcareous shales and black to dark gray impure limestone outcropping along the lake shore one and a half miles east of Windmill Point which leaves "no doubt of the Trenton age" of the beds.

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[1] Twelfth Report of Vt. State. Geol., p. 97.

PLATE XXI

Black River beds resting by thrust on thinner beds of probably Trenton age which have been folded and somewhat crushed. East shore of Isle La Motte, south of William Hill's landing and three-fourths of a mile east of Isle La Motte village.

Along the road that crosses the peninsula one and a half miles north of Isle La Motte station and again along the shore road and the shore near Dillenbeck Bay the shales yielded only graptolites and *T. becki*. The same fossils were found at East Alburgh and at Alburgh Springs along shore and also in some outcrops along the road between Alburgh Springs and Alburgh, west of Mud Creek.

The prevailing rocks now exposed over the Alburgh peninsula are the black, laminated shales and the conspicuous fossils are graptolites, probably *G. quadrimucronatus* and fragments of *Triarthrus becki.*

Isle La Motte.

(Rouses Point topographic sheet.)

In its main topographic outlines Isle La Motte bears much resemblance to Grand Isle, of which it is also to a large extent the geologic counterpart. In its general low relief it is like the other islands of the lake and portions of the Vermont mainland. Its rocks were noted very early in the history of geological exploration of the lake region and have been more recently described and mapped by Brainerd and Seely and by Perkins. In the published descriptions of the rocks their outstanding deformational characters have been mentioned, but no definite attempt has been made to account for the secondary relations which the formations have to one another, nor to correlate the conditions found on the island with those found in other parts of the region.

Several days were spent in a careful inspection of the island and the following brief review of the formations, as well as the more particular account and discussion of the secondary features are based upon personal acquaintance with the rocks.

The formations on Isle La Motte include a small area of the uppermost part of Brainerd and Seely's Beekmantown, exposed chiefly along shore in the southern part of the island, a large area of Chazy, including parts at least of all three divisions as defined by Brainerd and Seely and having a combined thickness as measured by these observers of about 500 feet, a small patch of Black River of roughly determined stratigraphic boundaries, a considerable area of Trenton limestone, and three relatively small exposures of the so-called "Utica" shale. In some of their structural characters and in their geographic arrangement many of the rocks have strong resemblance to similar rocks on Grand Isle.

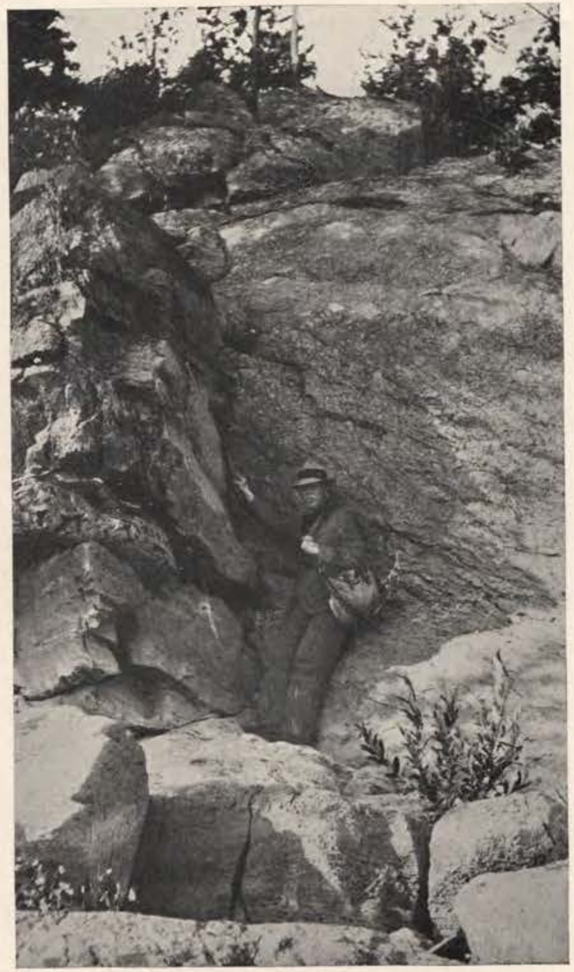
The Beekmantown of the main island (Cloak Island will be described beyond) is confined to the southern end known as "The Head." Its surface extent is relatively small, although its shore section is nearly a mile long. The top of the formation was drawn by Seely and Perkins at a dark, compact layer about 30 inches thick which carries *Isochilina* and which is further characterized by breaking into large cubical blocks. The rest of the formation, as exposed to the limit of low water, consists of firm and shaly beds, varying in thickness from 6 to 30 inches. The rocks pitch in a general northerly direction at a low angle of about 5 degrees and are overlain by the lower Chazy. The generally flattish position of the Beekmantown beds and their lack of any shearing deformation are noteworthy features. Their primary characters have been sufficiently described by other observers.

The Chazy strata, which succeed the Beekmantown, have a similar flattish position, dipping at a low angle in a general northerly direction. Their present surface outcrops have a somewhat sinuous strike across the island. The vertical variations both among and within the lower Chazy beds are noteworthy, and there are horizontal variations shown in the rocks along shore, which are often accentuated by weathering, but which it is not possible to trace for any considerable distance inland. As a whole, the Chazy formation is impressive because of the massiveness of its beds. This massiveness appears to be at its maximum in the limestone members of the Middle Chazy. The portion of the Chazy regarded as forming the lower division, or Group A of Brainerd and Seely, seems to have a larger visible extent on the island than any other portion of the Chazy. The so-called Middle Chazy is, however, widely exposed. Outcrops of the upper portion are confined to a relatively small area on the east side of the island about midway of its length. The beds of this upper portion appear to pass westward beneath surface material, but outcrops are lacking to show how far it may extend.

About midway of its length the island is divided by a low, swampy tract of land, south of which except for a small strip of shale along the east shore, the visible rock all belongs to the Beekmantown or Chazy. North of this swampy land much of the island is under clay or drift which conceals the hard rock and in these areas the interesting features are the old marine clays, the sea beaches with their fossils and the drift. The drift may be partly an outwash from a readvance of the ice. In it occur numerous shallow depressions, now often pools of water, which suggest "kettles" formed by stranded blocks of ice. The Pleistocene deposits present a problem by themselves which the writer has made no effort to work out.

Over the eastern part of the northern half of the island the hard rock outcrops in many places and apparently belongs chiefly to the basal Trenton of the region. How far the members of this formation may extend beneath the surface covering to the west and north is a matter for conjecture. The Trenton rocks may be traced by their outcrops over an area about one and a half miles

PLATE XXII



Contact along a fairly regular and nearly vertical plane of faulting between basal Chazy with subjacent Beekmantown beds and strongly brecciated middle Chazy limestone, at the southwestern end of Cloak (Hill's) island, Isle La Motte. View looking north.

long and a mile wide. They reach the east shore in a few places, but are usually separated from the lake by narrow bands of shale or by the Black River. The Trenton rocks are rich in fossils and in this particular and other features are much like those in the western part of Grand Isle.

At the southeast, north of Clarks Bay, the Trenton beds are separated from the lake shore by a small band of Black River. There is nothing to suggest that the Black River ever had on Isle La Motte a much greater extension in its secondary relation to the other rocks with which it is now associated than it has at the present time. As a whole the Black River and the Trenton beds lie in a flattish position and are not extremely deformed.

The Black River and Trenton beds seem to show with respect to alteration differences from the Chazy similar to those which have been mentioned for Grand Isle. The rocks of Isle La Motte are clearly part and parcel of the series to which those of Grand Isle belong.

Structure. The various expressions now to be seen of the noteworty deformations of the rocks on Isle La Motte are to be found chiefly along or near the eastern shore. Description will begin with rocks at the southeastern end of the island.

The gentle northerly dip shown by the beds at "The Head" continues around the southeast shore, nearly to the small point south of Waite Bay. After an interval of about 100 feet of sandy beach there is shown an abrupt change of structure. The rocks at the point are greatly disturbed and brecciated. There seems to be an easterly dip, but from the clear indications present of severe compression this dip was interpreted as that of a rough jointing due to shearing and not as that of bedding. The age af the rocks is uncertain, but they are probably some part of the Chazy.

South-southwest of Waite Bay is Cloak Island. Although only a few acres in extent it possesses some very remarkable structural features. A mere inspection would leave no doubt of the fact that its rocks have been under severe compression.

The rocks are apparently mostly of Chazy age. A few fossils were found, including *Lingula limitaris* Seely, and a somewhat plicated brachiopod shell showing both valves with their markings. In the latter, although the beak was gone, other characters were well preserved. These with the decidedly gibbous outline strongly suggested *Camerotoechia plena*. *Maclurea* has been reported from the west side of the island, but was not seen by the writer. There may be present a small portion of the Beekmantown whose relations will be described presently.

In the eastern part of the island are massive beds which have clearly been folded and which at some places show westerly dip and clear N.-S. strike. But this mass deformation is masked by severe brecciation. The fragments of this badly crushed rock vary in size from small bits to pieces two, three or more feet through. About midway of the island, east and west, and near the south shore, a huge block of house-like dimensions rests against the westward extension of the brecciated mass just described. In this block the beds stand on end with E.-W. strike. In them was found the plicated shell referred to above. This block or mass is followed westward by more brecciated rock and then occurs a somewhat detached mass of beds showing no apparent brecciation or shearing. This mass is perhaps 10 or 12 rods long from east to west and 5 rods wide from south to north. The beds in this mass all dip northerly at an angle of about 20 degrees. On the north they are cut off abruptly by a fault and rest along a more or less regular and nearly vertical plane (see Plate XXII) against coarsely brecciated rock similar in this respect to the rock described for the eastern end of the island. The lower members are much like some of the Beekmantown at "The Head" on the main island; they are rather thickly-bedded and often weather to a rusty color. Above these are other beds, perhaps in all about 15 feet thick, with some thin, almost shaly members. At the base of this upper portion in some sandy layers were found a number of fragments of *Lingula limitaris* Seely, which is thought to mark the base of the Chazy in the Champlain region. The northwestern and northern parts of the island are wooded and outcrops are not satisfactory for study. Along shore in these parts of the island the rocks usually form steep cliffs. On the west shore the rocks give the impression of big blocks jumbled together, but they are usually brecciated on a smaller scale as well. There are indistinct traces of folding and indications that in some places the beds stand on end.

The rather regular surface along which the conformable northerly dipping beds of the southwestern part of the island rest against the coarsely brecciated rock clearly marks a fault. It seems probable that the brecciated rocks are the younger; but what was the mode of deformation that brought these rocks into their present relations is far from clear. There seemed to be no indications of drag on any of the exposed edges of the conformable beds. The rocks of Cloak Island and those at the point just south of Waite Bay on the east shore of the main island give every indication of having been under severe compression.

Between the point described above and Waite Bay on the main island are some rocks that are apparently not much deformed. Then along shore is a short, sandy stretch which is succeeded northward by a beach of bowlders. Beyond this beach the hard rock outcrops along shore and continues to Holcomb Point. At some places friable layers have been cut by wave action so as to leave more massive layers overhanging. At other places the massive layers form the shore. South of Holcomb Point the rocks are probably all Lower Chazy. The layers are not appreciably deformed. Similar rock occurs along part of the shore of the bay north of Holcomb Point and is succeeded by beds whose age was not determined, although they are probably part of the Chazy.

About 40 or 50 rods south of Jordan Point a small bay shows a narrow band of the shale formation, perhaps 300 yards long. The rock is laminated like that on the Alburgh shore to the east. The dip of the beds, as shown by the laminations, is prevailingly westerly, but the rocks are crushed. North and south along shore the shale gives place to limestone, and often the limestone forms the higher part of a bank which lower down is composed of the laminated shale. Search was made for a contact between the limestone and the shale and what appeared to be one was exposed by digging, but the relation was not decisive on account of the weathered condition of the shale. Along the shore where this band of shale occurs blocks of limestone have fallen down the bank apparently from the action of the waves upon the soft shale; but it is not necessary to suppose that the limestone lay on the shale.

The rock in the wooded pasture above the bank carries faint coils of *Maclurea magna*, and appears to be somewhat but not severely sheared. North of the bay along shore is massive Chazy carrying *M. magna* and *Girvanella*. These Chazy beds form a gentle sag pitching northerly just north of the bay and southerly near Jordan Point. The dip in general is westerly. But along this part of the shore the bedding often loses distinctness or is practically obliterated and the rock often appears as a crushed mass with fragments varying in size from small, angular pieces to big chunks. At other places instead of brecciation a shearing structure is developed across the bedding, giving an impression of easterly dip. The brecciated rock occurs at the southern end of the band of shale mentioned above and again north of it, south of Jordan Point. Its outcrops are not extensive, perhaps 75 feet in the southern exposure mentioned and 200 feet south of Jordan Point. This brecciated rock may be seen in contact with regularly bedded layers of some of which it may be a part that has been crushed. There has been some differential movement and dislocation, but how extensive it is difficult to make out. Perkins reported *Illaenus* and *Maclurea* from two separate fragments in the breccia. It is interpreted by the writer as an autoclastic rock. The undeformed beds with which the breccia is in contact seems to be Middle Chazy.

The low swampy tract extending from Clarks Bay just north of Jordan Point, westward across the island probably is a zone of fracture.

Just north of the eastern end of this swampy tract Black River beds form a band along shore, perhaps 125 rods long and 10 or 12 rods wide. The beds of this formation form a gentle anticline at Hill's quarry, dipping westerly on one side at an angle of about 5 degrees and easterly on the other limb at an angle of about 12 degrees. Near the shore just east of Hill's quarry the surface of the rock shows many coils and opercula of a Maclurea, perhaps *M. logani,* and many small patches of sections of shells. Except for the *Maclurea,* which was not seen by the writer in the Black River elsewhere in the lake region, the rock closely resembles that which in many parts of western Vermont has been identified as belonging to this terrane.

For the most part the Black River beds are not marked by severe internal deformation; but at the northern end of the strip, at a small point a few rods south of William Hill's landing and perhaps 5 rods north of undisturbed easterly dipping beds, the rock is crushed with development of shearing (see Plate XXI). This structure may be best seen on the north side of the point just mentioned, where the thick layers of the Black River may be seen to form a subordinate anticline in which the roughly jointed, brecciated structure is particularly well shown. The bedding is obscured, but is still visible.

North of the crushed Black River beds the low bank and shelving shore are for a short distance in front of the William Hill place formed by Trenton beds. About 50 paces north of Hill's landing along shore are low ledges of a sheared, blackish rock which a few steps northward forms a sharp headland in which the lamination bands of the shale are clearly shown. The laminations dip at a high angle westerly, or are greatly broken and fragmented. The shale continues northward from the headland with the dip changing direction in the way so often observed on the islands lying to the east. If not mashed the rock is strongly sheared into a more or less fissile condition, and is often veined with secondary calcite.

Perhaps one-third of a mile north of Hill's landing the shale is interrupted along shore by a beach and then occurs a small mass of Trenton limestone which continues for about 200 feet. After another interval of beach the shale again forms the shore and continues along it for perhaps one-half a mile. Then the Trenton limestone outcrops again and extends to Cooper Point.

In all its exposure the shale forms only narrow strips on the shore, but in the most northern one the rock may be frequently seen in the bank and at one place it reaches across the shore road.

South of Cooper Point the limestone carrying Trenton fossils is at one place folded, overturned and broken and a part of the rock has overridden another part. At other places the rock shows westerly dip and at others lies nearly flat. North of Cooper Point the Trenton beds disappear under the shingle along shore. Around Cooper Point *Prasopora* is abundant, but much altered. Strong compression is manifest.

West of the outcrops that have been briefly described for the east shore, between the swampy tract and Cooper Point, the rocks exposed in the higher portions of the shore slopes, except for some Black River that has been mentioned, is all Trenton and the Trenton beds extend westward with numerous exposures through the fields to the main island road running through the village.

Away from the shore the Trenton beds exhibit less and less evidence of internal deformation and show a gentle northeasterly dip and northeast strike. The present topography of the pasture land between the shore and the main island road clearly displays the dip and strike of the beds as the land rises by terraces to the west.

In ascending from the shore to the higher ledges lying west of the camps along the shore road fossils appear, but there is an appreciable difference between these eastern outcrops and those that lie farther west with respect to the degree of deformation and alteration of the rock. At the east the beds show clearly more evidence of shearing strain, with subordinate mashing, although the westerly dip is usually discernible; the fossils are not well preserved.

The fossils in these Trenton beds west of the camps include the forms that distinguish the basal Trenton beds in the ridge half a mile east of the west shore on Grand Isle and the rocks themselves are counterparts.

To one who examines this island after a survey of the island of North Hero and the peninsula of Alburgh the scant occurrence of the shale formation on Isle La Motte is impressive. To one who may have been inclined to the view that the preservation at the present surface of broad areas of the weak shale formation, not only on the islands of the lake but also on the mainland, is perhaps due to a covering until rather recent times of a more durable formation which has been removed, the absence of any traces of rock that might have served for such protection anywhere on North Hero or Alburgh is also impressive. That such a covering does exist and probably has existed in some places in the lake region may be shown; but that all the shales had precisely similar thrust relations with massive limestones does not seem to have been the case.

But as has already been discussed for Grand Isle and for other parts of the Champlain basin the region is one eminently characterized by upthrust of older into younger formations. This mode of mass disturbance is widely prevalent and conspicuous, and dominates all others.

It has also been indicated that good evidence exists to show that subsequent to the great dislocations that piled the rocks against one another, normal faulting occurred by which the rocks were again fractured and displaced. It does not appear possible in many cases of displacement, both along and across the strike, to say whether the dislocation was the result of compression or normal tension faulting. In the case of massive and highly elastic limestone strata it is possible to conceive that under compression the conditions might have been such as to permit a fracture across the strike that would produce relations simulating those that would result from normal faulting. In the absence of any positive criteria by which the exact nature of the differential movements between masses now clearly lying in displaced relations to one another may be determined, the explanation of such relations must rest upon probability.

The conditions on Isle La Motte are in so many respects comparable with those on Grand Isle that it seems that an explanation which would fit one would also fit the other, and the conditions that exist in other parts of the region are such that any interpretation which fits these two islands may probably be applied to the relations involving similar rocks at other places, with certain modifications.

The absence, so far as could be determined, of any traces of older limestones at the present time on the shales of North Hero and Alburgh stands against the view that these shales were ever covered by such rocks and that the massive limestones of Grand Isle and Isle La Motte represent downfaulted blocks of a much more extended mass of such rocks that was thrust over the shale and which has now largely disappeared by erosion. This distinctly does not mean that such limestones do not now and never did rest on the shales at perhaps many places in the lake region, or that shales may not underlie the massive rocks on Isle La Motte and Grand Isle. It further does not mean that the visible shales of the northern islands of the lake never lay at some depth beneath overthrust masses. The discussion applies to the relations among the visible rocks of these islands.

The field relations in the northern part of the lake region have not after careful inspection seemed to favor the idea of down-faulting of the shales among the older limestones through gravitational stress. The field evidence everywhere rather suggests that the present relations shown between massive limestones and shales, where the latter, as indicated by their younger age, occupy the downthrow side of a displacement, are the results of compression, in spite of the probability of normal faulting in the region and the lack of positive proof of thrust contacts. It is proper further to weigh the question as to whether the massive limestones of Grand Isle and Isle La Motte could have been thrust into and perhaps over shales and whether the field relations and various kinds of deformation lend themselves to such a view.

On the islands under discussion, there have not been found any positive surface traces of overlap of older on younger rocks. Some of the basal Trenton and associated Black River beds that occur at the northern end of the ridge that runs east of the west shore in the lower western half of Grand Isle are older than the rocks along shore to the west of them and if normal faulting is ruled out the topographic position and attitude of the beds of the former fall in with idea of overthrust. Contacts are, however, lacking. The lake waters conceal the hard rock that lies to the west of the western shores of Grand Isle and Isle La Motte and whether the shales come to the surface beneath the lake is not known. Farther south in Shoreham and Orwell the margin of thrust overlap of the heavy limestones on the shale may be followed at the present surface, the shales lying to the west of the margin above the lake water level.

On Grand Isle, as has been described, the massive older rocks are more or less mashed and veined with calcite along their eastern margin. It is noteworthy that the more crushed and sheared condition of the massive rocks, both on Grand Isle and Isle La Motte, occurs along their irregular eastern margins.

A very similar condition has been noted and described by the writer for certain rocks in the Hudson valley.[1] Near Poughkeepsie, N. Y., massive dolomites and limestones have field relations to slates very similar to the relations shown in the lake region and which are plainly the results of the older rocks having been thrust into the younger slates. The older beds have broken both across and along the strike and in their eastern portions often show slickensiding and brecciation near their contacts with the slates. In the Poughkeepsie region, along their western margins, the older rocks may often be seen in contact with the slates into or over which they have been thrust. It is apparent from the generally flattish attitude of some of these overthrust rocks and the lack of deformation within them away from the brecciated zone along their eastern margins that they underwent little folding and essentially form great blocks that have been broken from an extensive formation lying at depth and driven upward. Although not equally manifest at all places a distinct horizontal component may usually be recognized in these displacements. Moreover, what sometimes appear now as reverse faults are probably eroded thrusts.

Taking the apparent absence of any traces of the massive Beekmantown, Chazy and Black River beds anywhere on Alburgh and North Hero at its face value, it is not reasonable to assume that the shales in these areas were overridden by a mass of the older rocks and that the older limestones of Isle La Motte represent a detached block of such an overthrust mass preserved by downfaulting. From the strong similarities which the secondary structural features in the northern part of the lake basin have to those of the Hudson valley near Poughkeepsie, it may not be unreasonable to suppose for each of these regions a similar

[1] New York State Bull. 148, 1911.

deformational history. The Beekmantown, Chazy, Black River and basal Trenton beds of Isle La Motte were broken from the respective masses to which they belonged and which lay beneath the shales and have under compression, through failure in any notable degree to accommodate through close shearing, moved up into the shale formation. By such deformation some portions of the shale would in some measure probably have been overthrust and other portions might be spoken of as underthrust. In both cases the shale would occupy the downthrow side. Along the plane of underthrust movement the relations produced might sometimes suggest normal faulting; but it is clear that displacement due to pressure would have involved differential movement between masses that were both under compression. The shales accommodated through cleavage and minor deformation, but the limestones refusing to do so moved as massive blocks.

If this interpretation is given to the relations of the limestones of Isle La Motte to the shales, it may be thought surprising that the limestones are not more generally present at the surface in nearby areas. But it is not necessary to suppose that such upthrust masses had in all cases the same amount of displacement with respect to the shales. Probably at depth the massive beds of Lower Ordovician rocks, and probably older rocks underlying them, have been variously broken and disturbed. The various kinds of deformation now to be seen on the eastern shore of Isle La Motte and along what was called the plane of underthrust bear out the idea that it was the massive beds which did the moving, so to speak. As is so frequently to be understood in application to faulting and thrusting, a plane is not to be thought of as a mathematical plane but rather as a zone of disturbance.

At some places it appears that the limestones along the underthrust side slid under the shales at a relatively low angle and at others ascended more nearly vertically. The massive rocks were all the while crowded against the shales and the crushed condition of the latter is in such wise not difficult to explain.

The thought has occurred that possibly the crushed condition of the rocks as described for the eastern shore of Isle La Motte and for Cloak Island was a character acquired within these rocks at depth before actual rupture and extensive bodily movement of ruptured masses. It certainly seems less likely that this condition was acquired during simple upward movement into the shales after rupture from the main mass at depth. The gradual transition westward from strongly deformed beds along the east shore of the island through those showing less and less strain to undeformed beds seems to indicate that differential internal deformation was followed by mass dislocation.

The relations and conditions on Grand Isle are in many particulars comparable with those on Isle La Motte and it seems

probable that the massive rocks of Grand Isle should be interpreted as upthrusts into the shale formation.

FRANKLIN COUNTY.

Highgate Township.

(St. Albans topographic sheet.)

General. The rocks of Highgate have long been known from the investigations of Logan, who worked out some of their important structural relations. While there have been some modifications with advancing knowledge of the age relations assigned to some of the rocks, the general conclusions of this able geologist have not been materially changed and his map, so far as it went, is accurate in detail of distribution and structure. The rocks of the township have been much disturbed and altered. Contacts are concealed and some relations much obscured by the mantle of surface material.

In Highgate rocks are found extending south from the Canada line along the lake shore and just to the east of it which are more or less similar to those of the areas just described or to some that occur near the lake farther south in Vermont, but some of these rocks are greatly altered. East of a narrow and somewhat irregular strip of such rocks are others whose counterparts have a great extension southward through western Vermont. Occurring among the latter are still other rocks which show features different from any of the others and present much difficulty in the definition of their age, in their correlation and in the explanation of their structural relationships to the rocks with which they are associated.

Between Missisquoi Bay and Rock River. Description will begin with rocks along or near the shore of the lake, south of the Canadian line.

Just south of the little bay at the village of Philipsburg, Province of Quebec, the shore is formed of black, slaty rocks carrying graptolites. These slates form a narrow, wave-cut platform and low cliffs for about a mile south of Philipsburg. Except for their greater alteration and more pronounced cleavage and disturbance these rocks are much like those of Alburgh and North Hero. They carry firm, siliceous bands, weathering rusty brown, which from their fragmented condition and scattered arrangement among the more shaly layers bear testimony to the severe crushing which these rocks have suffered. In their deformational features these rocks are much like those which will be described for the lake shore south of St. Albans Bay.

These slaty rocks are interrupted and replaced at places along the shore of the bay by great cliffs of massive-appearing limestones which often reach to the water's edge and are impassable except by boat. At the bases of many of these cliffs are great blocks which have broken from them and over which one may sometimes scramble for considerable distances without, however, coming upon the slates. Working southward along the tops of these cliffs one comes to a small bay, a little way south of the national boundary, in which the slate outcrops. Slate was observed in the bank not more than 10 feet below the massive limestone which caps it, but the actual contact is concealed. South of the bay the limestone reaches the water and continues for many rods. Its margin then recedes somewhat eastward and clay or shingle forms the shore with the slates peeking through at places. Finally the slates pass from sight towards Rock River Bay.

The surfaces of the massive limestones which have been mentioned, in the extension of these rocks east from the shore through woods and pastures to the Highgate-Philipsburg road, were examined for fossils, but nothing definite was found. In these rocks, which are greatly altered, fossils have apparently largely been destroyed. In the shore cliffs these limestones usually appear very massive, but at some places beds of not very great thickness were observed. Sometimes a massive appearance seems to be due to a sort of welding of beds by shearing. Where bedding was observed it showed easterly dip at a low angle.

The calcareous beds exposed along and near the shore are largely gray, dolomitic limestones distinctly siliceous and often carrying chert, but away from shore these rocks pass upward into white, more or less marbly limestones whose weathered surfaces are often covered with a tracery of fine siliceous lines of lace-like patterns standing out in low relief. These whitish limestones outcrop along the Philipsburg-Highgate road from the national boundary to and across Rock River and form numerous exposures west of the road in the pastures and woods. East of Rock River Bay, both north and south of the stream, the white limestones were found in close association with the gray dolomites and a similar association was noted east of Highgate Springs; but at the latter place there is suggestion of dislocation and at one place of westerly dip which is a variation from the rather uniform easterly dip shown by the rocks south of the Canadian line, between the lake shore and the valley of Rock River.

A mile east of the shore near the Province line are indications of synclinal structure which becomes well-marked two-thirds of a mile north of the line. About one-fourth of a mile south-southwest of St. Armand station and one-eighth of a mile west of the railroad track, massive bluish-gray and yellow weathering beds dip at an angle of about 18 degrees to the northwest. These are succeeded westward and upward by massive-appearing rock carrying fossils, some of which resemble *Lituites*. This massive-appearing rock may be seen to be composed of relatively thin layers which have been welded into a thick stratum, as it now

appears. Some of the rock shows a striped appearance in which feature it looks much like similar rocks, which have been thought to belong to the Chazy, farther south in Vermont. A half mile north of these outcrops along the road from Moore's Corners to Philipsburg the striped rock shows southeasterly dip and westward is underlain by the bluish-gray and yellow weathering beds. The rocks in the western limb of this syncline are plainly sheared across the bedding, with the easterly dip of the induced cleavage at a higher angle than the bedding. There was observed at some places what was interpreted as a mashed structure as evidenced by blocks of the yellow weathering beds involved with the dove-colored or bluish rock. Westward towards the shore are found rocks like those which have been described as making up most of the surface between the lake shore and Rock River south of the Province line, and a generally low easterly dip is maintained in these rocks to their western margin. West from the axis of the syncline just mentioned, the succession across the strike in the limestones is probably from younger to older and older rocks.

These various rocks were regarded by Logan as parts of his Quebec Group, a name that now has hardly more than historic significance. There is still a field for careful work among these rocks with regard to their exact age and correlation and the details of their structure.

Brainerd and Seely seemed to recognize in the Philipsburg series of Logan most of the members of their Calciferous (Beekmantown) of Vermont with some beds that may be Chazy. The identification was largely on a lithological basis.

These rocks have not undergone extensive deformation by folding. They have suffered considerable shearing and great alteration from pressure and their relations to the slates along shore, than which they are unquestionably much older, is that of thrust which probably involved considerable lateral movement.

Along Rock River valley, south of the Province line, the rocks did not give much hint as to the extent to which they may have been brecciated along their eastern margins; nor was it possible to determine if transverse and longitudinal fractures are present among these massive limestones between the lake shore and Rock River valley.

In their lithological features and massive character these dolomites and limestones show more resemblance to the similar rocks of Benson and Orwell, which the writer has described in relations to younger rocks quite like those shown by the rocks of Highgate, than to any other rocks which he has seen. The general resemblance is very strong and seems to point to a widespread substratum of similar rock which was broken here and there and thrust through and over younger beds, in which relations they are now exposed.

Highgate Springs and vicinity. About one-half a mile south-southwest of the mouth of Rock River is Limekiln Point. The rock at this place is a grayish limestone which has been quarried. It is unlike the rock that occurs along shore north of Rock River Bay, and that to the east, north of Carman Brook.

Limekiln Point is separated by Phelps' Bay from a blunt promontory lying to the southwest of the Point. This promontory is the site of a former picnic ground. Over most of its western portion the rock is a sheared, impure, shaly limestone which forms low cliffs along the edge of the lake. These impure limestones yielded somewhat distorted fossils, among which some were sufficiently well preserved to warrant the following tentative references:

Rafinesquina incrassata (Hall); compare *Leptaena plicifera* Hall, fig. 1a, pl. 4 bis, Pal. N. Y. 1847.

R. incrassata, but larger than preceding, showing convex? valve with narrow and fairly deep depression extending from beak to margin, widening somewhat towards margin.

R. fasciata, comparable in size with fig. 3c and in detail with figs. 3a and 3d, pl. 4 bis, loc. cit.

The smaller specimen compared with *R. incrassata* has some resemblance to certain illustrations of the dorsal valve of *Plectambonites sericeus* (Sowerby), but differs in proportions, being shorter along the hinge line. The striae are also coarser, fewer in number, and of uniform size, with intermediate ones appearing near the margin. The specimen referred to *R. fasciata* is comparable with *R. alternata*, (Emmons). A gastropod of *Ecculiomphalus* type was also seen. The specimen was badly worn, but in spite of excoriation seemed to show, particularly near the tip, low, annular ridges. There was no visible angulation.

These fossils suggest that the shaly limestone may be of Upper Chazy, or possibly Trenton age. These limestones are flanked on the east by certain less sheared calcareous rocks that are in turn overlain by beds that resemble the Black River. Portions of the shaly limestones are less sheared than others, but most of these rocks under the hammer break into irregular pieces whose surfaces are suggestive of slight movements in the rock. In fact, the condition of most of these shaly rocks is substantially that of irregular cleavage or crushing.

The shaly limestones just described occur on the east side of the road running north from the Franklin House to the wharf on the second promontory southwest of Phelps' Bay, and about a half mile north of the hotel. In spite of shearing an easterly dip is apparent. These rocks are succeeded westward, on the west side of the road, by interbedded gray limestones and buff-weathering dolomites which are well shown at the end of the promontory. Flanking these limestones and dolomites on the west and apparently conformable with them are purplish or greenish-gray quartzitic sandstones in beds from 2 to 12 inches thick standing on end. The quartzitic sandstones are perhaps a hundred feet thick. South and west they give place to younger rocks, from which they are probably separated by a dislocation. The sandstones form the western limb of a broken anticline. It is not clear just what the relation of the shaly limestones is to the interbedded gray and buff-weathering beds that lie west of them; they apparently lie above them.

The promontory bounded on the west by the sandstones is separated by a slight embayment of the shore from a small point at which occurs a series of very dark gray or blackish, thinly-bedded limestones which gave good Trenton fossils. In fossils and general lithology these Trenton rocks are comparable with the basal Trenton beds as seen on the islands to the southwest. They are folded and sheared. They grade into more shaly rocks which outcrop in the bank and along the beach below the camps southward until lost under the swampy land. Eastward above the bank in the fields among the summer cottages the Trenton beds are associated and folded with dense, black limestones of probably Black River age. These rocks continue southward, forming a ridge to the west of the Highgate-Swanton road. About one-fifth of a mile south of the hotel they form an unsymmetrical anticline with the Black River, forming the eroded crest and the Trenton beds the eastern and western limbs. On the east limb a reading gave the strike as N. 28° E. and the dip about 25° to the east. The Trenton rocks yielded typical fossils. On the west limb the beds dip at a high angle to the west or are overturned. About a half mile south of these outcrops and about on the same meridian a small ridge in the field west of the road shows the western limb of an anticline with the Trenton and Black River beds in inverted position. The Black River beds are from 2 to 3 feet thick and filled with small calcite veins, which, it may be noted, are frequent in all the beds of this formation around Highgate Springs as they are in many other places in western Vermont. The Trenton beds follow the Black River conformably on the west and dip at the same high angle easterly. The Trenton beds yielded crinoid stems and fragments of other fossils. Southward these rocks pass under surface material; the most southerly outcrop noted in Highgate occurs where the Highgate-Swanton road crosses the railroad track.

Directly east from the Franklin House, across the track near the mineral spring, beds carrying Trenton fossils (*Cryptolithus*) dip to the east. These outcrops are separated by a stretch of low, flat land about one-fourth of a mile wide from the massive limestones in the quarries of the Missisquoi Lime Works. To the south and southeast is an extensive sand plain under which the hard rocks are largely concealed. Just north of the Swanton line and a mile northeast of Swanton village, the road from Swanton to Highgate Center crosses a low ridge of dove-colored limestone carrying patches of buff-weathering rock. These beds seem to be like those at the promontory at Highgate Springs.

Structural Features at Highgate Springs. In conformity with their less massive characters the various rocks around Highgate Springs have been much more deformed by folding than have the heavy dolomites and limestones that lie north and east of them. The folding is distinguished by a tendency to overturning on the western limbs and actual inversion of beds in some cases. Although now seen to be disposed for the most part in folds the relations in some places indicate dislocations. The Chazy rocks have ridden on the Trenton and the latter has probably been thrust against younger slates. Shearing structure in the form of brecciation or cleavage is to be seen in many of the rocks. The more massive rocks show fewer distinct marks of internal deformation.

Between the rocks at Limekiln Point and Highgate Springs and those lying to the east, north of Carman Brook, as well as those lying practically on the same meridian with the latter in the westernmost quarry of the Missisquoi Lime Works, there is an interval of surface material so that it is not possible to state what are the contact relations between the rocks lying at the east and those nearer the lake. But there can be no doubt that the massive rocks along the lake north of Highgate Springs rest on the slates by thrust and it is probable that the rocks at Limekiln Point and Highgate Springs are separated from the altered massive rocks to the east of them by a plane of thrust, and that the present sinuous western marginal outcrop of the rocks lying east of Highgate Springs and north of Carman Brook is essentially a continuation of the obvious margin of overlap of the similar rocks on the slates north of Rock River Bay.

According to this view, the folded, overturned and broken strata at Highgate Springs and those of Limekiln Point probably represent an aborted thrust which developed only to the point of release of other rocks by rupture. These other rocks might not be those which now form the surface east of the margin of overlap discussed above, but might be other rocks that are now covered by these thrusted rocks. Such a view depends upon the idea of repeated minor thrusts or reverse faults preceding other thrusts. Exposure of rocks younger than the massive limestones has not been accomplished east of the margin of overlap of the latter in this part of Vermont and all sections east of this margin gives a succession from younger to older formations, at least as far east as the eastern valley of Rock River.

An alternative explanation seems to be that the rocks at Highgate Springs and Limekiln Point may have ridden forward on the same major shear with the more altered rocks lying to the east and that the present trace of this shear at Highgate Springs is on the west of the rocks at this place. This, however, assumes that a major shear cut minor thrusts and faults at depth and drove the truncated portions forward together. It is, of course, not possible to decide the point.

In every case where a marked dislocation occurred it is to be attributed to the more or less massive character of the rock and its reluctant behavior under powerful compression. The rocks behaved according to the elements of their primary structure. The heavy members moved as masses; the less massive accommodated by folding, crushing and shearing on a minor scale.

Northeast, east and southeast of Highgate Springs. Rock River has a roundabout course from its source to Lake Champlain. Its upper eastern portion flows northerly in a course roughly parallel with the shore of Missisquoi Bay and about three miles distant from it. The river crosses the Province line and about two miles north of it turns west across the structural axes of the hard rocks and then bends to a southwesterly direction to enter the lake.

Part of the rocks to be described under the above heading lie between the northward and southward courses of the river as it touches Vermont and the rest are found in the territory that extends southward and southwestward toward the Highgate-Swanton line.

Along the eastern margin of the valley of the lower (western) portion of Rock River is a modified escarpment in a series of interbedded, usually massive, siliceous dolomites, and quartzites or quartzitic sandstones, which belong to so-called Red Sandrock series, as this formation was named by the early geologists of Vermont. The western outcrop of these rocks, beginning at the Canada line, follows rather closely for a distance of about three miles the road that runs from St. Armand, P. Q. southward past Saxe monument to Swanton. For the rest of its course through Highgate the western margin is much less distinct and usually may be only approximately located from a few isolated outcrops emerging through the sand plain. The most western outcrop noted in Highgate was in a bed of quartzite at Kelly Brook, where this stream is crossed by a road one mile east of the Central Vermont railroad track.

Over the higher land north, east and south of Saxe monument the members of this series are well displayed. Outcrops are abundant along the roads and in the fields nearly to the eastern valley of Rock River, and the series was traced southward along the eastern edge of the sand plain through Carter Hill to a point just north of the St. Johnsbury and Champlain railroad and about a mile west of Highgate Center.

The members of the Red Sandrock series in Highgate form only a small portion of a great band of more or less similar rocks that extends for a long distance southward in Vermont. Even in rather widely separated areas in the northern part of the state there is close resemblance in sequence and thickness of beds of this formation and in their colors, but in other places in Vermont the members of the Sandrock series, are seemingly represented by rocks which are apparently so unlike them that their common membership in the same formation is easily overlooked. Even within short distances, however, the members of the typical Sandrock series show appreciable horizontal and vertical variations in lithological characters and thickness of beds which come out in tracing the formation from place to place. At many places these rocks show much confusion on account of disturbances which have brought them into abnormal relations with other rocks; but leaving out dislocations it would not be possible to describe any vertical section which would hold in detail for any great distance away from the locality selected.

It seems probable from studies that have now been made in various parts of western Vermont, reckoning with the principle of lateral variation among rocks of the same general age, that ideas about the age relations of some rocks will have to be revised. It seems likely too, in view of deformations of the rocks, that estimates of the thicknesses of some of them will have to be modified. When the general similarity in field relations shown by very different looking rocks is appreciated even the absence of fossils in some of them may not stand in the way of recognition of the existence of a formational unit whose depositional and deformational histories have been much the same throughout.

In Highgate the members of the Sandrock formation require only brief description. It would require long and patient work to catalogue all the minor variations, which when done would largely represent wasted effort from our point of view. However, when the depositional history of the Lower Cambrian in Vermont is written it will mean that much attention will have been given to details of such kind.

South and east of Saxe monument are more or less massive quartzites, often weathering to a rusty color, apparently passing along the strike into reddish quartzites, and eastward across the strike, towards Saxe Brook, into whitish quartzites, all more or less regularly interbedded with gray, siliceous dolomites. The quartzites are all more or less calcareous or dolomitic.

North of Saxe monument are gray, dolomitic quartzites and siliceous dolomites passing eastward into flaggy quartzites. A gray, rusty-weathering, impure quartzite east of the St. Armand road and about 100 rods northeast of the monument gave recognizable fragments of the glabella, cheeks and pygidium of *Olenoides marcoui*. These were the only fossils found by the writer. In these rocks fossils come out only when the rock has weathered; but as experience will show not all weathered rock gives fossils, although it is probable that these are very common in the rocks.

Southeastward toward Highgate Center are brownish-gray quartzites and gray dolomites interbedded with flaggy quartzites.

In almost all the outcrops noted the dip is at a moderate angle to the east.

As a whole, these rocks probably make up a considerable, but as yet undetermined, thickness of Lower Cambrian beds, showing a rather uniform easterly dip and hardly any evidence of folding. The topography gives an occasional hint of dislocation; about one mile east of Saxe monument, east of Saxe Brook, a prominent scarp in massive quartzite probably marks a fault.

The rocks of the Sandrock series are unquestionably older than the massive limestones that lie west of them along and east of the shore of Missisquoi Bay. The only reasonable explanation of their structural relations is that which Logan advanced long ago; the Sandrock has been thrust against the limestones. Whether the thrust carried the Lower Cambrian any considerable distance over the massive limestones cannot be determined from the relations in Highgate. No contacts were found, but about a mile southwest of Saxe monument a quartzite bed of the Sandrock series is in close proximity to rocks of the lake shore series. Outcrops that were seen in the sand plain southeast of Highgate Springs show the margin of the Sandrock to be farther west than it is at the north.

In their deformation the Lower Cambrian beds behaved like the massive limestones to the west of them. While they probably suffered subordinate dislocations which are not now generally recognizable, they did not fold much but rather moved as a mass.

In their lack of folding the members of the Sandrock series in Highgate are in contrast to some of the similar rocks found farther south in Vermont, which are, however, when folded, in thinner beds. In their lack of this kind of deformation they are in accord with similar heavy beds elsewhere. The rocks behaved under pressure according to the elements of their primary structure.

In Highgate the Lower Cambrian series is nowhere in visible contact with the shale formation as it is farther south on the lake shore. But what the relations may be beneath the sand plain that intervenes between Highgate Springs and Swanton the surface covering effectually hides.

Eastern valley of Rock River. Along the eastern valley of Rock River, or low on the eastern flanks of the hills of interbedded quartzites and dolomites that have just been described, occur outcrops of rocks very different from the members of the Lower Cambrian series that bounds them on the west and from rocks that lie immediately to the east. These rocks show interesting differences among themselves from place to place and in the same outcrop, but have a general resemblance to each other throughout and appear to make up a formational unit. They form the northern extension of the formation which includes the so-called "intraformational conglomerate," described by Edson for the towns of Swanton and St. Albans, and which he was inclined to view as of Middle Cambrian age. Logan showed these rocks on his map (Atlas accompanying Geology of Canada, 1863) as a band extending northward from Highgate Center across the Province line and as joining at the surface with his Quebec rocks in southern Stanbridge. Along Rock River these rocks as now exposed seem to hold to a fairly uniform width and band-like distribution, usually less than a mile in breadth across the strike and sometimes very narrow. Their representatives farther south are often more scattered and irregular in distribution.

This formation was traced to within a half mile of the Canadian line. At an exposure near the junction of the roads about a mile and a half east-northeast of Proper Pond are thinly-bedded, bluish limestones, whose outcropping edges along their strike appear as wavy bands on the weathered surface of the ledge. The limestone is associated with siliceous beds which lie on it and appear to be conformable, as though interbedded. Conglomeratic structure is not prominent, being confined to a patch about four feet square. However, the field was not exhaustively examined at this locality.

The valley of Rock River is more or less filled with drift and outcrops are intermittent. The next outcrops noted are one-third of a mile to the south, west of the road running parallel to the river. At this place the thinly-bedded, bluish limestone is intermingled with slaty rocks.

About a mile farther south, near the junction of three roads, are outcrops of sheared, bluish limestone, weathering to a dull gray. The rock is splintered and at places shows small dislocations which have completely severed the thin beds at numerous places.

Southward where the road crosses the river, in the bed of the stream, are sheared limestones now practically limy slates. The bedding is largely obliterated by the cleavage which dips easterly. The exposure of these rocks in the river bed may be 50 yards in breadth.

Above the river bank, southeastward, in a field east of the road, is a curious mixture of rocks which in general aspect are very like those making up several exposures in the towns of Swanton and St. Albans, to be described later. In fact the rocks at these several separated localities are counterparts, so far as lithological features go. The most conspicuous member is the conglomerate whose fragments range in size from small pieces to considerable blocks and are imbedded in a calcareo-siliceous matrix. The conglomerate portions are intermingled with other rocks, some of which are calcareous sandstones much like the

matrix of the conglomerate, and which sometimes weather to a reddish bluff, and others are slaty rocks like those in the river bed nearby. The fragments of the conglomerate are frequently bluish limestone and often sharply angular in section. There is much confusion and anything like orderly sequence was not discernible. There is visible shearing structure in some of the rocks.

A half mile farther south, where the road crosses the river, near Johnson's farm, is a gorge worn by the stream in dark, bluish-gray, finely granular limestone which yielded obscure fossils, too fragmentary for positive determination, including a tiny orthis-like form and several pieces of trilobites, all very small. The rock shows folding and shearing and some brecciation.[1]

Twenty-five rods southwest of the bridge at the last-named locality and west of the road, at a small ridge, are excellent exposures of the thinly-bedded, bluish limestones like those described for the outcrops farther north. The edges of the beds show a very conspicuous wavy arrangement and the layers show all stages of fragmentation or dislocation from incipient parting to rupture with varying degrees of displacement of broken parts. According to the writer's view, these are distinctly secondary compression effects, belonging in the category of brecciation, and not to be confused with conglomeratic structure which parts of this formation show. The angular character of the conglomerate fragments often gives a distinctly brecciated appearance to that rock in many of its outcrops and the fragments themselves often suggest broken-up, thin, limestone layers; but the principal structure of the conglomerate proper seems really to be primary, although the way it was produced remains a mystery. The conglomerate itself may show secondary shearing effects like some of those in the rocks associated with it.

Blue limestones like those in the ridge just mentioned continue southward on the strike and outcrop on the road going west, along which road after an interval of drift they are succeeded by the Cambrian dolomites and quartzites.

Highgate Center. In a cut of the St. Johnsbury and Lake Champlain R. R. one-fourth of a mile northwest of the village of Highgate Center is exposed a laminated bluish limestone dipping easterly at a moderate angle and cut by rough shearing joints which dip in the same direction at a high angle. The rock has weathered enough to bring out the essentially shaly character of the rock by the laminations bands which it shows.

The field south of the cut, above the bank, gives numerous exposures of the thin, blue limestones noted along the valley of Rock River. The beds sometimes stand at a high angle of dip and present the same wavy arrangement in the surface of the ledge. The limestones are intermingled with ledges of gray slates. All the rocks are greatly altered and without fossils.

[1] See supplementary note at the end of this paper.

Highgate Falls. At Highgate Falls the Missisquoi River flows through a narrow post-glacial channel which the stream has cut in a mass of jumbled rocks now exposed in its bed and banks. The section from the bridge to the final outcrops at the base of the falls is perhaps one-fifth of a mile long and practically cuts the rocks from east to west across their strike. The gorge lies about one-half mile south of the laminated, dark blue limestone and thin, lighter blue limestones and intermingled slates, described above for the locality just northwest of Highgate Center village, and about two miles north-northwest of the northern exposures in Swanton township of the thin limestones, shales and conglomerate which outcrop along the Highgate-St. Albans road.

In the upper part of the northern wall of the gorge just below the bridge is a massive looking stratum of dark, fine-grained, siliceous rock, twenty or more feet thick as now exposed, which may be seen to have suffered some shearing, and which as a whole shows little evidence of bedding. In the lower portion of this stratum is a curious "breccia" of small blocks of slaty rock, angular in section and imbedded in a matrix of dark, fine-grained material. About 75 feet below the bridge, in the base of the massive stratum, is included a large block of somewhat banded, coarse-textured slate in a piece of which were found two ill-preserved specimens of graptolites, tentatively identified by the writer as *Dictyonema,* probably *flabelliforme,* and *Staurograptus dichotomus* Emmons.

The occurrence of these bryograptoid forms at this locality is worthy of note. The specimens were submitted to Dr. Ruedemann of Albany. While recognizing their poor state of preservation, Dr. Ruedemann felt sufficiently sure of the general affinities of these fossils to write: "Even lacking a correct specific determination of the forms, it is safe to say that they belong either to the Schaghticoke or Deep Kill shales (Hudson valley formations) for the higher graptolite shales of the slate belt do not afford similar species." In specific reference to the opinion of the writer as to the forms to which these fossils might be referred, or with which they might at least be compared, Dr. Ruedemann wrote: "The fossil which you compare with *Staurograptus dichotomus* has indeed the general aspect and outline of that species. On closer inspection, however, it appears to be rather a young *Dictyonema,* flattened out in a vertical instead of a lateral direction. This conclusion is suggested both by the *Dictyonema*-like appearance of the thecae and the apparent presence of dissepiments connecting the branches. The fossil marked (2) is a fragment of *Dictyonema,* possibly of the *flabelliforme*-group, but also comparable to *D. rectilineatum* of the Deep Kill shale."

Dr. Ruedemann had no knowledge of the specific locality at which these fossils were found. His properly guarded and yet reasonably confident judgment that they probably represent a Beekmantown horizon is of interest.

The question would at once be raised as to the probable extent at Highgate of the formation to which these fossiliferous slates belong. This it would be difficult to state. In the gorge the rocks change in lithological character within short distances. The particular block yielding the fossils seems to be somewhat isolated, although similar rock appears to form part of the river bed adjoining the wall of the gorge. The rock carrying the fossils gives place rather abruptly westward to the brecciated rock described above as forming the basal portion of the massive stratum and which also forms part of the river bed adjoining the wall.

The section passes vertically downward from the "breccia" into a mass of jumbled grayish-black, or sometimes bluish-black slates carrying firmer bands of yellow-weathering rock. The slates are strongly sheared and the included firmer bands are usually twisted or broken so that large detached, more or less rectangular blocks, as they appear on the surface, now lie in helter-skelter fashion among the slates, often oriented across the strike at various angles. The disturbances which the slates have suffered interfere with any reading of the dip of the bedding and the thickness exposed remained undetermined. Close inspection of the surface of the slate at many places reveals the presence of small fragments of slate very similar to their matrix, the whole so thoroughly compacted that the broken up condition is hardly visible except at close range.

Downstream the slates pass into a "brecciated" or conglomeratic layer 8 or 10 feet thick. This is followed by a succession of alternating, thin bluish and more massive grayish-buff layers dipping easterly about 18°, with a bed of the grayish-buff about 5 feet thick at the base, all distinctly sheared. This stratum may be repeated for it is followed by a similar series which is succeeded by a "brecciated" stratum about 30 feet thick.

The rocks which form the bank of the river at the lower, western end of the gorge were only casually inspected at the end of a day's work. No fossils were found in them.

Though a diligent search was made in its upper part, no fossils other than those mentioned were found in the gorge.

The section at Highgate Falls shows that the rocks forming the gorge have been under great compression and that some of them have been greatly crushed and sheared. It is not clear that the "brecciation" shown by the various rocks is all of similar origin. The fragmental basal portion of the massive stratum in the upper part of the northern wall visibly grades into the overlying rock in such manner as to make it extremely difficult to imagine just how it could be explained as due to friction or mashing during movement. While there seems to be some indication that the massive stratum has ridden over the beds below it, the now thoroughly compacted "breccia" appears to be so related to the main mass of the massive stratum that if thrusting did occur the "breccia" could readily be imagined to have attained its present condition prior to movement.

The evidence of differential movement between the massive stratum, as it has been designated, and the black slates below it consists not so much in the identification of any distinct thrust plane between the two as in the contrast shown with respect to primary bedding characters and internal deformation. The crushing of the slates has been intense. It seems to suggest that they were crowded by a heavy mass above them which has partly been eroded. Perhaps they were also crowded from beneath. Data were not found to determine whether masses of very different age are involved. It is possible that most of the rocks belong to a conformable or disconformable series which behaved according to the nature of their primary structure. The block of slate in which the fossils were found has much the aspect of an inclusion caught up during thrusting.

Hungerford Brook. The road from Highgate Falls to St. Albans crosses Hungerford Brook a mile south of Highgate village. At the bridge and along and in the bed of the stream east and west of the bridge are blackish slates. According to Dr. Howell of Princeton, who has collected fossils from these rocks, but who wishes to study his specimens with care before announcing his final conclusion, these slates may be of Upper or late Middle Cambrian age. Dr. Howell bases his opinion in part on the reported discovery by the Canadian Survey many years ago of *Agnostus orion* at Hungerford Brook.[1]

Eastern Highgate. The rocks lying to the east of the blue limestones, slates and conglomerates along the eastern valley of Rock River were only casually inspected along the low ridge near the South Gore School and the road running from the school to Highgate Center. The rocks are slates of very similar and monotonous aspect and gave no fossils. They are associated with conglomerate at some places. It would require further study to reach any tentative opinion of the age of these rocks and their relations to the rocks lying to the west of them. They were mapped as "Georgia Slates" by the Vermont Survey.

Swanton Township.

(St. Albans topographic sheet.)

General. Swanton township is bordered by the lake on the west. It includes Hog Island, an essentially insular area joined to the mainland by the delta of the Missisquoi River. The township is bounded by Highgate on the north, by Sheldon and Fairfield on the east and by St. Albans on the south.

[1]Personal communication.

Hog Island. Hog Island, so-called, is the western extremity of a peninsula jutting into Lake Champlain. The designation of island is probably wholly correct with respect to the relation of the hard rock portion of the peninsula to that of the Vermont mainland; but the island and mainland are now joined by modified delta and flood plain deposits of the Missisquoi River which occupy a strip from two and a half to three miles wide, extending from Maquam Bay at the south to the eastern portion of Missisquoi Bay at the north. Over this delta surface the Missisquoi River now courses northward, in which direction it is extending its delta into Missisquoi Bay. The river enters the bay by three short distributaries. Three sluggish water channels, known respectively as Dead, Maquam and Charcoal Creeks, probably mark former distributary outlets of the river.

The hard rock is exposed along shore and in many low-lying ledges inland and apparently all belongs to the shale formation of the region. The rocks are everywhere so similar in lithology and structural features to those of Alburgh and North Hero that description would be largely repetition. Easterly and westerly dipping beds were noted and both were observed to be cut by easterly-dipping cleavage.

Northwest, west and southwest of Swanton village. The slates of Hog Island undoubtedly pass under the delta deposits of the Missisquoi River and the low sand plain west of the village of Swanton. There are few if any outcrops in the sand plain, but at some places along the roads the surface soil contains abundant chips of slate showing that the hard rock often lies close to the surface. The Missisquoi from Swanton village northward rarely cuts the slate above the surface of the river, as may be readily seen in passing along the road that closely follows the southwest bank of the stream; a considerable ledge was noted on the north bank of the stream about a mile north of Swanton Falls.

The slate outcrops at Swanton Falls in the western part of the village. The rock has the usual characters shown by the formation in its outcrops along meridians farther west, consisting of slates with firmer bands, the former highly cleaved and the latter bent or broken with small offsets. The slates are often graphitic and carry graptolites, which have retained their form but have largely lost their thecal structures. They seem to be *G. quadrimucronatus*.

The Missisquoi River makes a prominent bend to the south just south of Swanton village. Southwest and south of this bend is a wide expanse of lowland lying between the lake shore and a meridian passing just east of the village. The slate formation probably underlies this lowland throughout its breadth of three and a half miles to the St. Albans line. Away from the lake the slates are found only infrequently over the flat, sandy plain; but along the lake shore they are exposed from Hotel Champlain southward. They are laminated mud rocks with firmer bands, marked by crushing and cleavage, and abundant calcite veining. The shore section gives the same lithological and structural features found in the rocks of North Hero three miles to the west.

Between Swanton village and the Missisquoi River. Swanton village is situated largely on a sand plain. The only outcrops, except those at Swanton Falls, occur south of the main village between the road running from Swanton to St. Albans and the Missisquoi River.

The rock in the western quarry of John P. Rich (Swanton Lime Works) is a greatly altered, grayish-white, often somewhat marbly limestone and as exposed in the face of the quarry gives little evidence of bedding. In the southwestern part of the quarry, as exposed in the summer of 1921, the gray limestone was seen resting on black, graphitic, limy slate which is strongly sheared and filled with small veins of secondary calcite and quartz. In the slate a considerable hole had been dug apparently to see to what depth the slate extended. The photograph shows the general relations. See Plate XXIII. The slate is exposed over a small space in the floor of the quarry. Its presence served to drive quarrying operations in a horizontal direction eastward.

In an older quarry that lies to the southeast the rock is similar to that just described, but shows bedding more distinctly, with easterly dip. The gray limestone outcrops abundantly in the fields near the quarries. It is everywhere crystalline and barren of fossils. It extends eastward to the bank of the river, forming conspicuous ledges at the highway bridge. Southeastward and southward the rock either is not present or lies under the sand plain along the river. The whole mass of this limestone south of Swanton village as now exposed is about two-thirds of a mile in extent from west to east and two-fifths of a mile from north to south. It is now separated from all similar rock in the immediate vicinity by surface material. The nearest outcrop northward and the only one noted between this mass and similar rock east of Highgate Springs is about a mile east-northeast of Swanton village along the road to Highgate Center. At this place emerging from the sand plain is a low ridge of gray limestone associated with patches of buff- or chamois-colored rock which are probably parts of eroded layers.

The gray limestone ends rather abruptly west of Rich's quarry. The extent to which it overlaps the slate westward was not determined. It is probable that the slate passes round to the south of the limestone mass under the surface covering; for although not observed in the immediate neighborhood of the limestone, or along the river, about three-fourths of a mile to the southeast, slate like that in the floor of Rich's quarry has relation to gray limestone quite similar to that shown in the quarry. This

PLATE XXIII

Massive, crystalline, marbly limestone interpreted as resting by thrust on black, crushed slaty phyllite in the quarry of the Swanton Lime Works at Swanton village. View looking south at the Western edge of the quarry.

outcrop of the slate carries it to a meridian one-third of a mile east of the eastern edge of the limestone mass south of Swanton village, and about one mile east of the exposed slate at Rich's quarry.

Rocks south of Swanton village, bordering the eastern margin of the lowland. The slate at the last-mentioned locality is perhaps 20 rods east of the Central Vermont railroad track and a few rods south of the road which after skirting the southwestern bank of the Missisquoi passes eastward to join the Swanton-St. Albans road. The rock occurs in a shallow pit that has apparently been excavated for road material. Just east of the slate, gray limestone with some darker beds near the base and irregularly distributed yellow-weathering beds in the higher portions forms a hill just east of the slate. The slate and calcareous rocks were not seen in actual contact, but the space separating the two is small and there is no doubt that the limestone lies against the slate. Some of the limestone carries indistinct fossil markings; the rocks dip easterly and extend eastward to within about 250 yards of the Swanton-St. Albans road.

It was not possible to determine the horizon of the slate either at Rich's quarry or at the last-named locality; but there seems little doubt that it represents the slate formation of the lake region and that it is younger than the limestones with which it is associated. That there has been simple inversion of rocks due to folding and overturning seems extremely improbable, for it would then seem that other rocks should intervene between the slates and limestones, which is not the case. The reasonable inference is that the limestones rest by thrust overlap on the slates in both cases. The relations conform to the regional type of dislocation.

The limestones at both of the localities just described are probably of Lower Ordovician and possibly of Chazy age. This has hardly been proved by fossils, but is made probable by comparison with similar rocks in similar relations which will be described beyond.

About 50 rods south-southwest of the outcrops last described, west of the main line track of the Central Vermont R. R., in the angle formed by it and the Alburgh branch, is a low hill composed mostly of a schistose quartzite or quartzitic slate, apparently without fossils. Associated with this quartzite are somewhat isolated patches of bluish limestone in uncertain structural relations with the quartzite. In its thinly-bedded character and lithology the limestone has resemblance to certain rocks of Trenton age. It appears to be fossiliferous, but it is so altered that nothing distinct was obtained. Calcite veining is frequent. The limestone shows its bedding better at some places than at others and occasionally presents a wavy arrangement in the outcropping edges of the beds. It appears to have been caught up by the quartzite. The distribution of the limestone in the quartzite is peculiar. A conspicuous exposure occurs just west of the track. This is followed westward by quartzite and then occurs another somewhat band-like strip of the limestone which seems to be largely surrounded by the slaty quartzite. The dip of both rocks is easterly. It is suspected that the quartzite is repeated and that the limestone may also be. The distribution and visible structure thus gives a rough suggestion of interbedding, which however does not seem probable. The whole width of this hill from east to west is perhaps 200 or 250 yards. The rocks to the west of it are concealed.

About 100 yards south of this hill, and just west of the main line track a small outcrop of the schistose quartzite emerges from the surface covering in the low ground and just south of this is a small exposure of thinly-bedded, bluish limestone.

A third of a mile to the south of these last-mentioned outcrops, just north of Swanton Junction and west of the track, is another hill which shows a very different kind of rock. It belongs to the quartzite-dolomite or Red Sandrock series lying to the east, presently to be described. On the east side of the hill the bedding dips easterly at a moderate angle for the most part; but at the northeastern end near a small quarry, beds which dip easterly at a high angle lie against others with varying westerly dip. This hill shows a prominent scarp on the west, perhaps 60 or 75 feet high, with the beds apparently dipping westerly at a high angle. At the west the descent is everywhere abrupt to the surface of the low ground that lies to the west. No contacts with the rocks that lie beneath the plain were found.

South of this hill a private road runs westward across the plain to two farm houses about one-half mile west of the Junction. The houses stand on a low ridge, on the east side of which is a considerable thickness of rather heavily-bedded limestone, some of which is striped exactly like many exposures of the so-called Middle Chazy in other parts of the lake region. The beds of this series dip easterly at a high angle and have a sinuous strike with probable offsets. *M. magna* was not found, but a ledge just north of the barn gave numerous specimens of the characteristic *Girvanella ocellata* (Seely). These rocks are succeeded westward by beds of grayish-black limestone weathering to a lighter gray than the Chazy and possessing all the lithological characters of the Black River. They dip easterly like the Chazy beds and are full of small calcite veins. Fossils were not found. West of these, also dipping easterly, and apparently conformable with the Black River beds, are thinly-bedded, blue limestones of probable Trenton age. Crinoid stems, weathered section of shells and a much worn brachiopod were found with other indistinct fossils. The terrane is only partly represented.

These apparently conformable beds are thus seen to be overturned, probably on the western limb of an anticlinal fold, but possibly on the eastern limb of a syncline. The rocks in the plain, both east and west are concealed. The writer's notes record no siliceous beds in the Chazy at this place. The Black River seemed to be in conformable contact with the Middle Chazy limestone. This is a common association farther south in Vermont; but it will appear from later discussions that there are differences in the ways in which these associated formations are deformed at various places. The field relations at this place did not suggest any marked dislocations among the different members. As a whole, however, they are thought of as resting by thrust against younger rocks at the west.

A half mile to the south-southeast is the large mass in which the Fonda quarry is excavated. It forms a hill just west of the railroad track. The quarry has been sunk in the western slope of a massive, crystalline, gray limestone which forms much of the higher portion of the hill. Except for some blackish layers at one place in the floor of the quarry the rock has much the same appearance throughout and shows bedding imperfectly preserved, with easterly dip. The rock is very much like that south of Swanton village. South of the quarry on top of the ridge is a sort of "hog-back" of altered calcareous sandstone or quartzite, perhaps 200 yards long and 50 to 75 feet wide, which does not appear in the quarry and seems to be surrounded by limestone. East of this quartzitic rock is gray limestone associated with layers weathering to a pinkish buff, which approach close to the railroad track. East of the track is the Red Sandrock.

The ridge in which the quarry is located descends westward by irregular surface to the plain that extends towards the lake. The various rocks outcropping on the intermediate level west of the ridge have a confused arrangement. At the west are beds which are apparently to be correlated with the Chazy. The strike of these beds at some places changes as much as 90° within a few feet. They are associated with rocks having the markings of the Black River and veined with white calcite. Numerous outcrops of thin, blue limestones were noted in no very regular relation to the other rocks. The latter carry obscure fossils and seem to be of Trenton age.

The various rocks about Fonda's quarry have been much disturbed. They have probably been broken by thrusts. All are more or less crystalline, but this condition is most apparent in the massive, gray limestone and associated beds forming the eastern portion of the mass. The massive beds in the eastern portion of the hill have probably been broken within themselves and have also moved against the rocks now forming the lower western part of the hill and all of them are probably in thrust relations to younger rocks lying beneath the plain at the west. A certain amount of flowage and crystallization serving to integrate and weld layers into massive rocks, accompanied by a certain amount of folding and fracture, were the apparent modes of deformation of the rocks prior to a bodily thrust of all the rocks to the west, over the slates.

Thrusting may produce an apparent inversion of strata, but in such cases usually very thick and massive rocks are involved. The rocks in the eastern portion of the hill at Fonda's quarry dip easterly and pass beneath a series of beds with very similar dip, but which are unquestionably much older. The two series of rocks have the guise of conformability, but one may hardly be deceived thereby. It is hardly conceivable that the inversion has been produced by overturning of these massive formations during folding. The older rocks have their position by thrust.

It should not be understood that inversion of beds has never occurred by folding, even among somewhat massive rocks; but rather that rupture and dislocation were more characteristic modes of deformation among all the rocks, on one scale or other, in western Vermont and largely on account of the presence of very massive and exceedingly competent strata among them. Even among rocks that folded the end result was often, if not usually, fracture and faulting.

South-southwest of Fonda's quarry are two old, dismantled quarries, formerly known as Rich's Lime Works. The rocks at both these places are like the gray, marbly limestone and associated yellowish-weathering beds at Fonda's. In the fields nearby are ledges of calcareous quartzitic sandstone. The rocks at and near these old quarries form low ridges or discontinuous outcrops and suggest that similar rocks may underlie some of the surface deposits of part of the lowland roundabout. There is nothing especially striking in the structural features at these localities. The dip is at a low angle to the east. The southern quarry is practically on the St. Albans line.

The Red Sandrock series of dolomites, quartzites and slates, with associated limestones, in Swanton township. The rocks which will be described under this heading probably do not include all the rocks belonging to the Lower Cambrian in Swanton. Some other rocks that probably belong in this terrane, or to some other part of the Cambrian, will be mentioned beyond.

No outcrops of the Red Sandrock series were found in Swanton north of the Missisquoi River. The western margin of these rocks at the north begins just south of the river and about one-half mile east of the gray limestone at Swanton bridge. From this point the visible margin then runs southward for a short distance to the east of the Swanton-St. Albans road and then west of and roughly parallel with it to the St. Albans line, where it bends southwesterly in the direction of St. Albans Bay.

By comparison later with conditions farther south it will appear that the present western margin of these rocks is probably, at least to some extent, an erosion trace in the course of the recession of this formation eastward and that it is essentially an escarpment softened by erosion.

In Swanton the members of this Sandrock formation are not in contact with the younger rocks that lie west of them. The nearest approach to visible contact is southeast of Fonda's quarry where the eastern outcrops of the mass at Fonda's quarry are within about 100 yards of dolomite beds of the Sandrock series. As in Highgate and other parts of Vermont the extent of present and former overlap remains uncertain because a surface section does not expose the younger rocks beneath the Sandrock, east of its present western margin (see, however, Ferrisburg township described beyond). North of Swanton Junction the margin swings west of the railroad track and the older rocks lie there on a meridian occupied farther north by outcrops of the younger gray limestone. This relation is, of course, only a suggestion of appreciable overlap; but at places farther south definite contact relations support the idea that the Cambrian beds moved over the younger rocks.

Only the chief variations among the members of the Sandrock series may be noted. The history of these rocks with respect to the conditions under which they were deposited is a chapter by itself.

At Barney's quarry a mile east of Swanton village and on the western margin of the Sandrock south of the Missisquoi River, the rock has been removed for marble. The marble is a mottled red and white siliceous dolomite of "brecciated" appearance. Similar rock appears at other places in Swanton and in the townships to the south and its various outcrops often appear to mark approximately the same horizon, although it seems possible that its peculiar features are repeated in different beds. Bowlders of this rock are common on the islands of the lake and on the mainland. So far as it may be distinguished by color markings, the mottling is a variable feature and in the same bed the mottled rock appears to pass laterally into other rock of more homogeneous color and texture. While in a great many of its outcrops this mottled rock is certainly not far above the supposed plane of shear of the series of which it is a member, the rock itself does not seem to give convincing evidence that its apparently brecciated character was acquired from crushing during thrusting. If the apparent brecciation is an effect of internal deformation it would seem that unusual primary conditions must have existed, such, perhaps, as an alternation of thin beds of sandy and magnesian deposits. It is possible to imagine that such beds under pressure could be broken and crushed with subsequent welding of the whole into the massive condition which the rock now shows. On the other hand, if these rocks were accumulated in shallow water, which seems probable, it is possible to imagine that minor disturbances during deposition might have produced the confusion and that the compacted condition was effected by consolidation under burial, or by dynamic pressure, or both. The gray and red rocks into which the mottled variety seems to grade many times do not seem to show appreciable shearing deformation.

The rock yields few if any fossils. Obscure markings that might be interpreted in different ways are found in the more homogeneous beds above and below the mottled rocks. Probably some of these represent filled mud cracks or other purely physical features of shallow water deposits.

The generally massive, siliceous dolomites, including the mottled marble, pass eastward at the surface into rusty-weathering, sandy shales or shaly sandstones, often "flaggy." The latter outcrop frequently in the pasture along the road from Barney's quarry eastward toward Donaldson's farm. These rocks carry fragments of trilobites and in their lithological features are much like the shales at "Parker's ledge" in Georgia township.

In the woods north of the pasture road just mentioned, and perhaps one-fifth of a mile from it, is a small ledge of limestone, apparently interbedded in the Sandrock formation, from which were collected several specimens of a fossil identified as *Kutorgina labradorica*, var. *swantonensis*. The writer was guided to this locality by Mr. Donaldson and Mr. Bluett of Waterbury, Conn. This fossiliferous rock was not found elsewhere by the writer.

East of Donaldson's farm, between it and a road running north and also east of the road, are numerous ledges of rusty-weathering, sandy shales which were regarded as the eastward extension of those described above and as probably of Lower Cambrian age.

Except for the limestone member the series as just described, from sections made across it at different places, was observed to form a broad band occupying nearly the whole width between the Swanton-St. Albans road on the west and the Highgate-St. Albans road on the east, and extending practically from the northern boundary of Swanton township into St. Albans at the south. The dip is usually easterly at a low angle. About a mile east of Donaldson's and about one-fifth of a mile west of the Highgate road a westerly dip was noted.

East of Donaldson's the shales seem to be more conspicuously sheared than farther west and some of them are on meridians occupied farther south by ledges of gray dolomite. It was not clear whether shales passed laterally into dolomite; but at other places yet to be described, the field relations are not inconsistent with such a view, although probable disturbances among the rocks must always be kept in mind.

The so-called "Intraformational Conglomerate" and associated rocks along the Highgate-St. Albans road and at other outcrops in Swanton. South of Hungerford Brook in Highgate, and just north of the Swanton line, begins a series of outcrops of

PLATE XXIV

Surface view of coarse limestone conglomerate near Skeels Corner in northeastern part of Swanton township.

various rocks which from their field relations all seem clearly to belong to the same formation. The principal exposures are along or near the Highgate-St. Albans road which these rocks rather closely follow southward for a distance of about four miles. Outcrops become more intermittent towards the south. At the south in Swanton, scattered outcrops in the drift extend the geographical range of these rocks east of the Missisquoi Branch of the C. V. R. R. to the base of the quartzite hills in the southeastern part of the township, and apparently show that this formation was once more widely represented over the surface than now. However, as now preserved, these rocks form for the most part a rather narrow belt on the east of the broader band of quartzite, dolomites and shales described above.

The most conspicuous member of this series is a coarse conglomerate whose fragments vary in size from small pieces to huge slabs or blocks weighing tons. With the conglomerate and forming its paste or matrix is a finely-granular (arenaceous), calcareous sandstone, which at some places forms a stratum on which the conglomerate rests, apparently conformably. The characters of the conglomerate and its associated sandstone are well shown north of Skeels Corners, to the west of the road. At this place the sandstone, which is coarsely bedded, forms an irregular stratum beneath the conglomerate about 30 or 40 feet thick. The rock is prominently siliceous and carries many small veins of quartz which have weathered out in relief against the body of the rock. The accompanying photograph shows the surface of the conglomerate at this locality. See Plate XXIV. The larger fragments of the conglomerate are often large slabs of grayish or bluish limestone and these are mingled with many smaller pieces of all sizes.

In the conglomerate the matrix is not always distinct from the included fragments when the latter are small. The material surrounding the coarser blocks is itself a conglomerate-breccia, showing many small fragments on a broken surface.

North of Skeels Corners the conglomerate and its associated rocks continue northward as a low ridge west of the road, and by intermittent outcrops along the road, nearly to Hungerford Brook. One-fourth of a mile north of the Swanton line an exposure on the west side of the road gives unbroken thin beds of bluish limestone, perhaps 2 or 3 inches thick, dipping westerly and passing upward into broken and dislocated layers.

East of the road, north of the latitude of Skeels Corners, the surface west and east of Hungerford Brook is flat, with the hard rock mostly concealed. Along the road by Webster School are low-lying ledges of slate like that in eastern Highgate, to the east of Rock River. So far as surveyed over this flat land east of Skeels Corners, no conglomerate or limestone was observed.

South of Skeels Corners, along the road or in the fields, the members of this conglomerate-limestone formation outcrop at intervals to within a mile of the St. Albans line. To the east the hard rock that outcrops here and there through the extensive surface material is largely slate; but south of the road to Greens Corners in a pasture and on the bank of Hungerford Brook is a ledge of calcareous rock that probably is a part of the formation to which the conglomerate belongs, and a mile and a fourth southwest of Greens Corners, one-third of a mile east of the railroad track are inconspicuous ledges of bluish limestones like those seen along the Highgate-St. Albans road and farther north.

Various fossils have been reported from this conglomerate formation at its outcrops in Swanton, and those occuring in St. Albans which will be mentioned later, and these have been thought to indicate a Middle Cambrian age; but much uncertainty exists as to what forms should be referred to the matrix and what to the fragments. In Swanton the beds near Skeels Corners yielded a few fragments of linguloid brachiopod shells whose characters are too obscure for precise determination. In size and shape they resemble as closely as any illustrated forms, *Lingula riciniformis* Hall, or *Glossina trentonensis* Conrad; but it would be going altogether too far to claim that they are referable to either of these species. It was not clear whether the fossils were in the matrix or not.

Southeastern part of Swanton township. In the southeastern part of the township and in adjoining parts of Fairfield the surface rises, forming hilly land. As inspected near the track of the Missisquoi branch and along the road running parallel with it on the southeast the rocks at the base of this high land consist of quartzites and dolomites much like those found along the base of the Green Mountains farther south in Vermont and are tentatively regarded as of Lower Cambrian age. The slates which underlie the flat land west of these hills, between them and Hungerford Brook, may be and probably are of Cambrian age, but their exact horizon is not known.

St. Albans Township.

(St. Albans topographic sheet.)

Location. St. Albans township lies just south of Swanton.

The lake region. The broad area of low, flat land which forms the western portion of the township of Swanton continues with practically undiminished breadth into St. Albans. In St. Albans as in Swanton the rock of this lowland belongs chiefly to the Ordovician shale formation of the region. The shore of the lake gives an almost continuous section in these rocks which have the same general characters which have been described for them on previous pages.

Away from shore the hard rocks are mostly concealed, but outcrops are found on knolls and low ridges along the roads and in the fields. Along the road from the lake shore to St. Albans, past School No. 10 and the Tuller School, the slates were traced by scattered ledges eastward to within one-third of a mile of Stephens Brook. A half mile west of School No. 10 some rusty, sandy shales yielded large numbers of graptolites, which were identified as probably *Diplograptus foliaceous,* var.

In its southern portion the lowland forms a peninsula known as St. Albans Point, which is separated from the mainland by St. Albans Bay.

Among the shales, or slates as they might fittingly be called in most cases, which probably make up most of the lowland, there occur at several places other rocks which are very doubtfully members of the shale formation. In spite of somewhat scanty representation at the present time, these rocks may possibly have some structural significance.

In the first place these rocks may be described as appearing to have a stranded position among the shales and as foreign to them. They have not been seen elsewhere in the region in such relations nor in any other relations to the shales. In all their outcrops these rocks now form dense, very much altered quartzites, weathering white, but on fresh surfaces appearing blackened as though at one time they had been in a very hot fire. They are extremely tough and break reluctantly under the hammer. Because of the way in which they weather, their outcrops are conspicuous when close at hand, although they do not form large exposures nor high elevations. In the course of a general survey of the lowland along the roads and in adjacent fields the outcrops of these rocks were sufficiently conspicuous and different from the shales to call for a special examination. With the possibility always in mind that on the islands of the lake or over the lowland bordering its shore there might somewhere be found some remnants of overthrust rocks that once lay on the shales but which have now largely disappeared by erosion, these rocks were at first hailed as possibly affording an example of what had so persistently been sought. Since their outcrops are all low and topographically merge with the surrounding slates, it is possible that they are more extensive than is apparent and possibly there are other visible ledges which were not seen.

The possible significance of these rocks seems to lie partly in their geographical situation and relations and partly in the fact that they have not been seen at any place as forming a part of the shale formation.

The northernmost outcrops which were seen lie between the lake shore and Jewett Brook, about a mile and a half north-northwest of the Point School. At this place the rock has the greatest surface extent of any of the exposures seen. It forms three low knolls in a north-south line and smaller patches west of them. Roundabout are ledges of other rock more like the shale-slate formation, but not always of well-defined character. Typical shale, however, outcrops to the north on a meridian slightly to the east, and also westward.

A mile south-southwest on the road running from the lake shore to St. Albans Bay and one mile northwest of the Point School are other outcrops, along and near the road. In a low ridge just east of the road the bedding is distinct and there is a small fold overturned to the west.

Other outcrops occur practically on the same meridian with the last mentioned in the southern portion of St. Albans Point. About two-thirds of a mile north of Hathaway Point, at the summer place of Mr. Morton of St. Albans, shales may be seen to form a high cliff along shore. Above the bank in the yard near the highway occurs a small exposure of dense, white-weathering quartzite which appears to be in place. At the extremity of Hathaway Point the quartzitic rock appears to lie on greatly sheared and disturbed slate and the two are much involved. The relations strongly suggest a thrust contact. Along the road from Hathaway Point to "Kamp Kill-Kare" and in the fields west of this road are other outcrops of the quartzite, which westward gives place to typical shale.

The quartzite gives little or no hint as to its age. It lies on meridians which farther south on the mainland in Georgia township, south of St. Albans, are occupied by shales and overthrust limestones and members of the Red Sandrock series. It seemed to the writer not unlikely that the small areas of quartzite just described may be residuary fragments of a formerly much more extensive mass of such rocks, or of others structurally related to them, which once lay on the slates. The imagination must be exercised in such a view, but the suggestion is not without support from other field relations in nearby areas. East of Stephens Brook, north of the village of St. Albans Bay, are physiographic outliers of altered limestones, presently to be discussed, which are now nearly a mile removed from the erosion margin of similar rocks which outcrop from beneath the massive quartzites and dolomites of the Lower Cambrian Red Sandrock series. These limestone masses are quite clearly eroded thrust-inliers in the shale formation.

Equal in interest to the evidence of remarkable thrust phenomena which the region shows are the indications of the great amount of erosion which apparently must have occurred in producing the present relations among the rocks.

Limestones east of Stephens Brook in St. Albans. Leaving the main road that connects the village of St. Albans Bay and the city of St. Albans, about two-thirds of a mile from the lake shore, is a road running northward towards the Tuller School.

Along its southern portion this road is bordered on both sides by marbly gray or dove-colored limestone, but northward this rock occurs mostly on the east side of the road where it forms the lower portion of a scarp-slope that is capped by the Red Sandrock. About a mile north of the St. Albans road, west of the one running northward, are low outcrops of bluish limestone which may be of Trenton age. The gray limestone is intermingled with some sandstone and carries yellow-weathering layers. Without much doubt these rocks are the same as those at Rich's old quarry and at Fonda's quarry farther north. With some interruptions these rocks continue northward to within about a mile of the Tuller School. The dip is prevailingly to the east.

North of the village of St. Albans Bay and three-fourths of a mile west of the road just described as running northward, are two hills composed of gray limestone which has in its striped appearance at places much resemblance to certain rocks which the writer has elsewhere identified with the Chazy. The rock is altered and massive in general appearance, with obscure dip and strike. Faint markings were noted, but no distinct fossils were found. These two hills are probably joined beneath the surface material, but taken together they are isolated from the rocks forming the scarp to the east and are probably surrounded by slates. The slates are largely concealed roundabout, but outcrop to the west of the larger western hill.

In and south of St. Albans Bay village. East of the village of St. Albans Bay the escarpment formed by the gray limestone, with its associated rocks and the Red Sandrock formation and which in general borders the lowland on the east, is broken by an embayment along which ascends the road from St. Albans Bay to the city. This embayment marks a surface interruption in the band of limestone and an eastward curve in the margin of the Red Sandrock. South of the road the margin of the Cambrian rocks swings westward and in the eastern part of the village of St. Albans Bay the Sandrock is again in proximity to the gray limestone south of the brook. To the west of the dove-gray limestone occur other limestones which are much sheared and altered. Some of it appears like the dense, black limestone found with the Trenton at Highgate Springs and possibly represents the Black River. Southwest of the Catholic church and in other outcrops nearby are ledges of bluish limestone, weathering gray, which are sheared and veined with calcite. This rock shows fragments of fossils on the weathered surface and a small bowlder gave a worn brachiopod shell like *Strophomena*. The rock is probably Trenton and resembles other rock correlated with Trenton at localities to the north.

South of the village, to the east of the shore road, is gray limestone with some chamois-colored rock, associated with dense, blackish limestone carrying demilunar traces of fossils which are like the markings which so frequently occur in the Black River. Bluish, so-called Trenton limestone, is scantily represented. All the rocks are sheared and veined with calcite. West of the shore road the grass land is flattish, with no outcrops. The shale formation probably underlies the surface material near the lake shore.

The Red Sandrock series in St. Albans township. The Lower Cambrian quartzite-dolomite series of Swanton continues southward across the St. Albans line. Along their western margin the Cambrian rocks cap the gray limestones as described above and may be seen in actual contact at two places, at least. With the limestone the Cambrian rocks form an escarpment which faces the lowland and lake to the west. In St. Albans the Cambrian massive dolomites and quartzites are most prominently exposed along a ridge about one mile wide just east of the escarpment. A section made across the strike due west of St. Albans city showed essentially the same sequence of massive reddish, gray and mottled rocks as found in the western portion of the band of Cambrian rocks as described for Swanton. A reading on a bed of the mottled "Swanton marble" gave the strike as N. 10° E. and the dip as 8° easterly. The sequence is practically duplicated at the Georgia line with approximately the same dip and strike.

East of the ridge, along the valleys of Stephens and Rugg Brooks, respectively northwest and southwest of St. Albans city, the surface is lower and the rocks are extensively covered; but apparently Lower Cambrian rocks underlie most of the surface in the area between the western marginal scarp and the main road that runs from Georgia through St. Albans city to Highgate. In the western outskirts of the city of St. Albans, north of the road to St. Albans Bay, scattered ledges of sheared quartzite outcrop only short distances from small ledges of conglomerate and slate which will be mentioned again beyond, and well-bedded quartzite, not notably sheared, forms low but prominent ledges on and near the main road from St. Albans city to Georgia, about a mile south of the center of the city.

Aldis Hill. Aldis Hill, to the northeast of the city, is apparently composed chiefly of gray quartzite. At the northern end of the hill the beds may be plainly seen dipping at a moderate angle in a direction a little to the north of west. On the northeast slope of the hill the edges of the beds are well exposed and many of them may be seen to be only from 2 to 3 inches thick. They carry frequent thin veins of quartz and are somewhat but not severely sheared.

St. Albans Hill. This hill lies partly in St. Albans and partly in Georgia township. It is a prominent eminence lying just east of the St. Albans-Georgia road.

A private road leaves the main road about two miles south of the center of the city, and passes round the northwestern end of the hill. Along and near this road, perhaps 30 or 40 rods west of the main road, are low-lying ledges of blue limestone carrying some conglomerate. The topography suggests that there is a fault at the northern end of the hill and that this limestone is on the downthrow side. On the supposedly upthrow side is massive quartzite. This apparent displacement is seemingly traceable in a southeast direction on the east side of the hill, passing to the west of the farm house. Over the hill to the west and south the rocks are quartzite, sheared quartzite or phyllite, and dolomite, in such arrangement as to suggest that possibly that there was lateral variation in the different beds and that some of the rocks were sheared more than others; also that there may have been some faulting and offsetting so as to bring different rocks along the same line of strike. The western slopes are generally steep. On the southwestern side (in Georgia) are precipitous scarps which mark dislocations.

Southeastern part of St. Albans township and adjoining parts of Fairfield and Fairfax. East of St. Albans Hill the boundaries of the townships of St. Albans, Fairfield and Fairfax meet at a common point. East of this point, at the southwestern end of Bellevue Hill, are interbedded quartzite, dolomite and mottled rocks practically on end, dipping at a high angle to the west or east. At the base of the series is a stratum of dolomite which looks as though it had been crushed. It breaks into fragments which usually have small unaltered cores surrounded by rusty. decomposed rock. These various rocks lie about a mile east of St. Albans Hill. They are regarded as forming the eastward continuation of the rocks of the hill, or as possibly lying stratigraphically just below them; but in either case as members of the Lower Cambrian series. North of these rocks quartzite forms the western base of Bellevue Hill.

Bellevue Hill. The rocks on the northwestern slope of Bellevue Hill vary somewhat in character and are prevailingly sheared into foliated rocks. Apparently depending upon their original texture they are now sometimes phyllitic, sometimes schistose or gneissoid. In one place a conglomerate was noted, sheared into a coarse gneiss in which the squeezed pebbles could be plainly seen. Distinct small folds may be observed in some places, particularly on weathered joint planes cutting across the strike. The prevailingly easterly dip, as viewed on the surface, is then seen to be that of an induced structure. The colors are greenish, gray and sometimes purplish. The rocks are all prominently siliceous in composition and in general strongly suggest the basal portion of some overlapping formation. Well-defined bedding, repeated, small, sometimes overturned folds, variations in the purity of the material and in the texture, all seem to accord best with the idea that these rocks are later than pre-Cambrian. They are possibly altered derivatives of older rocks, not now exposed, and have been sheared into schists and gneisses whose surface exposures are deceptive.

The topography suggests that Bellevue Hill is part of an upthrust mass of rocks. The western slope is steep and is really a softened scarp. A banking of bowlder drift and a heavy covering of trees conceals the really precipitous character which the slope now has at some places. In the recognition of the upthrust relation of this hilly land at the east one finds the clue to the clearly disturbed condition of the rocks described for the southwestern end of Bellevue Hill and for the westerly dip at Aldis Hill. The beds were folded and sometimes tilted to a high angle or overturned before rupture occurred. Over the higher portions of the hilly land the dolomites have disappeared by erosion. East of the supposed plane of thrust the rocks have usually been strongly sheared.

East of St. Albans city. East of the city a road leads eastward over the rugged, hilly land to the French School. The rocks along this road were carefully inspected. As exposed at the surface they vary from slaty phyllites through coarser, darker colored schistose or gneissoid quartzites to gray, granular quartzites in no regular order. Slaty phyllites are more abundant eastward.

The limestone conglomerate and associated rocks in St. Albans. Mention has already been made of the small outcrops at the northern end of St. Albans Hill and in the western outskirts of the city. The latter locality, commonly known as "Adam's pasture," is one that has been visited by many geologists in their studies of the stratigraphy of the region. Logan was one of the first to report upon the rocks at this place (Geology of Canada, p. 858) and described them as part of a band that was traceable for about one-fourth of a mile north of the road before it disappeared. Logan also described another band of conglomerate about one-fourth of a mile to the west at the base of a mass of whitish sandstone. Both conglomerates were described as carrying fragments of pure gray limestone. Immediately beneath the base of the western strip "occurs a band of dark gray, slightly micaceous slate, with *Obolella cingulata.*"

The writer's observations at Adam's pasture showed that what is present of this conglomerate formation is partly surrounded by not very distant outcrops of sheared quartzite, and afforded nothing definite as to the primary or secondary structural relations of the various rocks.

In the conglomerate the fragments of gray limestone are imbedded in a matrix of calcareo-siliceous material like that found in the conglomerates of Swanton and Highgate.

West of the Central Vermont R. R. track, a half mile north of the Georgia line, is another prominent exposure of the conglomerate formation, perhaps two acres in extent. With unimportant variations the rocks are like those at Skeels Corners. The conglomeratic portion shows large and small fragments of bluish or grayish limestones, with some sheared, marbly limestone, in a calcareo-siliceous matrix which weathers to a yellowish gray. In association with the conglomerate are distinctly bedded ledges of arenaceous rock much like the conglomerate matrix. At this locality none of the thinly-bedded, bluish limestone was seen, but at the northern end of the exposure is a substantial thickness of blackish slates which seem to lie beneath the conglomerate and which have some resemblance to those found in association with the blue limestone at Highgate Center. The formation including the conglomerate, of which outcrops at various places in Highgate, Swanton and St. Albans have now been described, has yielded fossils to various investigators, but its age has not been completely determined nor its relations positively elucidated from such fossils as have been found. From its apparent relations to other Cambrian rocks and from such fossils as have been discovered the formation has been called Middle Cambrian. Dr. Walcott thought that the fossils collected by himself and by G. E. Edson indicated such an age. He listed thirteen species as found in the various members of this formation, among which *Paradoxides,* which was reported from the "argillite," seemed to argue very strongly for a Middle Cambrian age for the formation.

The distribution and characters of the various rocks which seemingly are to be regarded as together making up this singular formation may be susceptible of another interpretation, in spite of the apparent nature of the fossils. There is little doubt from what observation the writer has made that the removal of the surface covering would disclose a wider extent of these various rocks than their present outcrops show.

Georgia Township.

(St. Albans and Milton topographic sheets.)

Location. This township which lies just south of St. Albans is also bordered on the west by the lake. It is bounded by Fairfax on the east and by Milton on the south.

The slates and gray limestone along and near the lake shore in Georgia. The gray limestone and associated rocks found lying to the west of the margin of the Lower Cambrian Red Sandrock series in St. Albans continue southward into Georgia, forming intermittent exposures between the lake shore and the margin of the Red Sandrock series. The limestone seldom reaches the shore, but is separated from it by the slate formation with which it is in intimate field association at several places. The outcrops of the gray limestone and its companion rocks in Georgia may be briefly described.

East of the shore road running south from St. Albans Bay village, and a half mile south of the St. Albans line, on "Shore Acres farm," the gray limestone with interbedded, yellow-weathering layers, in some places may be seen dipping easterly at a high angle. The rock is, however, generally much sheared with partial obliteration of the bedding. The gray rock is associated at this locality with beds carrying markings that indicate a Black River age. The structural relations are obscure. Above the limestone to the east are the Lower Cambrian gray and mottled dolomites dipping easterly at a low angle.

Just west of the shore road, south of "Shore Acres farm" and between it and Mill River, are outcrops of sandstone with the beds dipping easterly at a high angle. Just west of the sandstone is bluish limestone which looks very much like the Trenton. The dip is again easterly at a high angle and the sandstone and limestone appear as though interbedded.

South of these outcrops is Mill River. In the bed and along the sides of the river, above and below the bridge, is exposed a gray sometimes obscurely striped limestone. Above the bridge the dip is not clear, but below it the bedding may be seen to dip easterly at a high angle, measured at one place as 53°.

About 200 paces west of the bridge the gray rock is succeeded westward by apparently conformable sandstone and shaly limestone which continue west for about 60 paces and are then followed by shaly limestones and shales. In the river section no beds were noted which had any resemblance to Black River rocks.

Gray limestone outcrops in the angle of the roads just south of the Everett School and one-fourth of a mile farther south on the east and west sides of the shore road. At Lime Rock Point the gray limestone reaches the water's edge, while south of the point the bank of the lake is formed of slate like that of the St. Albans lowland and the islands lying to the west, but indescribably crushed and jammed so that its included firmer bands of rusty, siliceous rock are squeezed and faulted out almost to obliteration.

East of the road on the farm of Mr. Wilcox the gray limestone is clearly much disturbed and greatly sheared. Just south of Wilcox's house black slate outcrops in the road and a fourth of a mile farther south the shale-slate formation may again be seen forming the shore cliff where the road closely hugs the shore just north of Melville Landing.

The slate forms the shore from the small point south of Melville Landing to the Milton line. Throughout this distance the margin of the Red Sandrock series is one-fifth a mile or less from the lake shore. The Cambrian rocks form the summit of a sharp slope against which is usually piled a large amount of drift. Through this covering the hard rocks outcrop at intervals.

South of Melville Landing near the top of the slope lie great blocks spread about "like ruins." Some of these are quartzite and others are composed of bluish-gray and chamois-colored limestone with a "brecciated" texture not unlike that of the mottled Swanton marble. Southward along the intermediate levels of the slope at several places the soil indicates that the slate formation is close to the surface and at one place about two miles south of Melville Landing the black slate was found outcropping well up the slope. A half mile farther south the gray limestone with abundant calcite veins appears from beneath the Cambrian dolomites and forms a conspicuous hill at the western base of which the black slate outcrops.

About two and a half miles north of Camp Rich the shore road turns abruptly eastward away from the bank of the lake which it closely follows to this turn. Slate outcrops where the road turns again southward. East and south of this slate outcrop is gray, often sparry limestone of uncertain correlation. One-half mile farther south, east of the road, sparry limestone has about the same dip as the Cambrian dolomite that clearly lies above and on it. West of the road is other limestone which continues nearly to the slate along shore.

As indicated above, the lake is formed of the shale-slate from the St. Albans to the Milton line, except at the Lime Rock Point. It thus appears that along the Georgia shore the same general relations prevail among the slates, gray limestones and Cambrian dolomites as in Highgate, Swanton and St. Albans. In Georgia it seems probable that at some places the Cambrian rocks rest directly upon the slates, as will be conclusively shown to be the case farther south, and as may be the case at certain places north of Georgia; but in Georgia and places north of it the surface covering leaves some doubt.

There can be no doubt, however, that the relations among the rocks along the lake shore in Georgia clearly mark thrusting and dislocations and show that older rocks have moved over younger ones. There was probably involved at least one great low-angle thrust by which the Cambrian rocks were moved to the west. Whether the gray limestone and its companion rocks were secondarily involved in the thrust that drove the Cambrian westward and were carried along with the latter, or whether they are rocks that were independently driven on the slates on which they now rest and were overridden by a later major thrust of the Cambrian it is not possible to tell. Either history seems possible.

The escarpment formed by the margin of the Lower Cambrian Red Sandrock and the various limestones that lie beneath it in southwestern Georgia is over a mile to the west of the meridian on which are located the fragmentary outcrops of quartzite which were described for St. Albans Point. It seems likely that the present margin of overthrust rocks north of Georgia is an erosion trace of a mass of older rocks that once had an extension to the west of the present western limit of these rocks and that the fragments of quartzite now isolated within the slate formation on the St. Albans lowland may be really remnants of resistant members of such a mass. This seems probable, even though it must be recognized that the thrust of the older rocks on the slates may not have carried them so far west in higher latitudes as it did in Georgia and farther south, for which idea one finds some support in the present northeasterly trend of the margin of these rocks in northwestern Vermont and in their extension northward into Canada.

The Lower Cambrian Red Sandrock series of quartzites and dolomites and associated shales in Georgia. The massive gray, red, and mottled members of the Red Sandrock series near the lake in Georgia are indistinguishable from the similar rocks in the townships to the north. They do not appear to have suffered any notable internal deformation and plainly dip at a low angle to the east. Away from the lake the hard rock is more extensively covered by surface material and emerges as knolls, hills and ridges of varying dimensions. Around Georgia Plains and northward along the headwaters of Mill River the underlying rock had clearly been somewhat dissected before the surface covering was spread over the region.

About a mile and a half north of Georgia Plains and about the same distance east of the lake is a hill known to residents as "Parker's Ledge." This locality has long been celebrated for the Lower Cambrian fossils which have at various times been found there. The farm of which the hill forms a part is now owned by Mr. Montcalm. The prevailing rocks at the "Ledge" are dense black or sandy, often micaceous, rusty-weathering shales, which after diligent search may now afford fragments of *Olenellus, Olenoides, Microdiscus* and other fossils. These shales have great similarity to the rocks of Swanton which lie to the east of the gray and mottled dolomites of that town and like the shales of Swanton have some dolomite associated with them. Some of the dolomites at the "Ledge" are of gray color and others are rusty-weathering, siliceous rocks. The rocks at the "Ledge" have for the most part a flattish position or dip to the east at a low angle.

A half mile south of the "Ledge" on the farm of Mr. Sartwell quartzitic shales are interbedded with dolomite, but westward on the Densmore farm the shaly members occur in greater force and have much similiarity to those at the "Ledge." These shales carry "fucoidal" markings, which are probably trails, but did not yield other fossils. They give place westward at the surface to the gray and mottled members of the Red Sandrock series.

The gray and mottled rocks near the lake in Georgia township are thus seen to pass eastward at the surface into somewhat different rocks with which they may be conformable. The general surface sequence and the dips of the various rocks suggest a continuous stratigraphical series, but it is not certain that the apparent conformity is everywhere real and that dislocations do not intervene among these various rocks that seem with more or less definiteness to be of Lower Cambrian age.

In the northern part of the township the dolomites are succeeded eastward at the surface along the road crossing Mill River, which passes School No. 7, by sheared quartzite, which also outcrops frequently along the main highway from Georgia Center to St. Albans, to the west of St. Albans Hill. Similar rock outcrops around Georgia Center; but west and southwest of Georgia Center the quartzite is intermingled with areas of limestone conglomerate presently to be described.

The road running directly east from Georgia Center ascends a slope over sheared quartzite. There is then an interval along the road of a little less than a mile with no outcrops. Near the junction of this road with one running south past School No. 11 are numerous ledges of massive gray and mottled dolomite clearly dipping westerly. A reading gave the dip as 37° and the strike as N. 10° E. These rocks may be followed northward and southward along their strike. Southward, about a mile and a half from the junction of the roads just mentioned, massive dolomite was noted dipping westerly, and northward, a mile north of Oakland, are similar rocks also dipping westerly. The latter outcrops are two-thirds of a mile southwest of Bellevue Hill, described above. Dolomite outcrops along the road on the lower western slope of Cushman Hill, but is succeeded farther up the slope by quartzite.

Taking into account the low easterly dip of the members of the Red Sandrock series at their western margin and the suggestion of their possible extension in that attitude eastward beneath the surface the westerly dips of the rocks just described might seem to show that the beds in question form a broad, shallow syncline over most of Georgia township west of the C. V. R. R. track. It is possible that they do and that the higher dips at the east represent a pushing up of the eastern limb, with crushing at some places (Bellevue Hill). The massive beds ruptured instead of folding, the rocks east of the railroad track now occupying the upthrow side of a reverse fault-thrust. But as mentioned above it is not certain that dislocations do not intervene between the western margin and the railroad track, so that it cannot be positively stated that Georgia shales are conformably above the dolomite series near the lake, although they seem to be.

The limestone conglomerate formation in Georgia. In Georgia the most conspicuous outcrops of the conglomerate, or of limestone that is apparently to be correlated with it, occur west of Georgia Center and east and southeast of Georgia Plains. On account of surface covering the outcrops are intermittent and of variable extent in present surface exposure. West of Georgia Center the conglomerate has all the essential features of the rock in St. Albans and Swanton. It carries abundant limestone fragments of different sizes in a matrix of strongly siliceous material which has enough calcareous matter to effervesce freely with acid.

Dr. Walcott in his early account of the Georgia section described the conglomerate as apparently forming a great lenticular mass of limestone, with intercalated beds of argillaceous shales, and more rarely with arenaceous layers imbedded in the argillaceous shales. The fauna was described as Cambrian in character, and, in the absence of *Olenellus* and other typical Lower (then called Middle) Cambrian fossils, as approaching the Upper Cambrian.[1] In his diagram of the Georgia section, Walcott shows the conglomerate formation as an interbedded member of the Georgia series. In referring to the vertical distribution of the fossils (loc. cit., p. 20) he remarks that one species of the typical Georgia fauna, *Ptychoparia adamsi*, "is represented in the great 'lentile' of the Georgia section," but he drew the provisional upper line of the Georgia Formation at the base of the lentile, as it is at this horizon that there occurs a decided change in fauna and that the deposit changes markedly from that below.

Several years later,[2] after the recognition of the Lower Cambrian age of the Georgia shales (the fauna of these shales having been regarded by Walcott in his earlier studies [1886] as Middle Cambrian) Dr. Walcott reproduced his early diagram of the Georgia section, showing the conglomerate as an interbedded member of the Georgia series and stated that it contains a fauna that may prove to be of Middle, or possibly Upper Cambrian age.

In commenting on the Georgia section as late as 1911,[3] Ulrich said: "The base of the section is here unknown. As worked out by Walcott, the lowest exposed formation is a limestone 1,000 feet thick. This is succeeded by 200 feet of 'Georgia shale,' and over this comes 3,500 feet of shale and thin limestone. A quartzite 50 feet thick follows and is in turn overlain by 1,700 feet of limestone and shale, and this by 3,500 feet of shale. I have seen only the upper part of this section, namely, the heavy bed of shale last mentioned, which, together with all the underlying beds has been referred to the Lower Cambrian by Walcott. Regarding the upper shale I am strongly inclined to view it as of Canadian age rather than Cambrian. There is some question in my mind, also, concerning the age of the limestone supposed to belong to the 1,700-foot bed. It contains small bivalved phyllopods (*e. g.*,

[1] Bull. U. S. G. S. No. 30, 1886, p. 17.
[2] Tenth Annual Rept., Director U. S. G. S., 1890, pp. 553-554.
[3] Revision of the Paleozoic Systems, Bull. G. S. A. No. 22, 1911, p. 617.

Indiana dermatoides (Walcott), *I. pyriformis* Matth., *I. secunda* M., *Bradoria scrutata,* M.) which are characteristic of Lower Acadian zones in New Brunswick and Newfoundland. As it is not yet decided whether the Protolenus zone is late Lower Cambrian or early Middle Cambrian, the exact age of the Vermont bed mentioned also remains uncertain." He then comments on the complicated structure of Vermont rocks and of those of the Taconic area in particular.

In the writer's studies of the structural relations of these rocks it was not possible to show that the conglomerate is interbedded in the shale series, or that it could not be interpreted as resting unconformably upon eroded rocks. The field relations leave much uncertainty as to the stratigraphic relations of the conglomerate to the rocks with which it is associated in Georgia. If the conglomerate lies in a broad, open syncline of Lower Cambrian rocks it might be interpreted *structurally* as belonging to any formation later than Lower Cambrian, and if its fossils are truly Middle or still later Cambrian they might be regarded as forming a primary fauna, or as secondarily included in a later terrane by erosion of Middle or later Cambrian rocks.

Fairfax Township.

(St. Albans and Milton topographic sheets.)

This township bounds Georgia on the east.

Near the summit of Cushman Hill, about two-thirds of a mile north of Silver Lake and just east of the Georgia line, the present surface apparently marks erosion into the lower portions of an overlapping formation. At numerous outcrops the rock, which may be a rusty, impure quartzite or a greenish-gray, schistose quartzite, carries scattered large grains or rounded pebbles of grayish-white quartz. In dimensions these pebbles range from the size of a marble to that of an egg. The pebbles are apparently not sheared, but the rock in which they are included is sometimes schistose.

The significance of this imperfectly developed conglomerate and the obvious impurity of its matrix in places seems to be that the rocks of this higher land are not a great way above or distant from the old sea-floor on which the series of which they are a part was deposited; but no unconformable contacts nor any recognizable older rocks were seen. The conglomerate is not purely local, for similar rock was observed three miles farther east in Fairfax, near Buck Hollow, and five miles to the north in St. Albans, and also at the northern end of Bellevue Hill. The conglomerate is, however, everywhere local in the sense that it grades laterally into impure quartzite, or derivatives of impure sands. It is, therefore, intraformational in this sense; it is basal only in the same general sense. It indicates particular local conditions of deposition and perhaps minor oscillations. It can hardly be interpreted as forming residuary parts of a formation that rested unconformably upon the other rocks with which it is now associated.

At the northern end of Georgia Mountain, in the southeastern part of the township, along the hill road running east, south of the Lamoille River, are outcrops of gneissic-looking rocks with foliations dipping easterly at a high angle. On their weathered surfaces, and on vertical joint or fracture planes across the strike, these rocks give somewhat the appearance of squeezed conglomerates with the foliations bending gently around squeezed fragments; but the latter, on close inspection, have little appearance of pebbles distinct from a matrix, and when the rock is broken it looks much like somewhat impure quartzite. On the whole the rock most suggests a sheared and welded quartzite, whose resistance to deformation resulted first in shearing and brecciation. The rock was then healed and compacted into a gneiss. The rocks are succeeded eastward by outcrops of granular quartzite.

CHITTENDEN COUNTY.

Milton Township.

(Milton topographic sheet.)

Location. Milton, another lake shore township, lies just south of Georgia. The southern boundary of Georgia forms the northern boundary of Milton, throughout its extent. Westford lies to the east and Colchester borders it on the south.

The lake border in Milton township. The escarpment, capped by the massive beds of gray, red and mottled dolomites, which closely follows the lake shore in Georgia and part of St. Albans continues southward into Milton. In Milton, as in Georgia, younger gray limestones and slate or outcrops of slate alone intervene between the margin of the Red Sandrock series and the lake shore.

North of Camp Rich, gray limestone occurs between outcrops of slate in the shore road and the margin of the Red Sandrock series. South of the camp, towards Camp Watson, the margin of the Cambrian rocks more closely approaches the shore and outcrops of gray limestone are fewer. The shore road from Camp Rich to Camp Watson is nearly all the way on the slates which continue south to Eagle Mt. Camp at the mouth of Stone Bridge Brook.

South of the mouth of Stone Bridge Brook, Eagle Mt. rises to a height of 500 feet. It is composed of the massive dolomites of the Red Sandrock series and has a steep scarp on the west which was estimated in some places to be 200 or more feet high. The Cambrian rocks continue southward with somewhat diminished but still conspicuous scarp to the vicinity of Camp Martin (generally known as Camp Milton). Between Eagle Mt. Camp and Camp Milton the margin of the Cambrian rocks is perhaps 300 feet from the lake and the slope between is steeper than is usual farther north, apparently largely on account of large talus blocks which have fallen from the scarp and which are now partly covered with drift. Between Eagle Mt. Camp and Camp Milton the slate formation shows continuous outcrop along shore and throughout this distance gray limestone was not noted between the shore and the scarp, except just north of Camp Milton.

East of Camp Milton is an erosion gap in the margin of the Red Sandrock series. Trout Brook flows along the southern margin of this gap to enter the lake.

The indication is strong that between Eagle Mt. Camp and Camp Milton the Red Sandrock series frequently, if not usually, rests on the slates. Just north of the mouth of Stone Bridge Brook the slates form isolated shore cliffs 50 feet high without any traces of overthrust rock resting on them. Just south of the mouth of the brook the massive dolomite of the Red Sandrock formation reaches close to the water edge with only a high water or storm beach of slate shingle between it and the shore, no outcrops of slate or other rock being visible. The topography and geology suggest a fault along the gap mentioned above, the rocks at the north occupying the upthrow side. The dolomite continues south along the eastern edge of the swampy delta of the Lamoille River to the delta portion of the Sandbar Bridge road, showing as a low cliff of varying height, to the east of which the surface ascends over the eroded edges of other members of the Red Sandrock series. South of the delta road the erosion margin of the overthrust dolomite series is less easily followed to the bank of the Lamoille River.

Between Trout Brook and the Lamoille the dolomite probably rests on the slates just as it does at Red Rock Point near Malletts Bay in Colchester.

The steep western face of Eagle Mt. gives suggestion of what the faded scarp all along the margin of the Cambrian Red Sandrock formation may once have been. It seems quite likely that the erosion modification of these resistant rocks along their present trace was subsequent to the formation of the lowland in the weaker shales and limestones in what is now the lake region. It is, however, not apparent from the present relations of these various rocks how far the Red Sandrock may have extended to the west of its present erosion trace. It is interesting to note that in some places the Cambrian rocks rest by thrust on limestone and at other places on shales or slates that are younger than the limestone. Such relations should have something to say about the mode of deformation by which the present relations could have been produced.

Just east of the road that runs from Camp Milton eastward, about half a mile from the lake shore, a ledge of brick-red quartzite-dolomite displays a texture which differs strikingly from that which the mottled "Swanton marble" member of the Red Sandrock series shows. The rock as a whole forms a massive bed in which may be clearly seen many angular fragments of different sizes, including blocks of rectangular shape as seen in section which bear strong resemblance to similarly shaped fragments seen in the limestone conglomerate formation. Moreover, the angular pieces are mingled with other larger, irregularly shaped chunks, giving an assemblage like that in much of the limestone conglomerate. The fragments are, however, of much the same color as the rest of the rock and apparently are composed of a material similar to the matrix in which they lie. From the conditions it is not possible to tell whether the fragmented rock is an intraformational conglomerate or a peculiar form of brecciation. A similar fragmental rock of gray dolomite occurs west of Checkerberry village and will be mentioned beyond.

The west-central portion of Milton township. East of the escarpment that borders the lake the surface over the west-central portion of Milton is largely formed of sand plains through which the hard rock emerges as dwarf exposures which are often fragmentary and unsatisfactory for study. Arrowhead Mt., Cobble Hill and the gorge of the Lamoille River give more extensive outcrops.

From the escarpment near the lake the massive beds of the Red Sandrock series extend eastward with low easterly dip, forming in the western part of the township a fairly well defined band of varying breadth from the Georgia line to the Lamoille River. East of this band the members of the series lose distinctness as one passes into the areas of more scattered outcrops of the west-central part. Between the western band just mentioned and another strip to the east that includes Arrowhead Mt., the village of Milton and Cobble Hill, the exposures are prevailingly gray dolomitic rock, rather sparingly associated, so far as the rocks are visible, with a more quartzitic rock, without any very clear structural relations between the two. Some of the outcrops may now be mentioned.

North of the Lamoille River, to the east and west of Streeter Brook, are numerous outcrops of gray dolomite which give way at places along the strike to quartzite. The relations suggest either that dolomite grades laterally into quartzite, or that different but conformable beds are exposed in different outcrops. Either interpretation seems possible, if, as seems likely, the rocks are to be correlated in a general way with the members of the series along the lake. By such correlation is not meant precise stratigraphic equivalence, but membership in a common formation which gives good indications that horizontal variation in its different beds was a common if not a usual condition and that dolomites and more siliceous beds succeeded one another in a more or less regular fashion within the formation.

From Milton village to the lake the Lamoille, in sinking its channel since glacial times, has cut through hard rock at many places, producing a considerable fall near Milton village and minor ones farther west. The rocks which the river has thus cut through show some interesting differences.

At West Milton the river cuts massive gray dolomite, which outcrops in both banks and in midstream. A mile above this village the rock is more notably siliceous. These rocks appear to be the southward continuation of those lying west of Streeter Brook, to the north. Farther up stream, from the point where Streeter Brook enters the Lamoille to the abutments of the old stage road bridge near the Milton Town Farm, the rock along the stream is a slate, with easterly dipping cleavage. Where worn by the water the rocks often show pseudolaminations probably corresponding with the cleavage. At places above the high-water mark the rock is often a dense slate. The river cascades approximately along the strike over these slates below the old bridge site, forming what are frequently called by the residents the "minor falls." The slates continue upstream towards Milton village and seem to pass beneath other rocks forming the upper falls at the mill of the International Paper Company. The slates near the upper falls have been jammed and sheared with obliteration of bedding and folded structure. Folding was seen at only one place. Induration is the rule. The rock which apparently overlies the slate at the upper falls is a somewhat indeterminate mass of gray dolomite and quartzite. At some places the rock shows a texture precisely like the "Swanton marble," but without the conspicuous variegated coloration. For the most part the rocks resemble the members of the Cambrian series near the lake. They are generally massive in present appearance, although there are observable planes of separation which may represent bedding or jointing. At the falls the massive rocks are cut by a dike 4 to 8 inches wide running across the strike. A dike of similar rock, with apophyses, cuts the slates just west of the mouth of Streeter Brook. The rock that makes the falls continues as a scarp into the woods north of the falls. The general relations suggest that the dolomites have been pushed over the slates that lie under and west of them.

Upstream above the falls, well shown both above and below the bridge and sparingly along the streets in the village near the bridge, is indurated quartzite.

Southwest and west of Milton village, south of the Lamoille, is a broad, flat, sand plain with no outcrops except at its western edge, west of Checkerberry village. A half mile northwest of this hamlet, low ledges of dolomite show the peculiar conglomerate or "brecciated" texture noted in previous pages as occurring in a reddish bed of the Sandrock series near the lake, in the limestone conglomerate and in the gorge at Highgate Falls.

North of the Colchester line and east of the road from Checkerberry village to School No. 9, is gray dolomite dipping easterly. This rock continues easterly across the road that runs west of Cobble Hill, but on the western slope of the hill the dolomite is marked by frequent inclusions of chert and lies at the base of a modified but still notable scarp in the schistose quartzite that makes up the principal portion of Cobble Hill and that outcrops north of it and along the road that skirts it on the east.

North of Milton village the Lamoille is deflected to a southward course by the mass of Arrowhead Mt. which rises to a height of 947 feet and forms a conspicuous feature of the township. The eastern slope of this mass shows gray dolomite and quartzite, often sheared, but at places showing clearly defined westerly dip. The westerly dip is conspicuous at the southern end of the mountain proper. West of Arrow Mt., along the road at the western base, are black, fine-grained, siliceous slates.

South of Arrowhead Mt., and about a mile north of Milton village, quartzite forms bold, massive ledges west of the Georgia road. The quartzite beds have been sheared so as to give a more massive appearance than they really possess, a feature common among these rocks in which shearing has welded not always especially heavy beds into very massive looking rocks. The quartzite just mentioned joins southward with that above the falls in the village.

A broad surface section from the river in Milton village eastward along the road to School No. 6, shows that the quartzite at the river is succeeded eastward by gray dolomite and quartzite which form a low ridge just east of the railroad track. The rocks are sheared but at places show a westerly dip. As one ascends the hilly land east of the village, dolomite and quartzite roughly alternate across the strike on the lower portion of the slope; but higher up the slope dolomite is absent and much of the rock, while apparently originally a quartzite, shows a gneissoid structure like that which has been described for the northern end of Georgia Mt. The rock sometimes shows the bedding across which the gneissoid structure has been developed. The gneissoid rock is succeeded eastward by ledges of not severely sheared quartzite, which may be seen in the vicinity of School No. 6. At some places the quartzite, including that which has been sheared into a gneiss, is disposed in gentle folds.

The gneissoid rock might be regarded by some observers as something different from the quartzite with which it is associated, but there are no contacts nor other field relations suggesting that the rocks are members of different formations. The

possibility that older rocks might have been thrust into the quartzite formation must be recognized; but when the gneissoid structure appears in a bedded quartzite and when the quartzitic character of other gneissoid rock is so obvious and no valid distinctions may be made among numerous exposures over large open fields, the membership of these different rocks in a common formation seems the ready and reasonable interpretation and the differences seem to be explainable as due to various degrees of shearing and primary differences in composition.

The quartzite and its gneissoid associate continue south from the road to School No. 6 towards Colchester, along the higher portions of the western slope of the hilly land; but on the lower portions of the slope the rock is quartzite.

A section was made along the road that runs from School No. 10 to Bowmans Corner in Westford. The quartzite at the western base of the hilly land continues to the bend in the road two miles west of Bowmans Corner. The rock is sheared, with strong cleavage dipping easterly. South of the road, at the bend mentioned, white quartzite is associated with brick- or cherry-red quartzite in such relations as to indicate that the two rocks are lateral color variants of each other. Eastward along and south of the road to Bowmans Corner are frequent ledges of gray siliceous dolomite which is more or less intermingled over large areas with quartzite and this quartzite-dolomite series extends eastward nearly to the corner.

From the descriptions which have been given it will be seen that much the same kinds of rocks and structures occur in Milton as in Georgia. Near the lake the members of the Red Sandrock series dip easterly at a low angle. Farther east are dolomites and quartzites in scattered outcrops which apparently belong to the same formation. Along meridians passing through and east of Milton similar rocks show westerly dip at many places or are apparently broken and thrust on rocks lying west of them. Most of the rocks so far mentioned probably belong to the same general formation in which there are differences among the beds due to primary horizontal and vertical variations and to secondary shearing effects. It appears that the underlying hard rock away from the lake shore in Milton is probably essentially a Lower Cambrian surface as is the case in Georgia. There are, however, among these rocks some others which are not easily correlated with them, such as the slates found along the course of the Lamoille River, west of Milton.

Certain rocks in Westford township, adjoining Milton on the east. At Bowmans Corner and along the road towards Essex Junction is greenish slate or phyllite which over long distances is more or less interchangeable with quartzite. The greenish slate shows coppery-colored phyllitic and schistose variants and all have a good deal of similarity to similarly associated rocks at some places in the Taconic hills many miles to the south.

A section along the road from Milton village by the Hardscrabble School to Westford gives quartzite at the western base of the hilly land, then farther up the hill the gneissoid quartzite, then a wide band of greenish slate, which is the northern extension of that near Bowmans Corner and then around Westford village quartzitic schist which was followed over the high land southwest of Westford village along the road to Essex Center by the Beecher School. At the east the quartzitic schist frequently carries segregated quartz and as a mass strongly resembles similar rocks found in the Sudbury Hills.

The limestone conglomerate formation in Milton. The extensive sand plains in Milton probably conceal some of this formation. South of the hamlet of West Georgia, but south of the Georgia line, are a few scattered ledges of rock, some of which bear such close resemblance to thinly-bedded limestone members of the conglomerate formation in Highgate and St. Albans that there is little doubt as to their correlation with each other. The exposures are few and were the only ones seen in Milton except some fragmentary rocks found seven miles to the southeast, near School No. 3, about a mile north of the Colchester line. At the latter place, east of Malletts Creek and the railroad track, are a few ledges of limestone, some of which resemble those found to the north. No conglomerate was seen.

Colchester Township.

(Plattsburg, Milton and Burlington topographic sheets.)

Location. This township is bounded on the north by Milton, on the east by Essex, and on the south by Burlington and South Burlington.

The rocks along and near the lake shore in Colchester. In Colchester township along what is now the border of the lake, pre-glacial erosive processes had breached the massive dolomites of the Red Sandrock series, producing a considerable basin which is now flooded by the lake waters and is known as Malletts Bay.

North of Malletts Bay, between it and the Lamoille River, various knolls and ridges give extensive outcrops of the members of the Sandrock series which have been traced from St. Albans along the margin of the lake. The erosion margin of these rocks may be followed south from the Lamoille, east of Camp Winnisquam, to Red Rock Point, where the formation dips into the lake. North of Red Rock Point the slates show in cliffs and low outcrops along shore and at Clay Point form a pinnacle capped by Champlain clays. About 200 rods north of Red Rock Point, massive dolomite may be seen in contact with the slates.

Around the bays and headlands of the serrated north shore of the Bay and nearly to its eastern limit are perpendicular or rugged cliffs of gray or mottled dolomite much like that at Red Rock Point. Similar rock outcrops along the road from Camp Winnisquam to the Colchester-Grand Isle road. The dip is easterly.

In a minor indentation at the northeastern portion of the bay is a beach of sand at the edge of a swamp that marks the southern end of a small valley. In the western wall of this valley the rocks are massive but apparently in somewhat thinner beds than those farther west and display the reddish and pinkish colors characteristic of the Sandrock series farther north. On the east side of the valley the rocks are prevailingly quartzitic and in thinner beds, which weather white, gray and rusty brown. Fossils were sought in the rusty layers, but without success. In some of these rocks around Malletts Bay the late Mr. Griffin of the Survey had found *Olenellus* and other fossils, but unfortunately, his localities have not all been described in print. A low scarp which bounds these quartzite beds on the west continues southward along the eastern edge of the swampy land and along the eastern shore of the lake north of the mouth of Allens Brook. Along this scarp may be seen lateral variations in the colors and thicknesses of the beds. The quartzite continues south of Allens Brook to the sandy beach that borders the bay on the southeast and south.

West of the sandy beach on the southern side of the bay a peninsula known as Coates Island juts into the bay. West of the "Island" and separated from it by a small bay is a peninsula known as Malletts Head which projects northward to within about one-half mile of Red Rock Point and somewhat to the west of it. The head forms a remnant of an old erosion margin of the Red Sandrock which was breached to form the bay. On the western shore of the Head the Ordovician slates underlie the dolomite which forms the surface rock of most of the peninsula. The relations at the head are entirely similar to those north of Red Rock Point, and there is little doubt that slate lies beneath the portion of the lake forming the inlet to the bay; but whether slate underlies any considerable part of the bay as the hard rock surface may only be conjectured.

The Red Sandrock lying on the slate on the western side of Malletts Head is two-thirds of a mile west of that at Red Rock Point, and unless there is a fault between, this fact points to a former more westerly extension of the dolomites farther north, confirming in a measure the suspicion that the margin of the Sandrock at least for some of its course north of Malletts Bay is a recession border.

The rocks of Colchester peninsula, west of the meridian of Malletts Head, to the north of the Winooski River, were not inspected by the writer. The map of the Vermont Report shows most of the peninsula as underlain by "Utica" or "Hudson River" slates and, therefore, as not having any of the Sandrock on it much to the west of the meridian of Malletts Head.

The Sandrock of Malletts Head and Coates Island is separated from other exposures of this formation lying south of them by a sand plain, the extension of which eastward and southward forms a wide, sandy, partly swampy tract stretching from the sandy beach that makes the southern border of Malletts Bay to the Winooski River. Along the eastern border of this tract, around the Colchester Town Farm, are outcrops of the Sandrock formation which are the southward continuation of the beds forming the east shore of Malletts Bay.

The altogether remarkable vertical variations shown by the quartzite-dolomite series known in this region collectively as the Red Sandrock has been described by Professor Perkins from his own detailed studies and those of his assistant, the late Dan Griffin.[1] Differences in composition, thickness and color appear in irregular but frequent succession between and within the different beds along different sections through the formation. Lateral variations with respect to composition and color may also be seen when the beds of this formation are followed along their strike. Impure sands, fairly pure sands and sandy muds seem to have been contemporaneous with each other and often at places not very far removed from one another during the deposition of these rocks. Many of the beds give clear evidence of shallow water accumulations, probably on a slowly-subsiding sea-bottom and one which underwent intermittent oscillation of level. Reddish shades of color, probably due to oxidation under atmospheric exposure, frequent cross bedding, and many markings that seemingly could have been produced only in relatively shallow waters, or on exposed flats, all bear testimony to the nature of the conditions under which these rocks were laid down.

There seems to be good reason for thinking that large areas of this Red Sandrock formation once formed a surface of erosion and unconformity on which other strata were deposited; but it is extremely doubtful if any considerable portion of such surface is anywhere now preserved over the region where this formation makes the outcropping rock. With the facts in mind that the color variations which are assumed to be due to some degree of oxidation of the material of the rock are repeated throughout considerable vertical distances in this Red Sandrock series and that lateral variations occur within continuous beds; that large exposures of this formation at the present surface hold to a fairly uniformly gray color which is presumably a primary feature; and that thrusting has doubtless tended at least to produce an imbricating rather than a conformable series in the formation, as a whole it is difficult to attribute the red color, where this may be shown to be an ancient character of the rock, as due to atmospheric changes following the elevation and erosion of the rocks subsequent to their deposition as a series. The possible explanation of the "brecciation" shown by the mottled members of this formation as a primary feature has been discussed above. All the noteworthy features of the Red Sandrock series are well shown in the vicinity of Malletts Bay.

[1] Sixth Rept. of the State Geol., pp. 227 et seq.

The age of this primarily conformable series has definitely been made out by the discovery of *Olenellus* and *Ptychoparia adamsi* in some of the beds near the bay.[1]

East of the lake in Colchester. East of the lake much of present surface is formed of sand. Gray dolomite or rusty, flaggy quartzite outcrop here and there along meridians in the central part of the township and dolomite and schistose quartzite which appear to be interbedded give numerous outcrops along the east road from Colchester village to Milton. The schistose quartzite grades laterally into more massive quartzite. The prevailing dip is easterly; a westerly dip was not noted.

Two miles east of the Town Farm, ledges of gray siliceous dolomite carry bunches of segregated quartz and some lace-like tracings of silica on the weathered surface. These features give the rock an appearance somewhat like that shown by some of the rocks in Highgate just south of the Canada line, which probably belong to a Beekmantown horizon; but such features are clearly altogether too indefinite for purposes of correlation and while the markings referred to were not noted in the rocks near the lake, they may well be present there and in any event might readily have been produced by agents of hydrothermal metamorphism in such siliceous rocks. There seems no good reason for regarding these particular rocks as other than Lower Cambrian.

A mile east of the Town Farm a quarry opened for road metal shows beds of gray dolomite dipping very gently to the east. Uniformity of color gives at first sight a somewhat massive appearance, but close inspection shows beds of moderate but variable thickness. Sections of the bedding planes, as seen in the face of the quarry which was opened along the strike, usually show as ammonoid-suture-like lines, often of brownish (limonitic) color. The bedding surface shows that these lines are traces of partings between irregular pittings or hollows on the surface of one bed into which project small cones from the under surface of the overlying bed. Separation of the layers may sometimes be complete along the pitted surface of the beds, but again will be accompanied by horizontal fracture across the little cones when there will appear small gray patches surrounded by irregular brown lines. The irregular surfaces seemed to indicate shallow rather than deep water deposits. These rocks are a half mile

[1] Sixth Report, p. 229.

or so east of the Red Sandrock ledges near the Town Farm. They are probably part of the same formation.

In the western part of Colchester village are low ledges of gray dolomite. These rocks are on the meridian of those in the quarry mentioned above. On the same meridian farther north, south and east of Munson Flat, are excellent exposures of rusty, flaggy quartzite which carries obscure fossil markings, but which yielded nothing definite.

The rocks of Colchester, so far as seen by the writer, seem to belong to a common formation and to be of Lower Cambrian age. No rocks were noted in this township which could be correlated with the limestone conglomerate, or with other rocks which have been noted in northern townships that seemingly were not so easily placed in the Lower Cambrian formation; but the apparent or actual absence of such rocks may be a circumstance due to covering, or erosion, or to the particular nature of the secondary structures of the rocks of this area.

Essex Township.

(Milton and Burlington topographic sheets.)

Location. This township adjoins Colchester on the east. It is bounded on the north by Westford, on the east by Jericho, and on the south by Williston and part of South Burlington.

General description. The rocks of Essex are the eastward continuation of those of Colchester and the southward continuation of those in Milton and Westford.

In western Essex, north of Essex Junction and east of the road from the Junction to Colchester village, quartzite and dolomite, apparently interbedded, form the western slope of hilly land over which ascends the road from School No. 2 to Butlers Corners. The rocks dip easterly and are entirely similar to the rocks of eastern Colchester. The quartzite is often somewhat mashed and veined with quartz. These rocks are succeeded along the road to Butlers Corners by greenish slate or phyllite. Slate was traced to a half mile east of Essex Center.

In the eastern part of the township the rock is prevailingly a quartzitic schist, carrying segregated quartz, and is the continuation of similar rock south of Westford village. On account of shearing, the primary structural features of the rocks in the eastern part of the township are obscure.

Black quartzitic schist outcrops in Essex Junction.

At the bridge across the Winooski, beneath the dam above and below the bridge, is gray siliceous limestone or dolomite, often much crushed and strongly crystalline. It holds to a rather uniform color and character throughout the considerable mass exposed. At one place at its western edge, below the bridge, the jammed limestone can be seen resting on crumpled blackish slate

on which it has apparently been thrust. The ages of these rocks are problematical. The limestone has been tentatively called Beekmantown. It is part of the band called the Eolian Limestone in the Vermont Report. The descriptions of the members of this band have not differentiated among the different kinds of rock found in it. As will appear in later discussions there is much variation and probably rocks of very different ages are associated. The structural relations are everywhere very obscure.

Burlington Township.

(Plattsburg, Milton and Burlington topographic sheets.)

Location. Burlington lies just south of Colchester. The lake forms its western boundary and it is bordered on the east and south by South Burlington.

The lake shore and vicinity. The northwestern part of the township forms a part of what may be called the Colchester-Burlington peninsula. In this part the land is low like that of the adjoining part of Colchester, from which it is separated by the Winooski River. East of this lowland is higher land marking the southward extension of the Red Sandrock of Colchester. Northwest of Burlington, at a promontory variously known as Sharp Shins, Split Rock Point, Lone Rock Point, or simply as Rock Point, the Sandrock reaches the shore. At this place it is often a yellowish magnesian sandstone, as weathered. On the south side of the point it rises abruptly from the water, but northward on the west it rests by thrust on crumpled Ordovician slates. This locality gives the finest thrust contact of the Red Sandrock on the slates anywhere to be seen and has been frequently fully described. The slickensided under surface of the Cambrian rock is most impressive.

From Rock Point southward, west and southwest of Burlington, a low sandy beach extends for a distance of over three miles, nearly to the blunt promontory marked at its southwestern extremity by Redrock Point. This point should not be confused with the one bearing the name Red Rock Point at Malletts Bay.

From outcrops near Lakeside Park to Queen City Park, the rock along the water edge is the variegated Sandrock, but in general is distinguished by red or reddish colors. Northward the ledges are low and permit one to walk close to the water, but near and at Redrock Point are bold, precipitous cliffs. Ripple marks and mud crack patterns are frequent in these rocks as at other places near Burlington. The beds dip to the east. These red rocks may be traced at the surface eastward through Redrocks Park. No massive gray dolomite was noted in association with them.

The rocks at Redrock Point undoubtedly extend eastward beneath the surface deposits to join with those at Willard's Ledge, now commonly known as Phelps' quarry, a locality in the southern outskirts of Burlington, to the east of the main road from Burlington to Shelburne. In the quarry one has fine opportunity to observe the variations in thickness and shades of color from bed to bed and to see various forms of markings due to their shallow water origin. The series is cut by dikes of igneous rock.

About a mile to the east-northeast of Phelps' quarry, along the road from Shelburne Falls to Burlington, are low ledges of gray sandy dolomite, dipping gently to the east, which presumably lie stratigraphically above the beds of the quarry. This sandy dolomite is on the meridian of gray dolomite lying on the red beds at Winooski lower falls, which will presently be mentioned.

Within the city of Burlington, outcrops of the Sandrock are few, but drilled wells in the western part of the city are described as penetrating this formation and there is no doubt that the city is underlain by it.

Gorge of the Winooski. The Winooski, like the Lamoille, has cut post-glacial gorges along its course and the rocks so exposed, with some that occur in Winooski village and to the east of it, may be conveniently described at this point.

At the falls in Winooski village are red beds much like those on the east shore of Malletts Bay and south of Burlington. Above these red beds in midstream and in the south wall of the gorge, below the bridge, is more or less massive-looking but obviously bedded, grayish dolomite. The reddish beds below the gray rock are prevailingly thin, of various shades of red color, often brick-red, and carry here and there ripple marks, mud cracks and some cross-bedding. The beds thin out and thicken laterally and have all the marks of shallow water deposits.

Gray dolomite outcrops in Winooski village in the railroad cuts, on the line of strike of the similar rock in the river bank below the bridge. On the south side of the river, in Burlington, east of the Greenmount Cemetery and west of Grove Street, are typical variegated beds of this formation dipping gently easterly.

It will thus be seen that along and near the lake in Burlington the Red Sandrock shows the same general characters and dip that it has farther north along the lake shore.

About a mile east of Winooski village the river has cut a winding gorge. At the hydroelectric power plant the wall of the gorge is made of gray siliceous rock which eastward appears to pass beneath other rock that is more calcareous and which in fact at the lime-kilns is a marbly limestone which is quarried for lime. No sharp line of separation was found between the two kinds of rock. In the old and new quarries at the lime-kilns the rock is strongly crystalline, remarkably uniform in appearance and without distinct bedding. A similar lack of bedding appears in the massive, weathered rock as it outcrops near the quarry in the wall of the gorge just below the bridge. West of the new

quarry, south of the river, surface exposures in the fields show bluish-gray, marbly limestone puddled with yellowish-gray rock. The latter as eroded most often appears as patches and streaks on the marbly rock. The white-weathering, marbly rock occurs north of the river and the railroad track, to the west of the highway bridge, and passes westward at the surface into gray, siliceous rock.

No fossils were obtained from any of these rocks and their structural relations are problems not yet solved. In notable particulars the limestone in the quarries and adjacent fields has very strong resemblance to the similar rocks east of Highgate Springs and south of Swanton village.

Professor Perkins has told the writer that fossils were found by Griffin in Colchester, north of the lime-kilns, which seem to be of Beekmantown age (*Rhaphistoma canadense* Bill. and *Cryptozoon wingi* Seely).

East of the lime-kilns the Winooski winds through a sand plain to the falls at the bridge south of Essex Junction.

South Burlington.

(Burlington topographic sheet.)

Location. This township bounds Burlington on the east and south. For a mile and a half south of Redrock Point the shore of Shelburne Bay forms its western boundary. Williston lies to the east and Shelburne to the south.

General description. The red beds of the Sandrock formation pass beneath the surface covering near Queen City Park, and the shore southward to the southern boundary of the township shows no outcrops. East of the shore, sand is plentiful; the eastward extension of the red beds in South Burlington may only be conjectured. Sand plains extend to the northwestern part of the township, to the bank of the Winooski River.

About two and a half miles southeast of Burlington a road from the Williston turnpike crosses Potash Brook. At this place is white, marbly rock like that at the lime-kilns two miles to the north.

Southeast of these outcrops and again southward along the road from Williston turnpike to Hinesburg and between the road and Muddy Brook are numerous ledges of limestone. Some of these are composed of thinly-bedded, bluish rock, of which the bedded characters are somewhat better shown in outcrops a little to the east in Williston, and other ledges are more massive looking rocks of somewhat striped appearance as though thin layers had been welded by shearing into more compact and thicker beds. This massive, striped rock is particularly well shown at the schoolhouse about two and a half miles south of the Williston turnpike. The rocks were searched for fossils without success. They lie on meridians a little east of those occupied by the marbly limestone and its associates at the lime-kilns east of Winooski. There is some resemblance between certain members of the limestones near the Winooski gorge and those in the southeastern part of South Burlington. The rocks at these two places are much more readily correlated with each other than either are with the gray, sandy dolomite (siliceous limestone) found in association with the red beds of the Sandrock formation at the west and that with which they or similar rocks are rather intimately intermingled a little farther south in St. George and Hinesburg.

In Hinesburg and Charlotte and townships south of them, marbly limestone is often in intimate field association with rocks of very different character and which may be correlated without much hesitation with the Lower Cambrian; but these latter rocks are quite similar in all essential features to rocks which more distantly surround the white, marbly or bluish limestones of South Burlington and Williston. In other words, there is a rather close correspondence between various rocks in South Burlington and Williston and others in the townships to the south of them; but the field intimacy among these rocks that are apparently of very different age is much more pronounced in some areas than in others.

Williston Township.

(Burlington topographic sheet.)

Location. Williston lies east of South Burlington. It is bounded on the north by Essex, on the east by Jericho and Richmond and on the south by St. George and a part of Hinesburg.

General description. In Williston, along and west of the road running south from Essex Junction to Hinesburg, about one and one-fourth miles from the outcrops in the river at the bridge south of Essex Junction, Allen Brook cuts through gray, siliceous limestone or dolomite much like that at the bridge.

The Hinesburg road crosses the Williston turnpike. One-third of a mile south of the turnpike, east of the road to Hinesburg, black, gray-weathering slate, with easterly dipping cleavage, is associated with mashed limestone or dolomite, bluish-gray on fresh surfaces, but weathering gray, which is very close to the slate. Contact is concealed. The limestone showed no discernible dip. The relations are very similar to those below the bridge south of Essex Junction, described above.

About a mile east of these outcrops, just south of the Williston turnpike, conspicuous knolls give a surface succession from west to east of siliceous dolomite, fissile, blackish and lighter colored phyllites, and quartzite. Gray dolomite outcrops a mile to the northeast, north of Allen Brook; but eastward the prevailing rock is quartzitic schist, often carrying segregated quartz.

South of Williston turnpike, east of the road running from Essex Junction to Hinesburg, except for the outcrops mentioned above, the prevailing rock is the quartzitic schist, which forms rolling, hilly land extending eastward into Richmond and southward into St. George and Hinesburg. This schist gives place at the surface westward, north of Brownell Mt. and Sucker Brook, to bluish limestone with which the schist is intermingled at places in no regular way. The arrangement gives the impression that the limestone lies on the schist. Westward toward Muddy Brook the limestone thickens and becomes more massive looking, as described above for the eastern part of South Burlington, and outcrops of schist are lacking.

At the foot of the steep western slope of Brownell Mt., near the road skirting the mountain on the west, is crushed bluish-black slate with cleavage dipping easterly and at some places clearly brecciated. The schist making up the mass of Brownell Mt. has apparently ridden by thrust over the slate. Westward the slate is succeeded by striped, bluish limestone like that described above.

Although no conglomerate was noted in the limestones south of the Winooski there is much resemblance between the striped, bluish members of them and similar rocks found farther north in the conglomerate formation. There is, moreover, a close correspondence in the associations with other rocks and in structural relations. At the north the rocks as has been shown are often no more conglomeratic than are the limestones of South Burlington and Williston.

Shelburne and St. George Townships.

(Willsboro and Burlington topographic sheets.)

Location. Shelburne lies south of South Burlington and borders the lake. The northeastern part of the township adjoins the southwestern part of Williston. St. George on the east is like a small strip cut off from the eastern end of Shelburne. On the south are Charlotte and Hinesburg. A long tongue of land belonging to Shelburne extends northward into the lake and separates the main body of Lake Champlain from Shelburne Bay.

General description. Most of the peninsula just mentioned is formed of the shale formation which extends from Shelburne Point southward on both shores, on the east nearly to the southern limit of the bay and on the west to join the shale of the mainland along which it continues with some interruptions along shore to the southern boundary of the township. Outcrops are frequent on the peninsula between its shores, but southward away from the lake the shales are mostly covered and are succeeded eastward by the red and gray rocks of the Sandrock series.

On Shelburne peninsula the shales, or slates, carry the firmer, rusty-weathering bands so characteristic of this formation all along the lake shore north of Burlington and in general lithological features are like the members of the formation on the islands and the mainland in the northern part of the lake region.

It seems probable that the lake bottom in Burlington and Shelburne Bays is underlain by the slates, in which these indentations of the shore have been excavated, probably in some cases after a covering of overthrust rock belonging to older limestones or to the Sandrock series had been eroded. The general field relations all about suggest such a history and further give some support to the view that in Shelburne and other places where these friable mud rocks have been preserved they owe their preservation to a covering of more resistant rock that was removed at a relatively recent date. Juniper and White Islands are insular outcrops of the shale to the west of the peninsula.

The slates on Shelburne peninsula are cut by numerous dikes which have been described by Kemp.[1]

The Sandrock forms headlands on the southwest shore of Shelburne Bay and gives numerous outcrops between the bay and the village of Shelburne. The red beds are conspicuous along the Shelburne-Burlington road just north of the LaPlatte River and these and other members outcrop west and southwest of Shelburne village. The dip is at a low angle to the east.

East of Shelburne Falls, to Shelburne Pond, the rocks are gray, siliceous dolomites not distinguishable from the similar beds around Shelburne village. The rocks just east of Shelburne Falls are on the meridian of those in the eastern part of Burlington.

East of Shelburne Pond, between it and the main road from Burlington to Hinesburg, the prevailing rocks are marbly or bluish limestones, forming the southward continuation of those in the southwestern part of Williston and the southeastern part of South Burlington. Near the Hinesburg road these limestones give place to gray, siliceous dolomite which continues over the western boundary of St. George township. East of the dolomite in St. George the hilly land is made of quartzitic schist which joins that of Williston and Hinesburg.

A generalized surface section from west to east across the areas south of the Winooski River, which have so far been described, gives the Ordovician shale formation at the west, then the Red Sandrock series of red and gray quartzites and dolomites, then a very different kind of rock that is a metamorphosed limestone, and finally quartzitic schist with some gray dolomite on the same meridians with the schist both of which belong to the same general formation. The types of rock and the sequence are the same as in the townships north of the Winooski. The varia-

[1] Bull. U. S. G. S., No. 107, 1893.

tions are perhaps less significant than the similarities, from a structural viewpoint.

Charlotte Township.

(Willsboro and Burlington topographic sheets.)

Location. Charlotte lies south of Shelburne and borders the lake. It is bordered by Monkton on the east and by Monkton and Ferrisburg on the south.

The rocks along and near the lake in Charlotte. From the Shelburne line to the latitude of Wing's Point the lowland along the lake is made of clay, with few outcrops of the shales along shore.

On the road running from Charlotte village westward to the lake shore and McNeil's ferry, about a mile east of the shore, Black River limestone, carrying the markings so familiar in this formation in the lake region, dips westerly at a low angle and is underlain apparently by Upper Chazy with similar westerly dip. Nearer the lake are Trenton beds, also dipping westerly at a low angle or lying nearly flat. At the water edge just south of the ferry the dark blue Trenton rocks are full of well-preserved and characteristic basal Trenton fossils. After a surface interruption along the shore of the bay south of the ferry the Trenton beds appear on the north shore of Cedar Beach promontory and continue around its border to McNeil Bay. At Cedar Beach promontory the dip changes to southeast or east. These Trenton rocks are nowhere severely altered. They are in fact like the Trenton rocks of Grand Isle and Isle La Motte. In respect to certain features of alteration they differ from the Chazy just as do the beds on the islands mentioned.

On the west shore of a small promontory that juts into McNeil Bay are beds that were correlated with part of Brainerd and Seely's Beekmantown. A third of a mile farther east are magnesian rocks of doubtful correlation, but probably also Beekmantown. These are followed eastward by ledges of Chazy limestone, dipping easterly, and carrying *Girvanella ocellata* Seely. There seems to be exposed a small patch of Black River to the east of these Chazy rocks.

The road on Thompson's Point crosses diagonally a series of beds that appear to belong to the Beekmantown by comparison with the Shoreham section. The beds dip at a low angle to the southeast.

On the southeast shore of the bay, south of Thompson's Point near the Ferrisburg line, are Chazy beds dipping to the southeast.

The various massive beds described as probably Beekmantown or recognizable as Chazy, are not folded, but as shown by changes in strike from place to place and by visible geographic offsets are twisted, and broken across the strike and probably along it. On the whole the rocks do not show pronounced indications of internal deformation. There is nothing to show their relations to the slates that probably lie north of them under the clay-covered lowland. The writer's field map indicates that shale lies on a meridian to the east of these massive, basal Ordovician rocks; outcrops were noted a mile north of Charlotte station and also a few rods west of Ferrisburg station in the adjoining town of Ferrisburg. These various rocks in southwestern Charlotte belong to the lake region proper, as defined in the early part of this paper. The probable relations among them may be judged from those shown by other rocks in townships farther south.

East of the Rutland railroad track in Charlotte. South of Charlotte station is a considerable mass of igneous rock forming Barber Hill. The rock has been described as Bostonite (a soda-rich, acid, dike-forming rock). Similar rock forms dikes on Shelburne Point and in North Ferrisburg village.

East of the railroad track in Charlotte township by far the largest part of the visible rock emerging through the drift belongs to the Sandrock series. East of Charlotte village the reddish members of this formation form Pease Mt. Along the road that runs southward, east of Pease Mt., similar rocks dip easterly and join with the red beds of Mt. Philo. The rocks of these two mountains are on meridians which are occupied farther north by the Sandrock formation in Shelburne, but which to the south in Ferrisburg are occupied by comparatively unaltered shales, thinly-bedded, dark blue, basal Trenton limestone and Chazy rocks which belong to the lake series and are in fact the eastward extension of the rocks along the lake in Ferrisburg.

East of Pease Mt., around East Charlotte, exposed at several places along or near the road running in a north-south direction through the village, are outcrops of beds of siliceous dolomite, dipping easterly at a low angle. On this road, about a mile and a fourth north of the village, is marbly limestone; but a mile farther north the gray dolomite outcrops again and continues towards Shelburne Falls.

Around Prindle Corners, two miles southeast of East Charlotte, interbedded quartzite and dolomite show a series much like that found around Middlebury and Brandon to the south. The rocks in southeastern Charlotte and adjacent portions of Hinesburg indeed mark a transition in the Lower Cambrian formation from the generally more massive, interbedded, siliceous and magnesian rocks of the Sandrock series in the northern townships and the recognizably thinner beds of what has been called by the writer in earlier papers the "interbedded series" of the Lower Cambrian in the Vermont valley.

As a consequence of their more thinly-bedded character, the rocks around Prindle Corners and neighboring parts of Hinesburg are frequently jammed into close folds so that the beds stand at high angle of dip or even on end.

Northeast of Prindle Corners along the road and in the fields the Cambrian quartzites and dolomites are intermingled with marbly rock, but the field relations as usual give no definite clues as to the structural relations.

Hinesburg Township.

(Burlington topographic sheet.)

Location. Hinesburg lies east of Charlotte.

General description. In the southwestern part of Hinesburg are interbedded quartzites and dolomites which join with those around Prindle Corners in southeastern Charlotte. The beds are usually sharply folded with high easterly or westerly dips, but along the meridians of such closely folded rocks, at other places the folding was not always so severe. The interbedded rocks east of Prindle Corners continue southward into Monkton and northward in western Hinesburg, but in northwestern Hinesburg are considerable exposures of marbly limestone, which, so far as the hard rock is now visible, seem more or less definitely to be surrounded by gray, siliceous dolomites.

West of Mechanicsville, along and west and east of the Hinesburg road, the gray dolomite is abundant and forms a conspicuous ledge known as High Rock on the east side of the road. Massive, gray dolomite occurs between Mechanicsville and Hinesburg and in numerous massive and prominent ledges southeast of Hinesburg on the east side of the road to Starksboro, continuing southward nearly to the township boundary. The extension of the dolomite east of the main road is irregular, being most marked in hollows around Mechanicsville and Hinesburg. East of the main road the land is mostly hilly and made of quartzitic schist. Dolomite and schist at different places occupy the same meridians and the field relations show that the two rocks are members of a common formation and that the preservation of the dolomite along the western margin of the hilly land is due to certain favorable structural relations resulting from the deformation of the rocks.

It will thus be seen that from the lake shore eastward through Charlotte and Hinesburg a broad surface section gives near the lake the shales and comparatively unaltered limestones of clearly recognizable Lower and Middle Ordovician ages, then an abrupt transition to the Red Sandrock of Pease Mt. and Mt. Philo which are succeeded eastward by gray dolomites and interbedded dolomites and quartzites more or less intimately intermingled in their present surface outcrops with marbly limestone, and finally the massive, gray dolomite and quartzitic schist of the hilly land at the east. A field inspection is essential in order to appreciate fully the similarity which such a section has in rock types, sequence and general field relations with the sections in northern townships which have been described, and its correspondence in all essential particulars with areas farther south. These resemblances are clearly due to what may be called strict homology, to borrow a biological term, in the secondary structural features and in certain primary relations which obtained among the various rocks, although all of the rocks may not be of precisely similar age.

The Lower Cambrian formation is seen to show from west to east and from north to south many variations of thickness, color and sequence in the vertical arrangement of its beds, corresponding with lateral variations in the original character of the material and variations in the conditions under which the material was deposited from time to time. North of Weybridge the more purely terrigenous rocks of this formation are found in the hilly land by which the Champlain lowland is joined to the mountains farther east, but such rocks also form the present surface rock over portions of the eastern edge of the lowland. South of Weybridge the terrigenous rocks are extensively preserved in the Taconic hills.

ADDISON COUNTY.

Ferrisburg and Vergennes.

(Willsboro, Burlington, Port Henry and Middlebury topographic sheets.)

Location. The township of Ferrisburg and the city of Vergennes are conveniently discussed together. Ferrisburg is on the lake shore south of Charlotte. On the east it adjoins Monkton and part of New Haven and on the south is bounded by part of New Haven, Waltham, Vergennes and Panton. Vergennes forms an area two miles square which is bounded by Ferrisburg on the north, by Ferrisburg and Waltham on the east, by Waltham and Panton on the south and by Panton and Ferrisburg on the west.

General description. Ferrisburg is a large township and includes a variety of rocks, all of which may be correlated with others which have been described in previous pages, but some of which show field relations of great interest in relation to the general structure of the region. Description will begin with the western and central portions.

Around Camp Meeting Point, north of the mouth of Lewis Creek, fossiliferous Chazy limestone forms a low, anticlinal fold. Between the point and the railroad track are low outcrops of shales which are undoubtedly younger than the rock at the point.

Near Bluff Point, west of the Little Otter, much of the rock is apparently of Chazy age. Specimens of *Maclurea magna* were found near the road from Kingsland Bay to Ferrisburg, at the bend in the road about two-thirds of a mile east of the bay. The beds dip gently eastward. East of this place outcrops are largely concealed along the sluggish creek.

Limestone outcrops at intervals along the road that runs south from Kingsland Bay. Just south of the junction of this road with the one that runs from it to Fort Cassin Point are extensive outcrops of probably Chazy limestone, dipping easterly; but about one-fourth of a mile from the main road along the one to Fort Cassin Point, graptolitic shales were noted. At Fort Cassin Point, which is probably really an island surrounded partly by water and partly by the delta and levee deposits of Otter Creek, are limestones which were assigned by Brainerd and Seely to division D of their Beekmantown formation. Bedding is distinct and the layers have a flattish position. The rocks are more or less indurated but fossiliferous. Although great numbers of different species have been found at this locality, particularly in the weathered rock, fossils are now found only after diligent search in the firm, unweathered rock. Seely states that the Fort Cassin rocks were assigned to division D by Brainerd after careful stratigraphic study of the region. The fauna of these rocks is in need of further careful study in order to be sure of its exact horizon. The apparent separation at the surface by shales of the rocks at Fort Cassin from the Chazy beds mentioned as occurring along the road to Kingsland Bay suggests that the succession east from the lake is probably not a conformable one, but rather that breaks, probably of the nature of thrusts, intervene.

East of the probable Chazy rocks on the Kingsland Bay road the surface is all clay. The hard rock underlying the clay is probably all shale.

West of Otter Creek and south of Kellogg Bay, are outcrops of fossiliferous Chazy which lie on a meridian slightly to the west of the Fort Cassin beds a mile to the north. With some interruptions the Chazy beds, dipping everywhere to the east, form the shore and slopes adjacent to it from Summer Point at Kellogg Bay southward past Basin Harbor to Button Bay. At many places, notably at Basin Harbor and between it and Button Bay, the beds afforded excellent specimens of *M. magna* and *Girvanella*. Near Kellogg Bay perhaps not all the rock belongs to the Middle Chazy; at Summer Point the beds may belong to a lower division of this formation or to Upper Beekmantown.

Eastward again between the outcrops along shore and Otter and Dead Creeks, presumably the underlying rock is shale, which is found in scanty, low outcrops along the road from Basin Harbor to Panton; but sand plains along the Otter and elsewhere clay conceal the rock to within a mile and a half of the city of Vergennes.

The Chazy rocks that form the point which projects towards Button Island, near Button Bay, pass eastward beneath clay which forms most of the shore of Button Bay. Along the shore south of the bay the shales outcrop for a distance of about two-thirds of a mile north of the Panton line. Fossils collected from these shales and those along the Panton shore southward by Gould and Ruedemann were assigned by Ruedemann to three different horizons in the Canajoharie shale of Trenton age.

About one and a half miles west of Vergennes, north of the Otter and between it and the road running from Vergennes to Fort Cassin and Kingsland Bay is a hill of badly crushed, magnesian limestone, without fossils or distinct structure. A mile to the east, north of the road, and just west of the playgrounds of the Industrial School are excellent outcrops of massive Chazy beds, dipping gently to the east and carrying numerous coils and opercula of *M. magna* and abundant specimens of *Girvanella*. East of the playgrounds and north of the city, similar beds with similar fossils dip to the west at an angle of 34° and strike N. 40° E. East of these outcrops, west of the railroad track, is a road running north to Ferrisburg. East of this road, respectively a half mile and a mile north of the westerly-dipping Chazy beds just mentioned, are other Chazy beds dipping easterly. The structure thus shown by the Chazy northwest and north of Vergennes shows the formation to be disposed in gentle anticlinal and synclinal swells. More altered rocks of probably Chazy age at Marsh Hill and south of it, to the northeast of the city, form a gentle, anticlinal fold.

At Vergennes falls the river tumbles over massive, grayish, magnesian limestone which apparently dips easterly. Close inspection shows it to be crushed and brecciated, but now healed into a compact rock. Seely called this rock Beekmantown.

Below the falls, near the boat landing on the Industrial School grounds, shales carrying numerous graptolites, identified as *G. quadrimucronatus*, outcrop in the low bank of the stream. Between the falls and the westerly-dipping Chazy beds north of the city, described above, shales or argillaceous limestones, usually much sheared and slickensided and filled with small veins of calcite, outcrop along the road, apparently exposed from beneath a mass of overthrust Chazy.

About two miles northeast of Vergennes, west and east of the main road from Vergennes to Ferrisburg, east of the railroad track, are Trenton beds somewhat sheared, but carrying hosts of recognizable basal, Trenton fossils, including *Calymene senaria, Cryptolithus tesselatus*, linguloid forms and bryozoa. These rocks are particularly well exposed on the land of Carl Fields. The Trenton rocks form a ridge between the main road and the one running from it to the west of Shellhouse Mt.

A half mile northeast of this ridge of fossiliferous Trenton, southeast and east of Ferrisburg village, are outcrops of Chazy limestone which are on meridians on which lie the rocks at Marsh Hill and south of it, as mentioned above. Rocks of apparently Chazy age continue northward, east and west of the road on the west of Shellhouse Mt. North of the mountain the road ascends over blue, Trenton rocks, which as outcropping in the road gave Trenton fossils, including *C. tesselatus*. Towards Mt. Fuller these Trenton beds are associated with more massive, dense limestones, weathering a light gray, now shattered and filled with calcite veins and which strongly suggest the Black River, and are in fact much like recognizable Black River rocks found farther south in Waltham and Addison townships. Sheared limestone, probably of Trenton age, continues northward along the cross road west of Mt. Fuller nearly to the North Ferrisburg-Monkton road. At one place along this cross road, sheared limestone is in contact with quartzite and probably overlain by it. One-third of a mile to the east is a scarp in the quartzite that makes Mt. Fuller.

At North Ferrisburg village, Lewis Creek has cut down into crumpled, black shales or shaly limestones which are exposed in the bed and banks of the stream at many points in the village and west of it towards the lake. Northward on the meridians of these shales in the creek is the Red Sandrock of Mt. Philo. These shales have been called "Utica"; they are without much doubt younger than the rocks that form the hilly land south and southeast of them.

The rocks that apparently belong to the Chazy formation and form the surface just west of Shellhouse Mt. give place in the steep western face of the mountain to white quartzite which is notably jammed. The quartzite extends eastward, giving place near the township boundary to interbedded dolomites and quartzites, all, including the quartzite at Shellhouse Mt., dipping easterly at a low angle. The interbedded rocks form a band along the eastern edge of the township and southward join with similar rocks in New Haven. South of Shellhouse Mt. the Cambrian rocks pass under drift and between the band of interbedded rocks at the east and the limestone of Marsh Hill and neighboring exposures is an area of low, flat land, with no outcrops; but directly north of the mountain, as has been shown, are limestones and shales of the lake series which occupy the meridians of the quartzite of the mountain and the interbedded, Lower Cambrian rocks that lie east of it.

The Trenton and Black River limestones southeast of North Ferrisburg village and the shales in Lewis Creek are visibly sheared or shattered rocks and somewhat metamorphosed, but are readily recognized and traced as the eastward extension of the rocks near the lake. They are notably less crystalline and marbly than the calcareous rocks found among the Lower Cambrian rocks on meridians farther east. The occurrence of the Lower Cambrian rocks north and south of North Ferrisburg village on the same meridians with the little altered lake rocks near the village and the extension of the present margin of the former at Pease Mt. in Charlotte to a meridian over a mile west of that passing through North Ferrisburg village, point to thrusts by which the older rocks rode over the younger. It is also probable that the massive limestones of the lake series rode over younger shales, either by independent thrusts or during the translation of the Cambrian beds.

The field relations near Vergennes certainly suggest that the older limestones of the lake series have ridden over the younger limestones and shales. The latter are sometimes sheared and crushed. At Vergennes falls the dolomite is brecciated; but the Chazy beds northwest, north and northeast of the city are not folded much. They are most sheared and altered in their eastern outcrops; but even then may sometimes lie flat, as may be seen near the cemetery east of Ferrisburg village.

The conditions around Vergennes seem to show what was argued to be the probable structure on the islands in the northern part of the lake. They also give support to the idea that a great, low-angle thrust carried the Lower Cambrian beds over the rocks of the lake region and that to some extent, at least, the present western margin of the former is an erosion trace of an overthrust mass of which some portions have disappeared.

Monkton Township.

(Burlington and Middlebury topographic sheets.)

Location. Monkton lies east of Ferrisburg and is bounded by Charlotte and Hinesburg on the north, by Starksboro on the east, and by Bristol and part of New Haven on the south.

General description. This township includes a prominent physiographic outlier of the Green Mountain plateau, generally known as "Monkton ridge," which enters Monkton from Bristol at the south and extends through the central portion nearly across the township. To the east of Monkton ridge, and separated from it by a valley of irregular surface, another prominent ridge, known as Hogback Mt., and which is also an outlier of the main range, enters from Bristol and extends northward just west of the eastern boundary to within about a mile of the northern township line.

These prominent physiographic features are fundamentally of structural origin. They are interpreted as primarily thrusted masses which were later modified by normal faulting. The depression which now separates Monkton ridge from Hogback and that which separates the latter from the main range is in each case

a more or less perfectly developed *graben* and on a small scale illustrates the structural character of the famous Vermont valley, which beginning farther south near Brandon extends to Pownal between the Green Mountain plateau and the Taconic range. The structural and physiographic features in the eastern part of Monkton and adjoining parts of Starksboro have their counterparts at other places along the western edge of the Green Mountain plateau.

Into the northwestern part of Monkton township the reddish beds of the Sandrock series extend from the southeastern part of Charlotte and give conspicuous outcrops on the low hillsides at many places. East of the road from Monkton to East Charlotte, northeast of Mt. Fuller, the red beds are interbedded with some dolomite and the dip is gently to the west.

At Mt. Fuller and southward along the road to Barnumtown, beds of cherry-red quartzite form conspicuous outcrops and dip to the east at a low angle. A low scarp bounds Mt. Fuller on the west. It is interpreted, as in some degree a recession scarp, for one-third of a mile to the west of it a fragmentary patch of quartzite rests against sheared, probably Trenton limestone, as noted above.

South of Mt. Fuller the surface falls off to slightly lower levels and apparently the purple quartzites pass under somewhat higher members of the Sandrock series; but whether this is actually the case or whether the interbedded quartzites and dolomites forming the surface rocks southward represent lateral variations of the beds at the north may not be easily decided.

Near Barnumtown the interbedded series appears in force and at places shows most severe effects of compression, being not only jammed into close folds, but twisted along the strike and otherwise deformed. The interbedded rocks continue south from Barnumtown over Cronkhite Hill and along the road to New Haven Junction. At some places the members of this series lie in flat attitude, but within short distances such beds pass apparently both along and across the strike into others that are highly inclined and greatly jammed. These features have much resemblance to others which have been described for quite similar rocks around Brandon (see first paper) and have their counterparts in other localities yet to be described.

In the northern part of the township, along the road from North Ferrisburg to the village of Monkton Ridge, are low-lying outcrops of closely-folded, interbedded quartzites and dolomites which are the southward extension of those in southwestern Hinesburg and near Prindle Corners in Charlotte.

Two miles farther south, just west of Monkton village (Monkton Borough), similar rocks with cherry-red quartzite members form the hill known as Mt. Florence and show numerous outcrops in the fields directly north of the hills. In the hill red quartzites apparently dip gently to the west, while directly east of the hill the members of the interbedded series are jammed into close folds and are sheared and crushed.

From Monkton Borough, over the ridge to East Monkton, the rock is mainly quartzite or quartzitic schist, apparently for the most part dipping easterly. Just north of East Monkton village rather thinly-bedded, quartzite beds stand on end or by apparent overturn now dip easterly at a high angle. These rocks are sheared and slickensided and give every indication of having been jammed against the beds that lie west of them.

Distinct scarps, irregularly disposed and overlapping more or less along the general strike of the rocks, are distinctly visible features along the eastern face of the ridge north of East Monkton village. These scarps probably mark planes of faulting by which the rocks that lie in the valley of Pond Brook have been left at lower levels. Quartzite forms the eastern slopes and scarps of Monkton ridge from East Monkton to Monkton Ridge village. South of the latter village, east of Monkton Pond, the gray and white quartzite is distinctly sheared so that the dip is obscure.

For a mile and a half east of Monkton Ridge village the rocks are distinctly bedded, gray dolomites, lying flat or dipping westerly, but just west of the northern end of Hogback Mt. the dip of the dolomite changes to easterly and this rock gives place eastward to quartzitic schist, or sheared quartzite, with some members of pure white, granular quartzite. Eastward towards the road that runs from Hinesburg to Starksboro the quartzite gives place to gray, siliceous dolomite, usually of massive appearance, but carrying some thin beds.

In Monkton township, just as in Hinesburg at the north, as one goes east from the western margin of the Cambrian rocks towards the hilly land, the interbedded rocks are seen to give place at the surface to dolomite or quartzite, apparently according to the manner in which displacements have altered the primary relations among the rocks. These relations are quite like those to be noted farther south in Bristol and Middlebury, and those which the writer has described for the Brandon region.

The southern portion of Monkton ridge, south and southeast of East Monkton village, is largely composed of sheared quartzite; but, as will be mentioned again later, in the northwestern part of Bristol the quartzite apparently passes beneath massive, gray, siliceous dolomite which lies to the east of interbedded dolomites and quartzites in the northeastern part of New Haven township.

The outcropping rock along the road that runs through the valley of Pond Brook is quartzite; but probably this quartzite was once overlain by dolomite like that which occurs at the northern end of the valley, to the east of Monkton Ridge village, as noted above, and presumably the softer rock has been largely eroded over what is now the floor of the valley.

The western face of Hogback Mt. is steep and marked by prominent scarps.

No marbly limestone was noted among the Cambrian rocks just described for Monkton. Its absence seems to be correlated with the relatively higher topographic levels of the members of the Lower Cambrian series in this township. The marble appears to the south and southwest in New Haven.

Starksboro Township.

(Burlington and Middlebury topographic sheets.)

Location. Starksboro lies east of Monkton and the northeastern part of Bristol.

General description. Lewis Creek has its source in the hills of Starksboro. The stream from the junction of its headwater tributaries flows north across the township through a valley that separates Hogback Mt. from the main range. The floor of the valley is dotted with hills. As noted above, it is a structural basin secondarily modified by the erosion of much of the relatively soft rock. The hills over its floor are formed of either quartzite or dolomite whose beds during the period of their compression were folded and sheared and now often stand on end.

Some of the special features of the Starksboro area have been described by N. C. Dale.[1]

The western wall of the valley is formed by the eastern face of Hogback and is marked by numerous scarps. The mountain is broken by transverse faults along which erosion has worked to give a serrated skyline to the ridge. Less prominent scarps occur to the east.

A feature to be noted is the apparent absence of the so-called interbedded series, which is a condition apparently to be correlated with thrust displacements which elevated older rocks against younger ones and not necessarily with the original absence of these beds over the area in question.

The rocks forming the hills to the east of the Starksboro road were not inspected in Starksboro township, except in a small area around South Starksboro village, which will be more conveniently described in connection with Bristol township.

Panton Township.

(Port Henry topographic sheet.)

Location. Panton borders the lake and lies between Ferrisburg on the north and Addison on the south. Its eastern boundary is formed by a portion of Otter Creek which separates it from the town of Waltham.

[1] Twelfth Report of the State Geologist, p. 43.

General description. In Panton the hard rocks are extensively concealed by surface material, and wholly so over the central portion of the township west and east of Dead Creek. In the western part, outcrops are confined to the lake shore and to a low ridge that lies between it and the road running from north to south across the township, through Panton village, and in the eastern part to scattered exposures to the west of Otter Creek.

The shore section beginning in Ferrisburg, two-thirds of a mile north of the Panton line, shows black shales pitching northerly which yielded scattered graptolites and brachiopods. These shales southward pass conformably into others with more numerous limestone bands and these are underlain conformably by thinly-bedded limestones full of characteristic Trenton species. The pitch of these various beds is in a general northerly direction. Southward is thickly-bedded, more massive limestone which resembles the Black River. The so-called Black River beds are somewhat folded so as to give at some places a westerly dip and an unusually massive appearance when viewed from the west. Southward are other massive limestone beds of different lithology and strongly brecciated. These rocks gave two small *Maclurea*-like coils on the weathered surface and it is thought that some Chazy rocks are at this place involved in the shore section. The brecciated limestone southward lies against black shales which are somewhat crushed. The contact is a short distance north of Arnold Bay. From this contact the black shales continue southward for a short distance with southerly pitch, and then, with change of pitch to north, to and around Arnold Bay, where they form the small promontory on its southern side.

The structural relation of the brecciated limestone to the shale, north of Arnold Bay, is far from clear. There is no doubt that the limestone is much older than the shale. The crushing of the latter near the contact seems slight, but if taken with the other disturbance shown by the southward tilting of the shale beds, it is possible to reconcile the conditions with the idea of an upward movement of the older rock into the shales which was probably preceded by brecciation of the limestone at depth. The folding shown by the somewhat massive, so-called Black River beds north of the brecciated limestone indicates that the rocks have been under compression and that, therefore, the contact in question is probably one of thrust.

East of Arnold Bay and the shore road is a low ridge. Just east of the shore road and south of the one running from Arnold Bay to Panton village are low ledges of what appeared to be Black River beds dipping easterly. Farther south along this ridge are numerous outcrops of what appeared to be Chazy beds and still farther south, others which appear to be part of the Beekmantown. Eastward to the west of and sometimes along the road running south from Panton village the Chazy rocks form an

almost continuous outcrop for over two miles and extend into Panton village. In the village, rocks that appeared to be of Black River age lie on the east side of the road, north and south of the one running to Vergennes. *Columnaria* was found in bowlders, but not in place.

From the meridian of Panton village eastward the surface is formed of clay and outcrops are lacking as far east as the low ridge about two miles east of Dead Creek.

In the southwestern part of Vergennes at a road metal quarry is dark gray, magnesian limestone which is conspicuously brecciated at some places. The rock is like that at the falls in the city and is probably a part of the Beekmantown by comparison with rocks in the Shoreham section. Farther south along a road running west of this quarry are outcrops of gray, magnesian rock and quartzite which resemble as much as anything in the region the rocks of Mt. Independence in Orwell, and seemed to the writer, without much doubt, to represent the lower part of Brainerd and Seely's Beekmantown and their so-called "Potsdam" as found in Shoreham. The outcrops of these rocks are, however, few and of small extent and the correlation is tentative.

For the rest, little may apparently be learned of the hard rock underlying this township.

If, as seems likely, the rocks in the eastern part of the township are Lower Beekmantown and those to the west beneath the clay are shales, the former have probably ridden over the latter by thrust much as they have north of Highgate Springs and also to the south in Shoreham and Orwell. The massive rocks in the western part of the township probably represent an independent upthrust into the younger shales.

Waltham Township.

(Port Henry and Middlebury topographic sheets.)

Location. Waltham is separated on the west from Panton and the northeastern part of Addison, which lies south of Panton, by Otter Creek. On the north it is bounded by Vergennes and part of Ferrisburg and on the east and south by New Haven.

General description. Waltham is distinguished topographically by the considerable elevation known as Buck Mt. Description may conveniently begin with the rocks lying between Otter Creek and the mountain.

A road to Weybridge runs directly south from Vergennes on the west side of Buck Mt. About a mile south of Vergennes, between the road just mentioned and another running east of the mountain to New Haven Junction, is strongly sheared, blue limestone of probably Trenton age. Fossils have largely been destroyed. A half mile farther south along the same meridian and east of the Weybridge road is very much mashed limestone having the lithological characters of the Chazy and often carrying numerous small indistinguishable fossils and recognizable specimens of *Girvanella*. The rocks have been sheared, but a general easterly dip may be discerned. Along the strike of the beds the dip changes from a high to a moderate angle. East of these Chazy rocks are outcrops of Trenton limestone beds also dipping easterly.

Eastward towards the road running from Vergennes to New Haven Junction, beds of limestone form an anticline along meridians which are occupied farther south by the Red Sandrock of Buck Mt. The limestone is not like the Trenton beds just west of it, but in its general characters more closely resembles the dove-gray beds carrying yellow-weathering or chamois-colored layers and patches which are intermingled with interbedded quartzites and dolomites in the areas farther east. It lies on the meridians of the Chazy limestone at Marsh Hill, east of the city of Vergennes. It was apparently regarded as Trenton by Seely and is apparently so shown on his "Geological Map of Addison County" (see Seventh Report of the State Geologist), but this map fails to depict in any detailed or accurate manner the various rock outcrops in Waltham.

North of Buck Mt. a cross road joins the Weybridge and New Haven roads. South of this cross road, along the one to Weybridge, Chazy limestone, dipping easterly and carrying *M. magna* and *Girvanella* forms numerous outcrops. South of these Chazy beds on the west side of the road, opposite the school house, is somewhat sheared, Trenton limestone with many surface markings of fossils. *Prasopora* was found at this locality. The beds dip easterly and are filled with many small veins of calcite. A mile to the south on both sides of the road, beds of Chazy limestone, dipping easterly, form conspicuous ledges. On the east side of the road the rock is visibly sheared, but its fossils are distinct and included distorted specimens of *M. magna* and many specimens of *Girvanella*. East of these beds are much altered Black River rocks, full of small veins of calcite, but still showing the characteristic surface markings of the Black River beds of the lake region. The Black River beds dip easterly. Some of the soil-covered spaces which now separate the Chazy and Trenton outcrops may be underlain by Black River rocks.

The various rocks along the Weybridge road just described belong to the lake series. They are the southward extension of similar rocks around the city of Vergennes and those which lie north of the city in Ferrisburg. All the various kinds of rocks are visibly sheared at some places and show other effects of compression On the southwestern side of Buck Mt., massive Chazy beds may be followed a half mile east of the Weybridge road and seem to be repeated across the strike as though piled on each other by successive thrusting, but in the presence of such apparent repetition of beds in this region it is not always easy to decide whether the conditions are due to thrusting or normal faulting, even when there can be no doubt that as a whole the rocks involved have been disturbed by thrusts.

The rocks along the Weybridge road are on meridians to the east of those occupied by the brecciated, gray, magnesian limestones at Vergennes falls and the similar rocks south of the city. From the fact that north of Vergennes the Chazy, with easterly dip, extends to meridians west of the falls makes it difficult to visualize the relations of these various massive rocks to each other. It seems probable that in a good many cases, massive Lower Ordovician strata broke at depth and were shoved upward into younger rocks in such way that the younger beds on one side were underthrust and on the other overthrust. The horizontal component varied. The brecciated condition of the rock at Vergennes falls and south of the city may be the expression of internal deformation within the Beekmantown rocks on either the underthrust or overthrust border of the ruptured mass. The rocks in eastern Panton which have been described and regarded as probably representing the Lower Beekmantown may have underthrust the rocks along the Weybridge road, in a general sense, and have overthrust the shales which are thought to lie to the west of them.

It is interesting to note that the calcareous rocks in eastern Panton and the western part of Waltham are on meridians occupied by the Red Sandrock formation of Snake Mt. in western Weybridge and the southeastern part of Addison.

East of the Weybridge road passing west of Buck Mt., the calcareous rocks above described in general lie at the base of a series of scarps that bound the mountain on the west. The drift that has been piled against these scarps conceals contacts between the limestone and the Sandrock. The scarps mark planes of faulting; but it is not clear whether the present structural relations of the rocks involved are due to reverse faulting and modifications simply from erosion, or whether primary thrusts have been modified by tension faulting as well as by erosion.

East of the scarps the surface of the mountain slopes gradually eastward across the eroded edges of red quartzite beds which dip gently to the east. East of the mountain, in the western part of New Haven township, the surface is generally covered with drift, but there are some exposures of red quartzites along the direct road from New Haven Junction to Vergennes.

In the southeastern corner of Waltham are interbedded members of the Lower Cambrian series which are probably to be thought of as stratigraphically above the red quartzite forming the eastern slope of Buck Mt. For the most part these members of the interbedded series, which carries some red quartzite, dip to the east, but on their western margin a slight westerly dip was noted indicating a small amount of flexure in these rocks. These interbedded dolomites and quartzites join southward with others in New Haven township which will be described beyond, and the red quartzite of Buck Mt. also extends southward with reduced elevation into New Haven at the south.

New Haven Township.

(Middlebury topographic sheet.)

Location. This township is one of irregular boundaries. In general it is bounded by Waltham on the west, by Ferrisburg and Monkton on the north, by Bristol on the east and by Middlebury and Weybridge on the south.

General description. In a small jog in the very northwestern part of the town are outcrops of Chazy limestone which are the southward continuation of the Chazy beds along the Weybridge road in the southern part of Waltham. The rocks carry Middle Chazy fossils and dip to the east.

A mile to the south of these rocks is an assemblage of dove-colored limestones, with buff-gray layers which now frequently appear as patches among their associated dove-colored beds. These rocks are not like the Chazy beds just north of them; but are somewhat like the calcareous rocks lying north of Buck Mt. and very much like other rocks found on meridians farther east, more or less intermingled at the present surface with Lower Cambrian rocks and which are very abundant over large areas in the townships of Weybridge and Middlebury. In northwestern New Haven these beds are usually much disturbed, but at some places may be seen to have easterly dip. In their various lithological features these rocks are not easily correlated with any of the members of lake series proper; fossils are absent or obscure and their age has been much of a puzzle to all students of the region.

A few rods north of the junction of the road from Addison village to New Haven Junction, and the one from Vergennes to Weybridge passing west of Buck Mt., members of this formation of dove and gray rocks rest on crushed and sheared, bluish-black, shaly limestone that has strong resemblance to the Trenton. The contact may be plainly seen on the eastern side of the Vergennes road. It seems to be a thrust contact. About a half mile to the west on the north side of the Addison road are graptolite shales with members of the dove and gray series forming the surface above the shales which are exposed in a cut in the bank of the road. East of the dove and gray beds is red quartzite which extends south from Buck Mt. Farther to the east and southward the hard rock passes under clay or drift.

About a mile and a half east of Otter Creek and the outcrops just described is a low ridge formed by the interbedded

rocks of the Cambrian, which are the direct southward extension of the similar rocks in the southeastern part of Waltham and which still hold to a gentle easterly dip. Traced southward these interbedded rocks pass under drift for a short distance. Then along the same meridian are scattered outcrops of gray, siliceous dolomite which continue to within a mile and a half of Weybridge village.

Northeast and east of Weybridge village, to the west of and along the railroad track, are numerous exposures of the dove-colored rock and its buff-gray associate. In their outcrops about a mile southwest of Spring Grove Camp Ground, these rocks frequently stand on end and show evidence of extreme compression. Similar rocks occur southwest of New Haven Junction, where they show the same evidence of compression and are strongly sheared.

East of the Rutland R. R. track at numerous places, over a strip about a mile and a half wide extending from the northern to the southern boundary of the township, are exposures of more or less striped or marbly limestone. Two miles north-northeast of New Haven Junction, near the Ferrisburg line, outcrops of gray, siliceous dolomite or interbedded dolomite and quartzite at places roughly alternate across the strike with outcrops of striped blue or marbly limestone. The structural relations are very obscure, but at places there seems to be suggestion that the marble lies on the dolomite and at others that the interbedded rocks have been thrust over the marble.

The surface of the hill just east of the quarry of the "Green Mountain Lime Works," gives massive, striped bluish and gray rocks interbedded with some siliceous layers and others that weather to a grayish-buff. The gray rock carries obscure coils, but a careful scrutiny of weathered surfaces did not give anything definite. In the quarry of the lime works the rock is generally more or less massive and crystalline and is practically a marble. Planes of stratification are visible, but the beds are much deformed and dip and twist in various directions. In the fields near the quarry, in what appear to be surface exposures of rocks like those in the quarry, are rocks quite similar to those just described for the hill east of the quarry.

Northward across the road from the quarry, white, marbly limestone is intermingled with gray dolomite. Still farther north, along the so-called "Plank road" in the southwestern corner of Ferrisburg, white, marbly limestone lies south of the road, just west of a mass of gray, siliceous dolomite showing bedding well marked, and on the north side of the road, on the same meridian with the marble, is a low ridge composed of interbedded quartzite and dolomite, at this place largely quartzite, showing a gentle anticlinal buckle pitching gently to the north. A fourth of a mile to the west is gray dolomite dipping at a low angle to the east;

and about the same distance to the east is gray dolomite again, which northward along the same meridian gives place to interbedded rocks lying nearly flat.

The field relations in the absence of definite contacts do not permit positive statement of structure; but at the time of inspection it appeared that the primary relation was that of marble resting on Cambrian rocks and that the latter had been thrust against and sometimes over the former. It will appear from later discussions that the primary relation of the marble probably was that just indicated and that in several cases the rocks, whether massive dolomite or interbedded dolomite and quartzite on which the marble lay, were broken and thrust over the marble.

Eastward towards Bristol, along the "Plank road," in the extreme southwestern corner of Monkton, but practically on the New Haven line, are ledges of massive dolomite forming the low, southern portion of Monkton ridge. Southward these rocks disappear beneath Cedar Swamp; but south of the swamp, on the same meridian, and just south of the Bristol R. R. track, begins a ridge of the interbedded series. Near the crossing of the New Haven-Bristol road and the railroad track are beds of red quartzite which dip gently to the west. Slightly to the southeast is a distinct scarp on the western side of a considerable hill of interbedded dolomites and quartzites. Two-thirds of a mile east, across a low area, is another hill or ridge of the interbedded rocks, which on the western side are terribly jammed and puddled. Eastward the beds undulate and stand at various angles of dip, but at the summit of the eastern slope they may be seen to dip gently to the west. The eastern slope of the hill from these beds down to the road that runs from New Haven Mills northward towards Monkton is drift covered; but southward, northeast of New Haven Mills, is whitish, granular quartzite apparently overlain by gray dolomite. The quartzite outcrops on both sides of the dolomite and dips to the east; the dolomite is sheared so that its bedding is obscured; but at places it seems to be standing on end.

South-southwest of New Haven Mills, south of the river, on the meridian of the quartzites and dolomites north-northwest of the village, is another ridge of the interbedded rocks. On the west of this ridge the rocks dip westerly, but on the eastern slope they form the distorted, pushed-up eastern limb of an anticlinal fold. The effects of compression at this place beggar description. The often somewhat massive quartzite beds are jammed into Z-shaped folds and strongly sheared withal and wave back and forth along the strike. The structure is identical with that shown by similar rocks east of Brandon, as elsewhere described, except that the jamming is more severe. The interbedded rocks may be followed along this ridge southward to the Middlebury line and have anticlinal structure throughout. Near the southern boundary of the township these rocks are only a mile from the quartzite scarp along the edge of the plateau, from which they are separated by the ledges of massive, gray dolomite forming the hill known as the "Cobble."

North of New Haven Mills, partly in Bristol, are several low, detached hills of gray dolomite, some of which show scarps on the west. Sheared, gray, siliceous dolomite forms the bed and banks of the river at New Haven Mills.

The interbedded rocks forming the hill with the prominent scarp southeast of New Haven village join at the surface with similar rocks along the road that runs directly south from the village along which they outcrop through a distance of two miles. One-half mile west of the road and about a mile south-southwest of New Haven village are outcrops of bluish-white marble, flanked on the west by striped bluish limestone with spots of marbly rock, all dipping easterly and all marked by strong flow-shearing. The striped rock has much superficial resemblance to some Middle Chazy of the lake series. No fossils have survived the severe deformation of the rock. About a half mile west of these outcrops are others of similar rock on the east side of the road from Spring Grove Camp Ground to New Haven village, and south of the latter are still other outcrops of bluish limestone somewhat involved with buff-weathering layers.

Two miles southeast of Spring Grove Camp Ground, in the angle of the roads, are outcrops of bluish and marbly limestone intermingled with fragmentary patches of the interbedded series. Since these rocks lie on the meridians of the interbedded rocks farther north it seemed likely that the marble had actually been overridden by the Lower Cambrian rocks. The relations again are similar to those among the interbedded rocks and the marble around Brandon.

On the meridian of the rocks described in the last paragraph, south of New Haven River and west of Muddy Brook, is a ridge which extends southward into Middlebury township. Great confusion prevails among the surface rocks along this ridge. At its northern end, which is the portion included in New Haven, on the east slope, gray dolomite is intermingled with striped blue limestone. Westward over the summit the striped blue limestone is intermingled with patches of interbedded dolomites and quartzites, the latter often forming exposures of considerable size, with well-defined bedding and dip. In some places the members of the interbedded series lie flat, in others they dip to the west and in others the structure may not be made out. A survey of the hill showed that quartzites and dolomites are often involved with the limestone in such a way as to give the appearance of being interstratified. The surface is greatly broken by gullies and knolls of various dimensions. In some places the striped blue rock shows in massive ledges; in others the rock is apparently all gray, siliceous dolomite.

The secondary structural features are very complicated; but the general field relations seemed to point to involved thrust relations like those which have been described for the region around Brandon. Similar conditions will be described for Middlebury in subsequent pages.

No fossils were found although it seemed as though they should be and diligent search was made.

East of this ridge, near Muddy Brook and on the township line, is a marble quarry, known as "marble ledge." Marble also outcrops to the north of the quarry, just south of New Haven River. Gray dolomite forms the eastern wall of the quarry and marks the surface along which the marble has been quarried. Again, the conditions are precisely like those in some of the quarries around Brandon.

Wing was reported by Dana[1] to have found an *Orthoceras*, resembling *O. primigenium* Hall (a Calciferous form), in rocks, a little way south of the quarry, east of the brook, in Middlebury. On the basis of this fossil the rocks were assigned to the Beekmantown by Dana and later by Seely. In fact all the various rocks that have just been described for the southwestern part of New Haven were called Beekmantown by Seely. A great deal of the marbly and striped limestone in the writer's opinion has more lithological resemblance to the Chazy and it is certain that Lower Cambrian dolomites and interbedded rocks are involved with the marbly limestone. The writer tried to find the spot which Wing, Dana and Seely visited, following carefully the directions given by Dana (loc. cit.) but failed to note the outcrop.

Dana further mentions discovery by Wing of other fossils a half mile northwest of the *Orthoceras* locality, and apparently on the eastern slope of the ridge west of Muddy Brook. At this locality "and apparently in the same formation with the last, there are specimens resembling *Ophileta compacta;* there was also found here a large *Maclurea.*"

"About a mile southwest of the Middlebury quarry and thirty or forty rods west of Mr. E. Kirby's residence, in an old orchard, several distinct convoluted shells were seen on a dark, siliceous limestone dipping west. The beds are probably Calciferous."

North and south of Beldens, in the fields east of Otter Creek and in the bed of the river itself, are extensive exposures of usually distinctly bedded gray and buff-weathering rocks which are different from the striped blue and marbly limestones that lie east of them. These rocks have also been called Beekmantown. They extend southward into Middlebury, where they present interesting field relations yet to be described. The age of the rocks is doubtful; they may be part of the Beekmantown, but in the writer's opinion, Beekmantown has been employed in much too inclusive a way for the more or less altered rocks over the eastern portion of the Champlain lowland.

[1] A. J. S., vol. XIII, 1877, p. 406.

Bristol Township, including parts of Lincoln Township.

(Middlebury topographic sheet.)

Location. Bristol borders New Haven on the east. Lincoln lies east and southeast of Bristol.

General description. The southern portion of Monkton ridge extends into the northwestern portion of Bristol. Most of the portion of the ridge included in Bristol is made of quartzite, but massive, gray dolomite occurs at the southern end near the New Haven line. South of this dolomite is Cedar Swamp, from which at the south emerge the interbedded quartzites and dolomites of the eastern part of New Haven.

A surface section southward from Monkton ridge into New Haven thus gives with interruptions a succession from quartzite through gray, massive dolomite to interbedded quartzites and dolomites and suggests that this is the usual stratigraphic sequence.

The valley occupied by Pond Brook in Monkton extends southward into Bristol, but its basin character gradually fades southward towards Bristol village owing to the falling off in elevation of the southern portion of Monkton ridge.

Bowlder drift topped by sand plains largely conceals the hard rock around Bristol village west of Hogback Mt. Gray, siliceous dolomite, dipping westerly, outcrops northwest of the village and southwest of it, west of "Bristol Flats," other dolomite marks the northward extension of the rocks at and north of New Haven Mills.

South of Bristol village, to the east of Bristol Flats and just east of the road that runs along the eastern edge of the Flats, the rock is largely a gray or brownish-gray, granular quartzite, dipping easterly; but eastward at places near the foot of South Mt. the quartzite dips westerly. Southward, gray dolomite forming the northern end of "Cobble" hill, conceals the quartzite.

In the township of Bristol, west of Hogback and South Mt., the underlying rock is thus seen to be quartzite with overlying dolomite which form a shallow, synclinal fold, suggesting that the valley of Pond Brook is primarily a syncline which has been modified by faulting.

In Bristol, as in Monkton, the western face of Hogback shows a succession of scarps along the strike. The rock along these scarps, which were inspected at many places, is essentially a quartzite which is usually strongly sheared and much like some of the rock that has been described for the hilly land east of St. Albans and Milton. In spite of shearing the bedding is visible and dips to the east. The easterly dip is well shown on the mountain at the ledge known locally as "Table Rock."

New Haven River enters the lowland through a gap between Hogback and South Mt. Along this pass the quartzite may be observed at many places dipping easterly and the southern end of Hogback may clearly be seen to be bounded by a series of scarps marking fault displacements across the strike. The river has availed itself of these lines of weakness.

At Ackworth, ledges of quartzite are abundant. The dip is easterly at a small angle and the rocks exhibit little or no internal deformation. There is a slight northerly pitch. On the road towards West Lincoln, about one-third of a mile east of Ackworth, the dip is westerly.

The valley of Beaver Brook and Baldwin Creek north of Ackworth is the southward continuation of the valley of Lewis Creek in Starksboro. It is primarily of synclinal structure, but is modified by faulting. The eastern face of Hogback shows scarps marking faults. A mile and a half north of Ackworth, gray dolomite on the west side of the road dips westerly.

Quartzite continues north from Ackworth east of the Starksboro road. At the western end of the gorge of Baldwin Creek is strongly sheared rock, much like that on the western side of Hogback. In the bed and banks of the stream a fourth of a mile east is blackish phyllite which is probably a sheared muddy member of the quartzite formation. Two-thirds of a mile farther east, in the north bank of the gorge, are impure quartzitic and calcareo-siliceous beds greatly sheared and crushed, which have some resemblance to the interbedded series found in the lowland to the west of the plateau. At South Starksboro the prevailing rocks are impure, coarse schists which were interpreted as probably originally forming impure basal portions of the overlapping Lower Cambrian series.

A mile southeast of South Starksboro, on the side of the road near a school house, was seen a small exposure of interbedded quartzite and calcareous rock. East of these beds in the fields are others of quartzite lying nearly flat.

The interbedded, impure quartzites and calcareous rocks west and southeast of South Starksboro seem to resemble the interbedded series of the lowland west of the plateau closely enough to be regarded not as precise equivalents perhaps, but as related members of a common formation. It would seem that in the process of overlap such rocks were carried eastward into what is now the plateau, just as gray dolomite was also carried at some places.

The quartzite exposed in the bed of New Haven River, southeast of Ackworth, gives place southeast of West Lincoln to gneissic rocks that are different from the sheared rocks that seem more or less definitely to belong to a formation which originally consisted of various kinds of sediments and which is probably of Lower Cambrian age. Similar gneisses were noted near the river at Lincoln Center and in South Lincoln and are regarded as probably pre-Cambrian and as forming a part of the floor of deposition of the quartzite-schist-dolomite formation.

Three and a half miles south of Bristol village the "little notch road" leaves the lowland and climbs over the mountain to South Lincoln. The western portion of the road cuts through the southward extension of the quartzite of the western part of South Mt. From places along the road, east of the front range of hills, they may be seen to be bounded on the east by scarps, to the east of which the surface is lower. The suggestion which the topography gives of down-faulting on the east of the front range is supported by the occurrence of considerable exposures of gray dolomite along the road towards South Lincoln. The dolomite is intermingled over large areas with micaceous, quartzitic schist, which apparently weathers fairly easily, but it did not appear from any outcrops which were noted that the schist is interbedded with the dolomite. The gray dolomite is lithologically much like that west of the plateau. In some of its outcrops it occurs in undulating folds sheared across the bedding. This dolomite was interpreted as the extension eastward into the plateau of the dolomite that is found in what is now the lowland to the west of it, and as part of the Lower Cambrian series.

Around South Lincoln in the beds of streams, foliated, gneissic rocks not easily interpreted as sheared members of the Cambrian formation were noted and at the time of their inspection seemed to be probably a portion of the pre-Cambrian formation of basal gneisses. No attempt was made to trace the quartzite-dolomite-schist formation into the eastern part of Lincoln.

While some of the members of the formation, which is regarded as Lower Cambrian, in their occurrence in the mountains are not very much deformed internally, others of them are and in some places shearing or crushing is severe, and gneissoid or schistose structure is common. The most severely sheared types might be confused with other rocks and assigned a different age and possibly to an older series, without careful discrimination; but it seemed that any of the gneisses which could be interpreted as probably older than Cambrian are sufficiently different from sheared and altered younger rocks to be fairly easily distinguished, at least within the areas examined by the writer. Such might not be the case farther east in the mountains.

Addison Township.

(Port Henry topographic sheet.)

Location. Addison township borders the lake and lies south of Panton. It is bounded on the east by parts of Waltham and Weybridge and on the south by Bridport.

General description. Like Panton, a large part of the western portion and most of the central portions are covered with clay. Outcrops are, therefore, practically confined to the lake shore and the somewhat hilly eastern part.

From the Bridport line northward along shore as far as Chimney Point is clay. At Chimney Point are beautifully glaciated ledges of Chazy with the beds dipping at a low angle to the west. Similar beds with about the same dip occur to the northeast, on the north bank of Hospital Creek.

North of Hospital Creek, to the west of the Chazy outcrops, on the lake shore, are thinly-bedded limestones, weathering gray but bluish on fresh surfaces, clearly derived from limy muds, and full of characteristic basal Trenton fossils. The beds also dip westerly and at an angle about like that of the neighboring Chazy rocks at the east. They have apparently a slight northerly pitch.

These Trenton rocks are succeeded along shore northward by more or less regularly interbedded, blackish limestone and shale. The limestone members contain Trenton fossils, including *Prasopora,* and the series plainly marks a transition from the "basal" Trenton beds into rocks that are more notably shaly and which continue along shore to Potash Bay. The dip throughout is gently to the west. Graptolites were found at numerous places in the shales, but *Triarthrus becki,* so common in the shales in the northern part of the lake region, was not seen. The shore section from Crane Point to Potash Bay is about three miles long. The dip is so gentle that the rocks lie almost flat. They seem to be broken hardly any, if at all, by displacements and as a whole give a considerable thickness of apparently conformable beds ranging from the base of the Trenton well up into the shale formation.

East of the shore section the hard rocks are usually beneath clay; some apparently Trenton rocks outcrop along the road north of Hospital Creek.

In general the rocks along shore in Addison appear to form the western limb of a gentle anticlinal fold. The apparent structure permits the interpretation that the basin of the lake west of Addison was excavated in shales that conformably overlay the rocks that lie along shore and that similar shales extend eastward beneath the clay. In other words, along the Addison shore there is little or no suggestion of overthrust of older rocks on the shales such as is seen in many other places along or near the lake. If the rocks around Chimney and Crane Points constitute a conformable series, Black River beds should intervene between the Chazy and Trenton, by analogy with conditions at other places in western Vermont. There are some outcrops on the road north of Hospital Creek which indeed suggest the Black River, but if these rocks are generally present they are for the most part concealed.

The eastern boundary of Addison zigzags through the mass of Snake Mt. which lies partly in this township and partly in Weybridge. North of Snake Mt. the eastern boundary follows Otter Creek to the Panton line.

The higher portions of the mountain are in Addison. The rock is chiefly red quartzite, like that of Buck Mt. The surface of the mountain falls off abruptly northward and gives place to a clay-covered lowland. The western face of the mountain is marked by scarps, against which at places rest banks of glacial drift.

Along and near the road that runs just west of the mountain are outcrops of limestone which may now be described.

From Addison village a road runs eastward to Weybridge, passing north of Snake Mt. About a mile east of the village another road runs southward just west of the mountain. East of this road on the northwestern slope of the mountain are beds of shaly limestone lying nearly flat but which have perceptible easterly dip and are rather conspicuously sheared. These outcrops yielded a few Trenton fossils. Perhaps 150 rods farther south, along the roadside, are ledges of Chazy limestone also dipping easterly and carrying characteristic fossils. The Chazy continues southward for a fourth of a mile and is flanked on the east by Black River beds. A mile to the south on the same meridian with these rocks are shaly limestones which outcrop intermittently along the road to the Bridport line.

To the west of the road just followed is another parallel with it which runs through Addison village. Sheared limestone carrying Trenton fossils and dipping easterly outcrops one-half mile north of the Bridport line and a mile farther north are ledges of Chazy with easterly dip.

The calcareous rocks lying west of Snake Mt. apparently form a monoclinal series dipping easterly, with the Chazy at the base overlain by Black River and sheared Trenton limestone. While the outcrops are scattered, the field relations among them permit the interpretation just given and also the inference that the beds are mainly conformable, although possibly displaced somewhat with reference to each other. About six miles to the west the same series dips in the opposite direction. It is not easy to imagine that the rocks along the lake shore and those west of Snake Mt. form the limbs of a common anticlinal arch, for the dip is so low that in the wide interval between them there seemingly should occur other outcrops of the heavier members, which does not seem to be the case. If there were several folds over the interval that now separates these rocks there should be intermediate ridges which do not occur.

Although along meridians, now occupied at the surface in Addison by clay, Chazy rocks are exposed in Panton, this circumstance does not seem to justify the inference that the clay in Addison is directly underlain by Chazy limestone; for in Shoreham to the south these meridians show the shales as the surface rock. As will be shown beyond, it is probable that the clay over central Addison and Bridport is underlain by shales, and that the older limestones are deeper down. The key to the structural relations among the various rocks in Addison seems likely to be found in the major kind of deformation which the region has suffered. Snake Mt. is primarily an unlift of the older rocks which have also been thrust to the west. The limestones west of the mountain have probably suffered similar deformation. The quartzite of Snake Mt. in Addison and the calcareous rocks west of it are on meridians occupied by probable Beekmantown farther north in Panton.

Weybridge Township.

(Port Henry and Middlebury topographic sheets.)

Location. Weybridge is bordered on the west by parts of Addison and Bridport, on the north by parts of Addison and New Haven, on the east by parts of New Haven and Middlebury, and on the south by Cornwall.

General description. The eastern slope of Snake Mt. descends into the western part of Weybridge. All the outcrops inspected west of the Lemon Fair are of Red Sandrock, which dips to the east.

Clay forms the surface over much of the valley of the Fair, and that of the Otter west of Weybridge village.

East of the Fair, at varying distances from it, the surface rises to form Weybridge Hill, which is a ridge of much the same pattern as that of Snake Mt., but of lower elevation. On the west of the ridge are steep slopes and numerous softened scarps from whose summits there extends eastward an irregular surface which in general descends to the bed of Otter Creek.

Near the Cornwall line the steep western margin of the ridge forms what is known as "The Ledge." It is marked by a scarp which extends southward into Cornwall. At "The Ledge" the rock is massive, gray limestone without well-defined structure or dip. It yielded no fossils. The same rock continues northward to within a half mile of Center, a small settlement two miles south of Weybridge village.

Southwest of Center, along a road that descends diagonally across the steep western slope, is black phyllite forming a distinct scarp, to the west and east of which lie calcareous rocks much like those of "The Ledge." The phyllite forms the northern termination of what was designated in the Vermont report and by later observers as the "central belt of slate," and has been regarded as of "Utica" or "Hudson River" age. In the writer's opinion, the rock has little resemblance to the so-called "Utica" of the lake region proper and does not suggest an altered derivative of that formation. On the contrary it is entirely similar to phyllite occurring in Cornwall at the south, which will be described beyond, and which seems clearly to be the northward extension of the phyllites of Whiting and Sudbury, which are regarded as much older. The field relations southwest of Center might possibly suggest that the phyllite is interstratified with the limestone that borders it on the west and east; but such relation is hardly possible if the phyllite is what the writer conceives it to be. The general relations point to displacements and it seems most likely that the phyllite was thrust into the limestone.

North of Center towards Weybridge, east of the road, is strongly sheared, calcareous rock of quite uncertain correlation which lies to the west of numerous outcrops of somewhat marbly, dove-gray limestone associated with chamois-gray patches which are badly crumpled and mixed up.

Farther north, south of Weybridge village, what now appears as massive, gray, dolomitic limestone forms scarps east of the road to Center. The rock has been under compression but is not conspicuously sheared. No fossils were found. In lithology it resembles somewhat the rock at "The Ledge" near the Cornwall line and to some extent also the gray rock that is found at the east in association with the quartzite. Similar rock forms the falls and banks of the river at Weybridge village. The gray dolomite at Weybridge village is on the meridians of that which occurs two miles north of the village in New Haven and the latter, as previously shown, with slight surface interruption joins the interbedded dolomites and quartzites southeast of Buck Mt.

According to Dana, Wing found at Weybridge upper falls, on the west side of the slate, presumably the northward continuation of the phyllite found farther south, "Rhynchonella beds" (called Chazy) lying beneath "Sparry limestone" (Trenton). The "striped stratum" (Chazy) was described as full of fossils. This locality was not seen by the writer, but became known to him from subsequent reading of Mr. Wing's discoveries in Vermont.

Southeast of Center, on the road towards Middlebury and in adjacent fields, are ledges of striped limestone which suggest the Chazy. Farther south towards Middlebury along the road, and over the part of the township lying east and southeast of Center and west of Otter Creek, are abundant ledges of sheared, dark bluish limestone resembling Trenton. These rocks apparently occupy a broad band in eastern Weybridge, west of Otter Creek. Fossils were not found in Weybridge. Later, on a trip made over territory southwest of Middlebury village in northeastern Cornwall, Trenton fossils were found in similar sheared, dark bluish limestones which lie on meridians practically marking the western boundary of the similar rocks in Weybridge.

The Otter which flows north from Middlebury village forms part of the eastern boundary of Weybridge and separates it from Middlebury. On the Middlebury side the sheared, bluish, so-called Trenton rocks give place to marbly, dull gray rocks with associated yellowish or chamois-gray layers which form a broad band in this part of Middlebury township and join at the north with similar rocks in the southwestern part of New Haven, which have been described.

From west to east across Weybridge the rocks, broadly speaking, are not disposed in folds, but in an irregular sequence probably due to reverse fault displacements along the strike, with probably some imbrication due to lateral thrust. The latter is not clearly exhibited by a definite contact in Weybridge, but in Middlebury village below the falls a good overthrust contact may be seen, as will be later described.

Middlebury Township.

(Middlebury and Brandon topographic sheets.)

Location. On the west Middlebury is separated from Weybridge by a portion of Otter Creek, and is further bounded by a part of Cornwall. On the north it is bounded by New Haven and a part of Bristol, on the east by Ripton, and on the south by Salisbury. The eastern portion of the township includes a strip along the western border of the Green Mountain plateau.

General description. The gray limestones and interbedded, buff- or chamois-weathering layers which lie just east of the Otter, north of Middlebury village, have already been mentioned. They give prominent exposures on both sides of the railroad track south of Beldens, and between the track and the river southward towards Middlebury village. In the village below the falls they are in juxtaposition with strongly sheared, limy shales and at one place show a good thrust contact, with the shale which has been pictured by Seely. Seely called the shale Trenton and the overthrust rock Beekmantown.

South of the latitude of Beldens these rocks continue eastward at the surface to the road running from Middlebury village to New Haven Junction. Southward, west of Chipman Hill and east of the railroad track, they largely pass under drift.

North of Chipman Hill a cross road leaves the main road between New Haven and Middlebury and runs one-third of a mile due east and then bends southeastward. South of this road at the northern end of Chipman Hill is sheared limestone which corresponds closely with rock in Ferrisburg to the northeast of the city of Vergennes and which near Vergennes by the fossils in several places and by the lithology in others, was correlated with the Chazy. East of the cross road, after it makes it bend to the southeast, is altered, now somewhat crystalline limestone, weathering to a light blue, which suggests the Trenton. It is apparently without fossils at this place. This rock is on the western margin of a ridge which extends from New Haven into Middlebury, the rocks of which at its northern end in New Haven have been described (page 249). In the Middlebury portion of the ridge, west of the road that runs lengthwise along it, is much the same assemblage of rocks found at the northern end. Rocks identified as members of the interbedded series of dolomites and quartzites are more or less intermingled with outcrops of striped or gray limestone and some gray dolomite. East of the road are abundant exposures of gray limestones associated with somewhat yellowish-weathering rocks. These sometimes give place to striped limestone which resembles the Chazy.

Eastward is Muddy Brook, west of which was seen quartzite associated with some dolomite. These rocks lie on a meridian west of the marble at "marble ledge" quarry near the New Haven line. At the quarry the marble is associated with gray dolomite which forms the eastern wall of the quarry.

East of Chipman Hill is a topographic break in the ridge mentioned above. South of this break, a little north of east of Middlebury village, is a hill of camel-hump shape which is geologically a southward continuation of the ridge. This hill presents relations of much interest. On the top of the hill are interbedded quartzites and dirty, somewhat yellowish-weathering dolomites, dipping westerly and not strongly sheared or folded, which apparently lie on bluish-gray or dull gray limestone which seems to be more deformed and altered. This hill seemed to show the interbedded rocks of probably Lower Cambrian age resting on probably younger (Chazy) limestone.

South of this hill a road runs from Middlebury village eastward towards the mountain. The road forks about a mile east of the village, and near the fork gray dolomite is seen to form a fold or "roll" very much like the structure seen at the old quarry southeast of Leicester Junction and at the Norcross quarry south of Dorset Mt. One-half mile east of the fork, on the north side of the road running east, is the quarry of the Middlebury Marble Co., now worked for lime. The marble is not a very good commercial stone, but in all essential particulars is like the marble in the quarries around Brandon. The marble continues eastward for a short distance at the surface and then gives place to gray, siliceous dolomite and interbedded quartzite and dolomite, the latter dipping easterly at a high angle. The dolomite and interbedded rocks lie along meridians occupied both to the north and south by similar rocks. Eastward is other gray dolomite and then the scarps in the quartzite along the edge of the plateau.

About two miles south-southwest of Middlebury village are ledges of dove-gray or bluish rock which were regarded as probably of Chazy age. The noteworthy structure is the strong shearing. The dip is obscure; in some places it seemed to be to the west; in other places the beds appeared to stand on end. These outcrops are a mile east-northeast of other ledges in eastern Cornwall which carry Trenton fossils, including *Prasopora*.

Two miles directly east of the rocks called Chazy, which were just mentioned, and south of the road from Middlebury village to East Middlebury, are two short ridges composed chiefly of dove-gray or bluish limestone carrying patches of yellowish-gray rock. Similar rocks occur one and a half miles to the southwest, just west of Otter Creek on the road from Farmingdale to Cornwall.

At Farmingdale are outcrops of gray, siliceous dolomite like that usually associated with the quartzite along the eastern border of the lowland. This gray dolomite is intermingled with some marbly limestone along the road running from Farmingdale eastward to within a fourth of a mile of the main road from Salisbury to Middlebury. West of East Middlebury village, near the junction of the main roads, are interbedded dolomites and quartzites forming a gentle anticline, the beds dipping westerly south of the road from East Middlebury to Middlebury on one meridian and easterly to the north of the roads on a meridian slightly to the east of the other.

Along the road from East Middlebury to Bristol, a mile northwest of East Middlebury village, is massive quartzite overlain by dolomite, the latter clearly dipping westerly.

In the bed of the river east of East Middlebury village, beds of quartzite dip westerly.

South of East Middlebury is a hill composed of granular, gray quartzite which is a dismembered part of the rock of the plateau.

The geological relations and topographic features in the eastern part of Middlebury township are very similar to those found at many places along the eastern edge of the lowland and in the Vermont valley. They are in all cases apparently of similar genesis. The rocks in the eastern part of the lowland are dismembered parts of the formations of the plateau.

Bridport Township.

(Port Henry and Ticonderoga topographic sheets.)

Location. Bridport borders the lake and lies south of Addison. It is bounded on the east by parts of Weybridge and Cornwall and on the south by Shoreham.

General description. Away from the lake shore in the western part and over the central portions of Bridport, clay usually conceals the hard rock. Outcrops of shale yielding broken graptolites outcrop intermittently along shore from a point near the northern township line southward past Plumies Point to a conspicuous jog in the shore line about one and a half miles north of Crown Point ferry landing.

Near the landing at West Bridport are what appear to be Chazy and Black River beds.

Seely mentioned some exposures of so-called Beekmantown rocks near the head of the West Branch of Dead Creek; but on his map showed such rocks at the head of the East Branch. The writer did not see these rocks, but found flat, clay-covered land around the head of the West Branch. Southward in Shoreham, shales outcrop on meridians occupied by the West Branch in Bridport.

Shales outcrop north and south of Bridport village and at places along the road which runs east from the main Bridport-Addison road just north of the village. Along the second road running east, north of the village, about two miles east of the Addison road, and on the meridians of the Red Sandrock to the north in Addison, are blackish shales which sometimes are strongly folded and sometimes lie rather flat, all marked by well-developed cleavage. Southwestward these rocks give place at the surface to sheared, shaly limestone and these in turn to somewhat massive, plainly bedded limestone, which is not severely deformed internally and which has much the aspect of other rock a mile to the southwest which is clearly older than the shale. The shale is a mile slightly to the west of south of the southward extension of the Red Sandrock of Weybridge into the northeastern part of Bridport.

South of Bridport village a road runs easterly, to the north of Hemenway Hill. Along this road and south of it in the field are blackish cleaved shales, which a mile east of the main Bridport-Shoreham road are succeeded along the road by thinly-bedded, blue limestone with good Trenton fossils. East of these Trenton beds a road runs southerly on the east side of Hemenway Hill. West of this road and just south of the fossiliferous Trenton outcrops are ledges of rock which in its lithology suggests part of the Beekmantown in Shoreham. Farther south on the east slope of the hill are outcrops of rock of more decided resemblance to some of the Beekmantown. The beds dip to the east and are on meridians occupied by beds correlated with the Beekmantown at Mutton Hill in Shoreham.

The rocks outcropping on the east slope of Hemenway Hill are separated by the flat land along the Lemon Fair River from rocks forming a low ridge in western Cornwall and which appear to be the northern continuation of the rocks of Cutting and Delano Hills in Shoreham, which are considered to be of Beekmantown age, as defined by Brainerd and Seely.

The conditions in the eastern part of Bridport certainly strongly suggest upthrust of older rocks into younger ones, with some overlap of the former. The older rocks are in some cases members of the Red Sandrock series and in others probably of the Beekmantown. Probably Chazy and Trenton beds have in some cases been involved in thrust.

Cornwall Township.

(Port Henry, Ticonderoga, Middlebury and Brandon topographic sheets.)

Location. Cornwall on the west adjoins the southeastern part of Bridport and the northeastern part of Shoreham. It is bounded on the north by Weybridge, on the east by parts of Middlebury and Salisbury, and on the south by Whiting.

General description. The red quartzite of the Red Sandrock series of the Snake Mt. mass projects from Bridport and Weybridge into the northwestern part of the township.

On the meridians of this quartzite, farther south along the western border of the township, is a ridge falling off on the west into the flat land along the Lemon Fair in southeastern Bridport, and sloping more gradually eastward into more or less drift-covered land. The rock in the ridge has been called Beekmantown and certainly has resemblance to part of that formation as described for Shoreham. The dip is apparently generally if not always to the east.

East of Beaver Branch rises another ridge of somewhat similar pattern which is the southward extension from Weybridge into Cornwall of the ridge already described for its northern portion in Weybridge. Its western margin begins at the north in a precipitous scarp known as "The Ledge." The scarp continues southward for a distance of two miles and merges with a more gentle slope northwest of Cornwall village. The beds dip easterly. The rock may be largely Beekmantown, but about a half mile northwest of Cornwall village are beds of dove-gray rock also dipping easterly and apparently stratigraphically above the rocks to the northwest of them. These beds may be Chazy.

Outcrops of Chazy limestone, which in some places show fossils, occur south of the village along the road towards Whiting.

These rocks are succeeded southward by exposures of sheared limestone of uncertain correlation.

The main road going north from Cornwall village forks about a mile and a half north of the village. Along the west branch, near the fork of the road, is black phyllite. Just east of this rock are ledges of sheared limestone which gave good Trenton fossils, as previously described (page 258). The Trenton rocks continue southward to the east of the road through Cornwall village and are intermingled with black phyllite or schist carrying some massive quartzite.

One-third of a mile north of the village a road runs easterly towards Farmingdale in Middlebury. Two-thirds of a mile east of the main road are ledges of quartzite with associated black phyllite which are succeeded easterly by ledges of limestone resembling the Trenton. Fossils were not found. Eastward are beds of sheared rock resembling the Chazy. These presumably Chazy beds form a short, low ridge along the western border of the northern end of Cedar Swamp; the beds dip easterly and carry obscure fossils.

Near the Whiting line a road runs easterly from the main Whiting-Cornwall road towards Salisbury station. Black phyllite outcrops along this road and in the fields north of it, to the west of Cedar Swamp. Observations showed that the black phyllite or schist is frequent north of this road, between the swamp and the Whiting-Cornwall road. It is associated with sheared limestone of uncertain correlation.

Black phyllite was also found along the road running west from Middlebury village, about two and a half miles west of the village and a mile south of the Weybridge line. This phyllite joins that of Cornwall with that of Weybridge.

The relations northeast, east and southeast of Cornwall village are strikingly similar to those found at the northern end of the Taconic range in Sudbury, except that in Cornwall there is less quartzite exposed and more phyllite mingled with the calcareous rocks than is the case in Sudbury, and that the calcareous rocks carry obscure fossils in Cornwall and in other respects seem to be more easily recognized. The phyllites of Cornwall join through the similar rocks of Whiting with the quartzites and schists of Sudbury.

In the early descriptions of the black and lighter colored phyllites and the quartzites which extend north from Sudbury through Whiting and Cornwall into Weybridge they were regarded as of "Utica" (Brainerd and Seely) or "Hudson River" (Vermont Report, Wing and Dana) age. The principal reason for such assignments seems to have been because they are associated with rocks of Trenton age, which are intermingled with them or border them.

The Vermont Report and Wing both recognized that the "central belt of slate" in Weybridge, Cornwall and Whiting is the northern continuation of the Taconic range; but apparently neither considered the possibility that the rocks composing it may be much older than they indicated.

It has already been remarked that the phyllite of Weybridge bears little resemblance to the rocks near the lake. The quartzite occurring with the phyllite in Cornwall and Whiting in such way as to leave no doubt of the common membership of the two in one formation seems to prohibit the inclusion of these rocks with the Ordovician shale. On the other hand, the phyllite and quartzite are so similar to rocks in the Taconic range and at some places along the western margin of the plateau near Brandon that they probably belong to the same formation and to one including the granular quartzite, and are probably, therefore, of Lower Cambrian age.

There may also be said to be some doubt as to the inclusion of all the gray, dolomitic limestone that occurs to the east of the Red Sandrock of Snake Mt. in northern Cornwall, but particularly in Weybridge, in the Lower Ordovician (Beekmantown). On a lithological basis, which is often the only one that may be employed, it would be hard to decide; for some of the gray rock is siliceous and has much the same appearance as the rock associated with quartzite nearer the plateau. The matter is complicated not only by undoubted deformations, but probably also by unusual conditions of sedimentary overlap of Ordovician beds on an eroded surface of Cambrian rocks which included siliceous dolomite, as has been frequently shown.

Shoreham Township.

(Ticonderoga and Brandon topographic sheets.)

Location. Shoreham lies south of Bridport and is bordered on the west by the lake, on the east by parts of Cornwall and Whiting, and on the south by Orwell.

General description. In his first paper the writer briefly discussed certain features of the geology of this township, based upon a personal review of the geological relations described by Brainerd and Seely, and in connection with the geology of the town of Orwell which adjoins Shoreham on the south. The eastern part of the township displays the type section of the so-called Beekmantown of western Vermont. For a detailed description of this section the reader is referred to Brainerd and Seely's original account.[1]

What underlies the flat land along the course of the Lemon Fair River in southeastern Bridport may only be conjectured; but immediately east of this flat area in Cornwall and south of it

[1] Bull. No. 3, Amer. Mus. Nat. Hist., 1890-91.

in Shoreham are rocks which by comparison with those of the East Shoreham section are apparently to be correlated with the so-called Beekmantown. In the very northeastern part of the township the Lemon Fair has trenched these rocks and low cliffs appear in them on both sides of the stream. On the east side, practically on the Cornwall line, and on the road running west from West Cornwall village, a steep westerly dip was noted and the beds are sheared across the bedding. From these ledges a scarp runs southward along the western base of the hill and the prevailing dip along it is apparently to the east. About two-thirds of a mile south of the westerly-dipping beds some Chazy appears to be present on the west side of the road. Southward along the old "Amherst road" to Richville what appear to be Beekmantown rocks may be followed by intermittent outcrops showing easterly dip nearly to Richville. The rocks along this road are the northern extension of those of Delano and Cutting Hills which are included in Brainerd and Seely's Shoreham section of the Beekmantown.

Observations show that the eastern half of Shoreham township is largely formed of Beekmantown which is associated with some older rocks of so-called "Potsdam" age and younger beds belonging to the Chazy and Trenton. Chazy and Trenton beds border the Beekmantown on the east and are involved with it just east of Shoreham village. As Brainerd and Seely clearly showed, the massive rocks have been broken by thrust faults along the general strike of the rocks at several places. By these thrusts the older Beekmantown and underlying "Potsdam" have been fractured so that older beds have moved into and over younger rocks. Prior to or during thrusting, some folding occurred; but the major deformation was that of fracture accompanied by thrusting.

At Mutton Hill, two miles north of Shoreham village, massive beds of quartzite of so-called "Potsdam" age dip easterly on the west side of the hill and appear to pass conformably beneath Beekmantown beds which also dip easterly. Southeast of Mutton Hill quartzite and dolomitic limestone show the effect of great pressure and at some places have easterly dip.

The "Potsdam" quartzitic sandstone and overlying Beekmantown may be followed south from Mutton Hill through Shoreham village to Barnum Hill near the Orwell line and then into Orwell, where the marginal trace of the overthrust rocks may be seen north of Huff's Crossing.

West of Shoreham village, at Sisson Hill and west and northwest of it, and along the road from Larrabee's Point to Cream Hill are abundant exposures of the black Ordovician shales, often folded, but sometimes lying nearly flat, and always sheared. These shales show practically the same structural features as those which have been described in previous pages. It has become evident that the shales hold throughout a long distance in western Vermont to much the same structural features. Near the margins of overthrust they are always excessively jammed and sheared, but may nevertheless often retain a flattish attitude, having undergone their chief deformation by shearing.

The shales outcrop at Fivemile Point and southward along the lake shore, but in northwestern Shoreham the area intervening between the shore and the road running north from Larrabee's Point is covered by the ubiquitous clay.

East of Cream Hill is Cedar Swamp, which separates the shales of Cream Hill from the "Potsdam" and Beekmantown of Mutton Hill. Shales presumably underlie most of the area of the swamp, which marks a zone of displacement.

Near Larrabee's Point, north of the boat landing, are Trenton beds in association with shales and, south of the landing, Trenton beds are underlain by others of Black River age and these by gray limestone of uncertain correlation.

In Shoreham the evidence for reverse faulting and thrusting is clear and distinct. It is even more so in Orwell at the south, as the writer has elsewhere shown.

Whiting Township.

(Brandon topographic sheet.)

Location. This township lies directly south of Cornwall. It is bounded on the west by parts of Shoreham and Orwell, on the east by parts of Salisbury and Leicester and on the south by Sudbury.

General description. For Whiting a brief description will suffice. The hard rocks are concealed by surface material over much of its area, particularly in the eastern portion to the west of Otter Creek. As already mentioned, the phyllites extend north from Sudbury through the central part of Whiting. In the northwestern part, limestone of apparently Trenton age borders the band of phyllite on the west. In the southeastern part along and near the road running from Whiting village to Leicester Junction and also south of this road are more or less detached exposures of limestone which seems to be the northern continuation of sheared, marbly and bluish limestone carrying layers and patches of yellowish-weathering rock which make up the conspicuous hills in the northeastern part of Sudbury. Eastward, these rocks join with others that are similar in the western part of Leicester.

Salisbury Township.

(Brandon topographic sheet.)

Location. The western boundary is formed by a portion of Otter Creek, which separates the township from parts of Cornwall and Whiting. It is bounded on the north by Middlebury, on the east by parts of the mountain towns of Ripton and Goshen, and on the south by Leicester.

General description. The western portion between Otter Creek and the railroad track is low, flat land and affords few outcrops. West of Salisbury station, in the lowland that borders Otter Creek, are a few island-like knolls of marbly or bluish limestone with layers of chamois or pinkish-buff color. The rocks frequently show thinly laminated structure. The whole assemblage is much like that found southward in Leicester and in the northeastern part of Sudbury and adjoining parts of Whiting.

A road runs south from Salisbury station, just to the east of the railroad track. East of this road and a few rods south of the station, dove-blue or marbly limestone, often with thinly-laminated structure that represents or simulates bedding, is associated with chamois or pinkish-buff colored beds and the two give an assemblage that is very much like that found in the hills in the northeastern part of Sudbury. The structure is often much like that found among the interbedded quartzites and dolomites lying to the east; at places beds which have been closely folded and now stands on end lie against others forming a gentle syncline. Between such compressed zones and the less violently folded rocks there apparently exists a displacement due to reverse faulting. These rocks continue southward. A mile south of the station, south of a cross road running east, in some outcrops of westerly-dipping beds which appeared to be conformable, bluish, marbly limestone is interbedded with chamois colored rock and these are apparently underlain by interbedded marble, chamois-gray limestone and quartzite, the latter usually in thin beds but showing one about a foot thick.

Two-thirds of a mile to the southeast of these outcrops is a hill in which the rock on the west slope and part of the summit is marbly, dove-blue rocks showing extreme effects of pressure which is expressed by conspicuous flow and fracture shearing. At the summit of the east slope of this hill are patches of quartzite which seemed either to rest on the sheared, marbly rocks or to be involved with them by thrust.

On the meridian of these rocks, about a mile south of West Salisbury village and east of the road running south from it, is another hill on the northwestern side of which are many outcrops of striped blue rock, strongly resembling the Chazy of the lake region. The beds have prevailingly westerly dip, but are strongly sheared with easterly dipping cleavage. No fossils were found. A cross road skirts this hill on the south and runs easterly to join the Farmingdale-Salisbury road. Along the cross road, to the east of the hill, is gray, siliceous dolomite like that associated with the quartzite along the eastern edge of the lowland. A few rods east of this dolomite is marble, then more gray dolomite dipping easterly, then east of the Farmingdale road the interbedded series of quartzite and dolomite which forms an anticline between the Farmingdale road and the one that runs northward from Salisbury village on the west of Sunset Hill.

From descriptions just given, it will be apparent, by reference to the writer's first paper, that northwest of Salisbury village, marble, gray dolomite and interbedded dolomites and quartzites are involved in field relations quite like those which occur around Brandon.

West and north of Lake Dunmore, quartzite, siliceous dolomite and interbedded quartzites and dolomites have such field relations to one another as to leave no doubt, even in their present disturbed and eroded condition, of their common membership in one formation. To what extent these different rocks may grade laterally into one another the conditions in the eastern part of Salisbury do not permit statement. As has been elsewhere shown, at some places in the Vermont valley the vertical sequence is more or less plainly from basal quartzite through gray dolomite into interbedded quartzites and dolomites.

East of Lake Dunmore is a very prominent scarp of quartzite forming the western edge of the plateau. Dolomite resting on quartzite occurs above this scarp around Silver Lake. It also occurs at places around the shore of Lake Dunmore in such relations as to indicate that normally the dolomite rests on quartzite. The rocks around Dunmore and north of it are in fact more or less completely dismembered portions of the plateau.

A section from Lake Champlain eastward through Shoreham, Whiting and Salisbury to the Green Mountain plateau is comparable with one farther south extending from the lake eastward through Orwell, Sudbury and Brandon. The essential similarity is disguised but not obscured by differences in degree of displacement of the rocks. The northern section is a downthrow region in relation to the other, partly from flexure in the direction of the strike and partly from faulting, due in part probably to deformation subsequent to earlier thrust displacements. It should again be noted, perhaps, that it will apparently always be difficult to discriminate between displacements primarily resulting from pressure and those which were caused by normal faulting either along independent planes, or along those of earlier thrusting.

In the northern section the younger rocks (Ordovician) are more fully preserved and apparently show, in spite of deformation, an overlapping, probably disconformable, depositional series ranging from the "Potsdam" (Ozarkian) through "Beekmantown," Chazy and Trenton. Thrusting has partly restored the ancient Cambrian surface on which these rocks were laid down.

In the southern section the Cambrian is more fully shown (see writer's first paper).

Leicester Township.

(Brandon topographic sheet.)

Location. Leicester lies south of Salisbury. It is separated by a portion of Otter Creek from Whiting on the west and is bounded on the south by Brandon and on the east by Goshen.

General description. The rocks of this township join those of Salisbury with those of Brandon. They present practically nothing that is essentially different in respect to rock type or structure from the areas to the north and south.

The ledges in southern Salisbury are separated from outcrops in southern Leicester by the wooded flats or swampy land along Leicester River and its tributaries.

In the Huntley lime quarry, west of the Otter at Leicester Junction and west of the main quarry at some smaller holes, may be seen buff and pinkish colored beds of marble or crystalline limestone, usually standing at a high angle of dip. At the big quarry these beds are jammed in with gray dolomite and all show the effects of extreme compression; but none of the rocks indicates much in any respect as to its age.

At the so-called Swinnington quarry, southeast of the Junction and east of the Otter, marbly limestone which has been quarried is overlain by gray, magnesian rock which shows a remarkable fold in the form of a recumbent, closely compressed anticline which has been aptly called a "roll." This is pictured by the State Geologist (Seventh Report, p. 352). The roll is interpreted by the writer as the portion of a mass now largely eroded which was thrust over the marble on which it now rests. The peculiarly folded structure was probably acquired by frictional drag during thrust. Similar rolls have been mentioned in previous pages for other places in western Vermont at which apparently similar rocks were involved.

Two-thirds of a mile east of the Junction, north of the road running east from the covered bridge, are ledges of dove-blue or marbly limestone with patches of chamois-gray. Eastward these pass under drift; but about a mile to the east are ledges of strongly sheared, striped, blue, crystalline limestone not very distant from others of gray, siliceous dolomite like that which is associated with the quartzite at the east. East of these are other ledges of dove-blue limestone and its associated chamois-gray rocks and farther east the interbedded dolomites and quartzites which are much folded and form the southward continuation of the similar rocks of Salisbury and the northern extension of those in Brandon. The interbedded rocks extend in Leicester to the east of Mt. Pleasant, which is bordered on the east by a distinct scarp, at the base of which lies Mud Pond.

Lake Dunmore lies in a structural basin perhaps primarily of synclinal structure, but bounded on the west and east by faults. Those on the east are the southern extension of those marking the western edge of the plateau in Salisbury.

In some particulars the interbedded rocks of Leicester form a transition between those found farther south in the Vermont valley and those occurring over the eastern portions of the lowland in the northern townships. This transitional character is shown by thicker beds and by reddish colors which are more common at the north.

GENERAL SUMMARY.

Edward Hitchcock in his "Preliminary Report," a sort of preface to the first volume of the Geology of Vermont, wrote in substance that the rocks of Vermont were the most difficult ones to understand of any with which he had ever attempted to grapple. It does not appear in his remark whether he drew any distinctions among the different rocks; but apparently he recognized that although the geology of some parts of the state is easier to comprehend than that of other parts, the whole region is one of great complexity. The efforts of many workers have contributed only to a partial solution of the age relations and structural features of the various rocks.

In the lake region proper, as defined in this paper, fossils were found many years ago and the ages of the different rocks are now for the most part at least approximately known; but their structural relations have always been and are even now obscure. While distinct progress has been made by Wing and others in tracing the formations of the lake region into the eastern parts of the Champlain lowland, the Vermont valley and the Taconic range, it has not seemed altogether strange that Hitchcock was confounded by the obscurity which prevails over the areas which he mapped as "Eolian Limestones," in which metamorphism and deformation have introduced so much confusion.

It is not the purpose of this summary to point out in detail how the writer's views differ from those of others; but it seems as though confusion has often resulted from failure to interpret correctly the major structural features of the region.

For the sake of convenience of discussion, western Vermont may again be broadly defined as that part of the state which includes the islands of the lake and the low areas along its borders, herein called the lake region proper, the relatively low land lying between the lake region and the Green Mountain plateau, the western marginal portion of the plateau, the Vermont valley and the Taconic range. These various divisions together form a fairly broad region east of the New York boundary, reaching across the state from north to south.

The writer started out on the program of surveying this whole region. The work has been accomplished, after a fashion, for the Vermont valley and the Champlain lowland and for parts of the Taconic range and the western margin of the plateau. The survey as made has hardly been exhaustive, but has been carried out as carefully as possible in the time that has been available for the purpose. Experience has served to show how puzzling are the problems presented by the region and how elusive is any final and definite solution of some of them. However, in spite of the difficulties that stand in the way and the uncertainties that exist, there seem to be manifest such similarities among various rocks and in the field relations shown by them that some generalizations may be offered which would hardly be warranted without a survey of the region as a whole.

When the various outcrops that have been described in the preceding pages have been plotted on the several topographic sheets involved and these are placed in their proper positions with respect to each other, certain features and field relations stand out which now deserve examination and discussion.

In the first place it becomes very evident that the major physiographic features and many of the minor ones as well are primarily due to ancient deformations of the rocks which set the stage for later structural changes and the action of erosive agents. The various divisions which have been defined are all structurally homologous areas, some more obviously than others, which are at the present time largely separable only on geographic and physiographic bases. This homology consists in the essentially identical types of rocks found in each and the major structural relations which these formations have to each other. While the writer's studies in the Taconic range lack the measure of fullness of those carried out in the lowland divisions, it seems most probable that this division is only a special physiographic type whose principal features are incident to the ways in which the forces which deformed the whole region acted in the portion of the region occupied by it at different phases of its history and to certain primary variations among the various related rocks that were laid down in what is now western Vermont. It seems probable that distinctions among the various rocks of the region have often been made on secondary features and that an essential unity in rock type and structure has been overlooked.

A tendency to regard different portions of the region as things more or less apart has appeared in one form or other during and since the days of the early surveys, and it may be said that by reason of the heterogeneity that exists over western Vermont as a whole, on account of primary differences among the rocks and metamorphism and deformation, it is not surprising to find that what now appear to be subordinate or secondary features have been emphasized and that fundamental similarities have been overlooked.

In the first place, it is well again to note that the lake with its islands differs in no essential way from the mainland areas which adjoin it; the clay or sand or bowlder drift that usually conceals the hard rock on the mainland differs only in physical properties from the water of the lake. In fact, as has already been pointed out, in many places near the lake and within its confines, clay instead of water may be said to inundate the land where the surface of the hard rock is below the present water-level. The areas of the hard rock now beneath the waters of the lake, or beneath the deposits of one kind or other which take their place, are probably primarily old stream denuded surfaces which have been generally modified by glacial action and in certain portions after inundation by water also by the waves. The topography of the lake region stands in contrast to the rest of the Champlain lowland on account of the more vulnerable character of its rocks, whose presence at the surface is a circumstance consequent upon relations produced by ancient deformations which the region underwent.

If, as seems likely, there have not been any marked displacements of the crust during or since the action of the erosive agents which shaped the present surface, then the several physiographic divisions of the region may be regarded as chiefly consequent upon relations produced among the formations by crustal disturbances.

The islands of the lake and also, without much doubt, the hard rock surface beneath the water, as well as extensive areas of the adjacent Vermont mainland over which the hard rock is partly exposed and partly hidden, are dominated by rocks which, although altered and deformed in varying degrees, are on the whole less metamorphosed and less crystalline than are the various formations of calcareous rocks found over the areas that lie to the east of the lake region. Away from the lake along surface sections from west to east at some latitudes the succession is often marked by a sort of transition from comparatively little altered rocks, through others in which fossils have been largely obliterated to highly metamorphosed rocks with dim, uncertain traces or else no suggestion of organic remains. Even along such sections it should be understood that the sequence is not one marked simply by difference of metamorphism of the rock, but is an interrupted one caused partly by deformations and partly by erosion. In some sections, on account of displacements and thrusts which have moved rocks from the east over those at the west, the change from rocks whose geological age may be fairly readily apparent, at least so far as the fossils are understood, to rocks which have been profoundly altered is abrupt.

The rocks of the lake region, including the islands and much of the adjacent mainland, as determined by their fossils, range in age from lowest Ordovician (possibly Upper Cambrian), "Ozarkian," through various horizons of "Beekmantown," Chazy and Trenton, possibly to horizons that are homotaxial with the Utica as elsewhere known. The so-called Ozarkian is an indurated sandstone, in some places apparently lying conformably beneath basal Beekmantown magnesian limestone. In New York, in the Mohawk valley and elsewhere, these two formations are described as separated by an unconformity which it is claimed has been traced into the Champlain and St. Lawrence valleys; but the unconformity in the lake region is not apparent from any physical evidence. The fossils are scanty and poorly preserved.

The East Shoreham section appears to give the complete series of the Beekmantown of the lake region, but elsewhere usually only parts of this formation are shown. The special characters of the members of this formation will not be described at this place. When all are present the thickness has been estimated as about 1,800 feet. The Chazy succeeds the Beekmantown, and at some places, as at Isle La Motte, the lowest beds of the series show indications of shallow water or shore origin, suggesting oscillations of the sea bottom and probably a disconformity. In a large number of places the Chazy rocks have a considerable thickness, but usually this formation, like the Beekmantown, is apparently only partly represented, at least in surface exposures. At numerous localities Chazy rocks, often clearly belonging to the intermediate members of the series, or so-called Middle Chazy, are overlain by beds of dense, black limestone of Black River age.. The Black River is suceeded by the basal Trenton ("Glens Falls") limestone, which is in turn followed by a series of argillaceous limestones and shales, some of which form a more or less distinctly transitional group with respect to both lithology and fossils between the basal Trenton limestone and the mud rocks that make up the youngest Ordovician of the lake region. These mud rocks are apparently of Trenton or of Trenton-"Utica" age.

Without much doubt, the original primary sequence among the various rocks now exposed to view in the immediate region of the lake was as above given and may be summarized as follows:

1. "Ozarkian" sandstone.
2. Beekmantown siliceous and magnesian limestones.
3. Chazy limestone, including some sandstone at the base.
4. Black River limestone.
5. Trenton (basal or "Glens Falls") limestone.
6. Transitional limestones and shales ("Canajoharie," Trenton, Ruedemann).

7. Later shales ("Stony Point," Trenton, Ruedemann), some of which may be contemporaneous with Utica as elsewhere known (New York).

Whether the different formations just enumerated are separated from one another or are broken within themselves by erosion intervals will not be discussed at length in this paper. Apparently our present knowledge is insufficient to decide the matter in many cases. From what is known of the relations among apparently equivalent formations elsewhere, as in New York for example, disconformities are probably present; but in Vermont the conditions make it difficult or impossible to say whether the partial representation of a formation at many places is due to non-deposition or to displacements among the rocks. At the present time there is no section which shows all these formations in their sequence. In some places a surface covering undoubtedly conceals portions of formations; but at other places parts are clearly absent, either as the result of non-deposition or from other causes.

The various formations of the lake region have clearly been disturbed and probably by more than one deformation. As a whole they have been faulted down with reference to the crystalline rocks of the Adirondack region; but in addition they show unmistakable evidence of profound compression which finds expression in disturbed relations due to fracture and reverse faulting within the various formations with varying degrees of actual overthrust, which sometimes carried the older rocks on the younger limestones and shales. The less resistant, more thinly-bedded rocks have been somewhat broken and faulted as masses, but have been more conspicuously sheared by fracture cleavage; the more massive formations were also internally deformed but were more characteristically disturbed by mass dislocation. At some places it is very evident that the rocks have been moved and are now not in their original relations to other rocks with which they are contiguous and at other places the presumption is often very strong that displacements have occurred. It is not always easy to decide whether a deformation which is clearly due to compression is a case of relatively simple reverse faulting, or whether considerable lateral movement with actual overthrust has taken place. In the preceding pages the probabilities have already been discussed for various localities.

In the lake region the base or floor on which the series of formations above enumerated were laid down is not exposed. One would suppose that at some depth or other the oldest member of the lake series which seems to be the so-called Ozarkian sandstone must rest on older rock; but rocks older than this sandstone which apparently could have formed the floor of the Ozarkian sea are not certainly known in the Vermont portion of the lake region, except the members of the Lower Cambrian formation

which have been brought to their present relative positions by thrust. Furthermore, the Ozarkian sandstone at no place where it is now exposed is, so far as the writer knows, in undisturbed condition, but on the contrary occupies its present position by thrust. On the west side of the lake the Potsdam sandstone is often in faulted relations with the members of the lake series. The Lower Cambrian rocks that lie to the east of the lake give only a vague suggestion of what is at depth in the lake region proper. Presumably these Lower Cambrian rocks extend beneath the lake at some unknown depth; but what immediately overlies them is not known.

Why the various thrusts which may be shown to exist in the immediate lake region have always cut through the Ozarkian or some younger formation it is not easy to understand. If the lake series rests on older rocks than the Ozarkian but younger than the Lower Cambrian, one wonders why such rocks do not now appear at the surface somewhere or other in the lake region. The fact that they do not and that the members of the Lower Cambrian do not appear by upthrust west of their present margin forms the basis of the conception, first clearly formulated by Logan, that there was a great lateral thrust fault by which the older masses at the east were driven over the rocks of the lake region. But of the fact that the members of the lake series have themselves in varying degrees participated in thrust movements there is now no longer any doubt.

It is possible that there exists a deep-seated plane of major thrust that cut through the roots of successive reverse faults and that this plane is beneath any rocks now exposed in the lake region and is concealed because of subsequent normal faulting which dropped all the rocks that lie betweent the Adirondack mass and the Green Mountain plateau. If such a plane exists and if it cut through pre-Cambrian rocks it might not be easy to recognize and could hardly be detected on the Vermont side of the lake.

On the New York side of the lake is a sandstone of Upper Cambrian age which is not like the Ozarkian sandstone of the lake series in Vermont. This sandstone has not been recognized in Vermont, but has a wide distribution on the east and north of the Adirondacks, where it apparently rests unconformably upon pre-Cambrian rocks. One is confronted with a problem of great complexity in trying to account for the deformations and primary conditions which could have produced the present relations.

It seems probable that so far as thrusting is concerned the situation involves some such history as follows: Possibly during a time when overlying masses of rock which are now eroded were present in the region, there occurred more or less extensive thrusts by which older formations were driven through younger ones. These great shears, as such, did not necessarily pass to the surface at the time they occurred, although if they did, they seemingly must have had some expression there, probably as folds. In any event the effect obviously was to bring older against younger masses. This was not accomplished in any set fashion, but by irregular displacements of varying degrees. There was, however, produced a considerable regularity in the relations which certain formations came to have to one another. One may imagine that at certain places, notably in the lake region, on account of diminishing pressure, older rocks were not driven into overlying formations far enough to cause them to appear at the surface during later erosion. It seems also probable that during such deformation older rocks were often carried over relatively undeformed younger formations and that the latter were preserved until relatively recent times by a covering of more resistant rock. The present preservation of relatively soft rock was not due, however, simply to the service of a protecting covering, but was favored by crustal deformations due to normal faulting which occurred after the period of thrusting and which brought different areas of the region to a lower elevation with reference to the base level of erosion.

It seems clear that all the different rocks were subjected to a certain amount of compression, but that on account of the massive character of many of the formations involved, folding was subordinate and fracture with thrust became the dominant type of displacement.

There are good reasons for thinking that a thrust which was initiated, perhaps as a reverse fault, in one formation often sheared away from it into an overlying one and that from such behavior either the older formation or the one overlying it was driven over a still younger formation. Various modifications might have been produced. By a series of reverse faults preceding the development of a horizontal thrust the latter could be conceived as cutting the planes of the faults at depth and as driving several blocks on a common shear. If the several reverse faults were of different degrees of throw the thrust might have cut through younger rock at the west than at the east or have driven in different ways at different places, producing final effects not very different from those resulting from the mode of behavior postulated in the first part of this paragraph.

The applications of the ideas as to possible or probable thrust behavior which have just been given depend, however, not only upon the recognition of thrusting as the dominant mode of deformation of the region under compression and upon the present apparent relations which the various formations have to each other, but also upon the relations that existed among these formations prior to the action of pressure. The explanation of the conditions which now exist requires, therefore, some examination of the question of the probable primary relations of all the rocks to each other.

For the lake region proper the probable primary sequence of the various formations now found within it has been given. On the New York side of Lake Champlain, for the areas that lie along or at various distances away from the lake, apparently studies yet remain to be carried out in detail with regard to arrangements among the rocks with special reference to displacements. In Vermont, as is evident from the descriptions that have been given, the lake rocks have been disturbed by thrusts and there may be recognized a more or less well defined zone of demarkation at the present surface between the relatively unaltered rocks of the lake region and others lying to the east which are either visibly more altered or are notably different in age and lithological character. This zone constitutes what has long been known as "Logan's line."

Regarding this zone for convenience as a line, by which symbol it would be portrayed on a map, it may be described for purposes of summary as follows: Entering Vermont from Canada in western Highgate it follows the present lake shore for two or three miles, then extends through the south-central part of Highgate into Swanton, then passes approximately through the central parts of Swanton and St. Albans to St. Albans Bay. From St. Albans Bay southward it extends roughly parallel with and near the shore in the southwestern part of St. Albans, and on through Georgia and Milton to Colchester, where it coincides with the present shore north of and around Malletts Bay. It cuts across Colchester peninsula to the shore north of Burlington and southward across Burlington and Shelburne Bays. From Shelburne Bay southward across the southwestern part of Shelburne, on through Charlotte, Ferrisburg, Waltham, the southeastern part of Addison, and the northeastern part of Bridport, the surface relations usually permit fairly definite separation of the older or metamorphosed rocks from the lake series, but drift often more extensively separates outcrops and hides relations in these townships and from Ferrisburg to Bridport the apparent line of separation is a decidedly sinuous and irregular one with encroachment eastward at some places of the members of the lake series on meridians which to the north and south are occupied by overthrust rocks.

From the Canadian boundary to Bridport the line that is being described marks for the most part an abrupt separation of the youngest Ordovician rocks, which are generally shales with some included siliceous bands, from more or less altered and metamorphosed calcareous rocks, or from massive, interbedded quartzites and dolomites that belong to the Cambrian system.

From northeastern Bridport southward through Shoreham into the northern part of Orwell the Cambrian rocks are concealed and the zone of overthrusting is occupied by not very greatly altered rocks belonging to the Ozarkian or Beekmantown formations of the lake series which take the place of the members of the Red Sandrock formation or of much altered calcareous rock which are prominent along the margin of overthrust for so many miles in the northern townships. In the latitude of Shoreham the rocks that apparently represent the Red Sandrock series farther north are black phyllites with interbedded quartzite members. These rocks lie farther east in Weybridge, Cornwall and Whiting and emerge from beneath more or less altered calcareous rocks that may in some cases be rather satisfactorily correlated with members of the lake series. The phyllites of Whiting join southward with those of Sudbury at the northern end of the Taconic range. The phyllites and quartzites of Sudbury and Hubbardton pass beneath the calcareous rocks of eastern Orwell and northeastern Benson, which are of Chazy-Trenton age, and rise in central Orwell and in Benson to form high hills which are on meridians occupied by the Red Sandrock of Snake Mt. in Addison township.

The phyllites and quartzites of the northern part of the Taconic range are here and there overlain by Chazy and Trenton limestones with which they are now involved through thrusting and faulting. In the writer's first paper an attempt was made to show that phyllites and quartzites, like those of the Taconic hills, probably pass beneath the various calcareous rocks of the Vermont valley and join with similar rocks of the Green Mountain plateau, although attention was distinctly directed to the probability that both reverse and normal fault plane now separate the rocks of the Taconic range from those of the plateau.

A broad acquaintance with the rocks of western Vermont would, in the writer's opinion, serve to show that the fractures and displacements constituting the zone which has just been traced are only accentuated instances of many such displacements which break the rocks along their strike in the lake region, in the eastern parts of the Champlain lowland and along the western margin of the plateau. Along Logan's line, so-called, it is easier to discern the presence of thrust dislocations because of the wide difference in age and lithological characters of the rocks now in contact; in the lake region and particularly in the areas to the east the differences between rocks that lie in displaced relations are not always so readily seen.

The rocks east of Logan's line essentially form a Cambrian surface. Different maps that have been published and different descriptions of the region have recognized the presence of rocks of later age than the Lower Cambrian here and there over this surface. In some cases the rocks that with more or less definiteness may be distinguished from Lower Cambrian have a considerable extent and continuity, but on the whole, they may be said to be fragmentary in character, as now preserved, and more or less intermingled with Lower Cambrian and possibly other Cambrian rocks.

The rocks which in this paper are correlated with the Lower Cambrian are far from being homogeneous throughout their extent. In previous pages, frequent mention has been made of the manner in which these rocks vary in lithological character in a lateral direction, even within relatively short distances, and vertically from bed to bed. Some types of rock found in the terrane have a wide geographical extent in the region, but it is not certain that at different places they belong to the same horizons. Over the region as a whole, the terrane as now displayed is distinguished by notably different kinds of rocks, some of which are extensive enough to be regarded as formations; but such differences, even though pronounced, seem to be explainable in part as due to differences in respect to sources of supply of material and to different conditions of deposition and in part to disturbances and alteration which the rocks have experienced. Over a large part of the region an ancient Cambrian surface has been partially restored by processes of thrust; it is not a perfect restoration, partly because of irregularity of thrust and partly because of erosion. Within the areas which have been surveyed the presumably younger rocks that are here and there intermingled with the Cambrian in the lowland have not been found on the higher land that borders the lowland on the east.

The rocks which in this paper are correlated with Lower Cambrian include:

1. Apparently altered derivatives of older rocks of probably pre-Cambrian age; sheared quartzitic rocks, frequently gneissoid or coarsely schistose, sometimes conglomeratic and sparingly arkosic, found at numerous places along the western marginal portion of the Green Mountain plateau and in the hilly land adjacent to it.

2. Extensive areas of white and gray, granular quartzite, frequently sheared but often without pronounced internal deformation, occurring in heavy layers or as thick masses of relatively thin beds. These rocks grade laterally and vertically into flaggy quartzites, schists, phyllites and slates. These various rocks are now found within the marginal portions of the plateau, and along the eastern portion of the Champlain lowland and mixed with graywacke quartzite are found in Weybridge, Cornwall and Whiting and in the northern portion of the Taconic range.

3. Massive, gray, siliceous dolomites and dolomitic quartzites grading laterally into one another and into quartzite and downward into sheared or massive quartzite and perhaps laterally and downward into schists or phyllites; grading upward and perhaps laterally into

4. More or less distinctly interbedded dolomites and quartzites which vary in different parts of the region with respect to thickness and color of the different members.

Members of 3 are common along the margin of the plateau and in the eastern portion of the lowland in association with different members of 2 and with different phases of 4 occur over much of the lowland, intermingled with quartzite or schist, or with calcareous rocks of probably younger age.

These different rocks appear to be parts of the same general formation. Very different kinds of rocks were probably essentially contemporaneous and all together probably originally composed an essentially conformable series. Published descriptions of the different geographical or more or less altered phases of this series have differentiated them into Granular Quartz, Talcoid Slates and Schists, Talcoid Conglomerate, Dolomite, Red Sandrock, etc. and have recognized only in part what the writer believes to be their essential contemporaneity. Into the nomenclature that has at one time or other been employed to describe these rocks there have crept some terms indicative of age which seem to be in many cases distinctly misleading in their implication.

Topographic conditions may be largely discounted. Present geological relations must reckon with the evidence that the rocks of western Vermont have been jammed, sheared, faulted and driven over one another. Ancient effects due to compression and normal displacements which apparently came later are sufficient to account for most of the field relations, if the principle of lateral variation, as discussed in preceding pages, be allowed.

Fossils have been found by different workers at various places in western Vermont among the rocks enumerated above and correlated with the Cambrian. Most of the fossils are regarded as of Lower Cambrian age.

Some observers have assigned a different and much later age to certain rocks which have not yielded fossils and which the writer regards as probably parts of the Lower Cambrian. Such assignment has apparently often been based on such features as superposition with respect to rocks probably younger than Lower Cambrian and intimate field association with such rocks. Such relations might readily have been produced by thrusts and other displacements, as has been elsewhere discussed.

Others have "hazarded" an opinion that at some places some members of the series that is herein regarded as probably Lower Cambrian may be of Middle Cambrian age; but apparently such opinion is based on the idea that the thickness which has been assigned to the Lower Cambrian is too great along certain sections in which the rocks appear to be conformable. Again it seems that sufficient account has not been taken of the deformations of the region and the probable existence of displacements in an apparently conformable series.

It is recognized that fossils have been found, as has been mentioned in this paper, which suggest a Middle or late Cambrian age for certain rocks now present in western Vermont.

The localities at which these fossils were found are in the northwestern part of the State. The rocks yielding them are in some places slates, in others, a peculiarly fragmental rock which has been referred to as an "intraformational conglomerate."

From the time when the Cambrian rocks of western Vermont, which were first called Middle Cambrian, were recognized as belonging to the lower part of the Cambrian system it has usually been supposed because of failure to discover over any considerable portion of the region, fossils that could positively be called Middle or Upper Cambrian, that rocks belonging to those horizons were never deposited in what is now western Vermont. It cannot be affirmed to-day that such rocks were ever laid down over any considerable part of it. But taking such fossils as have been found at their face values, it would appear that Cambrian rocks later than the Lower Cambrian were formed in some parts of the region.

It apparently does not follow from failure to find Middle or later Cambrian rocks preserved over the region as a whole, that such were never present. It is clearly necessary to recognize that such rocks may have been eroded. But if such rocks were ever present and were later eroded it is reasonably clear from present field relations that they were removed, at least for the most part, prior to the deposition of the various calcareous rocks of presumably later date that are now intermingled with rocks that apparently belong to the Lower Cambrian.

The present conditions in western Vermont seem to point to some sort of disturbance of the region after the Lower Cambrian rocks were laid down. This disturbance may have occurred so early in the Cambrian that late Cambrian rocks were formed only in a small part of the region or it may have occurred after Cambrian rocks younger than the Lower Cambrian were widely distributed. There seems to be no positive evidence to show which condition was more probable. The apparent result was a denuded Cambrian surface which, except as it has been more or less deformed and eroded subsequent to deformation, is what we see to-day. This eroded surface was submerged and on it were laid down rocks of younger age than the Cambrian.

On account of the profound deformation of the whole region after these later rocks were deposited, their original relations to the denuded surface on which they were laid down are everywhere greatly obscured. At no place which the writer has visited can there be clearly identified at the present time an unconformable sedimentary contact between the Cambrian and younger rocks, while at the same time, apparently little doubt may be entertained that most of the altered, calcareous rocks, with some of which the members of the Cambrian are now associated or even contiguous, are younger than the latter and separated from them by a great unconformity. This seems to be the situation practically everywhere, both in the lowland regions and in parts of the Taconic range. It is conceivable that in some parts of the region late Cambrian rocks were not completely eroded before the denuded Cambrian land mass was submerged; but if such is the case the localities are apparently few in number.

Where later Cambrian rocks remained in place after general denudation, it is not difficult to imagine that when these rocks were washed by a transgressing sea fossils of Middle and possibly Upper Cambrian age could have been involved and preserved in the basal member of a transgressing series, which member instead of being of Cambrian age would belong to a much later date. Cambrian types might or might not have been intermingled with other fossils.

The so-called "intraformational conglomerate" from its field relations often appears to be a facies of the basal member of a younger formation that was deposited on an eroded Cambrian surface. It was hoped that in Vermont, fossils might be found in the matrix of the conglomerate that would confirm this idea; but up to the present time the writer has found nothing that is conclusive.

The conglomerate formation in its Georgia occurrence was described by Walcott as a great lenticle or lentile in the Cambrian series; its present distribution and relations in some places do not seem to bear out this idea.

The conglomerate may be traced from its outcrops in Highgate southward through Swanton and St. Albans into Georgia, but it occurs as detached areas and very apparently as a facies of a formation which includes some calcareous sandstone, thinly-bedded, blue limestones and shaly rocks. The conglomerate is sometimes only slightly developed as a lateral variation of limestone beds and then is usually fine grained. In other places it is more extensive and composed of bowlders of all sizes, usually with a matrix of calcareo-siliceous material and arenaceous texture. The formation is from all appearances represented at some places in the northern townships by bluish limestones in which the conglomeratic phase in present exposures is either not at all or only sparingly present. South of Georgia, in Milton and Colchester, rocks which in a more or less satisfactory way may be correlated with this formation are only sparingly present in surface exposures. These have been mentioned in preceding pages. In Williston township near Brownell Mt. and west of it, thinly-bedded, bluish limestones were noted; but south of the Winooski River the calcareous rocks which are intermingled in surface outcrops with quartzite, dolomite, or interbedded quartzite and dolomite are striped, blue limestones and bluish or white, marbly rocks in which conglomerate was not noted.

The usually distinctly crystalline and often highly metamorphosed, calcareous rocks that are intermingled with the Cambrian

beds over the lowland region south of the Winooski River and east of the western, marginal zone of overthrust of Cambrian and other rocks on the lake series have been mentioned somewhat in detail in preceding pages. Attention was frequently directed to the resemblance which many of these rocks have to members of the lake series. These rocks have not often yielded fossils. In a few cases they have afforded obscure or recognizable markings of shells of gastropods or cephalopods on the basis of which they have been called Beekmantown, Chazy and Trenton.

Published descriptions and maps of the eastern portion of the lowland south of the Winooski River have certainly confused Cambrian rocks with others. On account of the confusion which exists it would not be easy to distinguish the various rocks from one another on a map. It does not seem surprising that Hitchcock was puzzled by these rocks and that in the absence of any means of separating them he embraced them all in one formation called the "Eolian Limestone." Later observers have apparently done what amounts to the same thing.

Since Hitchcock's time some progress has been made in separating the members of his Eolian Limestone on the basis of fossils; but apparently if we are to understand the geology of the areas of disturbed and altered rocks of the eastern part of the lowland, the Vermont valley and the Taconic range, other criteria will have to be used, as well as fossils.

In the work of finding the fossils, Mr. Wing wrought with great perseverance. Proceeding east from the lake region he "identified" the Trenton east of the "central belt of slate" in Leicester, Cornwall and Middlebury. He found the Chazy at West Rutland, and Trenton rocks in the northern hills of the Taconic range. The Chazy was described as affording fossils in Leicester, Cornwall and Middlebury, while by means of the "striped stratum" the Chazy was traced into the western part of Brandon, in the fields and quarries of that town, and from Brandon southward into Pittsford and northward into Salisbury. Beekmantown (Calciferous) beds were also described as occurring in Salisbury, Leicester and Brandon with their fossils.

In a section reproduced by Dana[1] from Wing's notes and intended to show the arrangement of the rocks from west to east, beginning with the Red Sandrock in eastern Shoreham and extending to the quartzite east of the main belt of "Eolian Limestone" in Leicester, beds are shown as Lower and Upper Calciferous which probably are interbedded dolomites and quartzites belonging to the Lower Cambrian.

From the investigations of Wing and from the writer's studies, it appears that Chazy and Trenton rocks are present in the main belt of the "Eolian Limestone." The Beekmantown may be present in the western part of this belt, but the data are

[1] Amer. Jour. Sci., Vol. XIII, May, 1877.

not conclusive. Some of the rock so described appears to be Chazy and some of it is Cambrian.

From the evidence that has come in of various kinds, it now appears that a broad region of denuded Cambrian rocks was gradually submerged in Ordovician time and was transgressed by an Ordovician sea. The overlap probably began at the west, but from present field relations it is not clear just how the transgression proceeded. The altered calcareous rocks now distributed among the Cambrian rocks over the eastern portion of the Champlain lowland and the Vermont valley and parts of the Taconic range are probably largely the eastern representatives of members of the lake series. By faulting and thrusting the younger rocks have been much disturbed, together with the Cambrian floor on which they originally lay. The Cambrian beds have in many places been thrust into, through and over the younger limestones. In the process the latter have been sheared and metamorphosed so that they can be with difficulty identified with their representatives farther west near the lake.

The character of the basin in which these younger rocks were deposited is not now clear. It seems probable that there was in general a sort of trough produced by a warping of the crust and that there occurred a sort of periodic pivotal oscillation of land and sea bottom, producing retreat and advance of the strand line. One of these seems to have occurred at the close of the Middle division of the Chazy and another at the close of the Upper Chazy. Similar episodes may have occurred during the Cambrian. The older parts of the trough were, however, gradually deepened and the positive areas were slowly submerged. The Beekmantown apparently never reached far to the east, but part of the Chazy encroached eastward as the trough widened. A positive movement confined the Upper Chazy to the present lake region, but a resubmergence brought in the Black River and Trenton. Whether the later mud rocks ever lay over the disturbed areas east of the lake it is hard to tell. How far east the lake rocks may once have extended may only be conjectured.

There are reasons for thinking that the Cambrian rocks and the younger rocks involved with them have in general moved as a whole for a considerable but indeterminate distance westward over the eastward extension of the lake rocks. In Ferrisburg, along Lewis Creek, the Ordovician shales extend a considerable distance to the east of the irregular margin of thrust overlap of older rocks. These shales appear to be on the under side of a great lateral thrust. At numerous places along the present shore of the lake members of the Lower Cambrian or limestones clearly older than the shales lie on the latter by thrust.

At some places also there are indications of remnants of overthrust rocks isolated among the shales and now some distance removed from the apparently recessional margin of older rocks lying to the east of them. It seems possible that isolated patches of quartzite found among the shales in the flat land in the western part of St. Albans township may be such remnants. The thought occurred that these outcrops might be exposures of older rocks that had been thrust through the shales, but such history seems unlikely. That the quartzite belongs to a different formation from the shales is apparent, for no such rock has anywhere been found making up a part of the shale formation.

In Orwell there are detached masses of massive Beekmantown limestone which are apparently surrounded by shale and which may be thrust-erosion inliers of older rock.

SUPPLEMENTARY NOTE.

During the summer of 1923 the ledge in the bank of Rock River, at the bridge near Johnson's farm, was revisited. A number of additional fossils were found, among which were well preserved valves of *Nisusia* (*Orthisina*) *festinata* (*Billings*) and the pygidia of *Eodiseus* (*Microdiscus*) *speciosus* (Ford). These fossils were sent to Dr. Ruedemann of Albany for his inspection. Dr. Ruedemann confirmed the writer's recognition of the trilobite and identified the brachiopod.

The ledge in which these fossil fragments were found is just north of the west end of the bridge. The outcrop yielding fossils is small and partly covered with soil, but the rock seemed to be in place. In lithology it is not just like the banded limestone that lies in the bank just beneath and which forms the bed of the stream above and below the bridge.

The fossils are clearly of Lower Cambrian age; but it is not certain that all the limestone associated with the rock carrying the fossils is of similar age.

PROGRESS OF STREAM GAGING IN VERMONT

During the Two-Year Period Ending September 30, 1922.

C. H. PIERCE.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY.

WATER RESOURCES BRANCH

BOSTON, Novemer 20, 1922.

TO THE HONORABLE, THE GOVERNOR OF VERMONT,
State House, Montpelier, Vt.

Dear Sir:

During the biennial period of 1921-1922, the investigation of water resources of Vermont has been carried on by the United States Geological Survey in cooperation with the State of Vermont, the cooperating state official being Mr. H. M. McIntosh, State Engineer, during 1921, and Mr. George A. Reed, State Engineer, during 1922.

The work of measuring the flow of the rivers has been continued during these two years, and the results of stream gaging at ten stations are shown by the accompanying tables. Efforts have been made to continue the records throughout the winter periods, and this has been very successful, despite the fact that very low temperatures are experienced at times. The maintenance of the gaging stations during the winter and the making of measurements under ice conditions are much more difficult and expensive than the maintenance during the summer months, but inasmuch as the lowest stages of the rivers in Vermont are as likely to occur during February as any other month of the year, it seems very essential to obtain information of the flow during the winter periods.

In addition to the work of maintaining gaging stations mentioned above, we have also made a tabulation of the existing water power developments and notes as to where additional power could be obtained. Although the most obvious power sites have already been put into use, there still remain many opportunities for additional power development. With the increasing difficulties in obtaining fuel for steam power, it is apparent that more difficult and expensive water power development will be made use of in the near future. A study of the stream flow records will show that a very large percentage of the total run-off from the rivers goes to waste during the spring months and at other times when

the rivers are at high stages. The saving of these flood waters which now go to waste, and the construction of a system of storage reservoirs to equalize the flow and increase the available power during periods of low water, would be the the most effective means of increasing and conserving the use of this great natural resource. A greater amount of cooperation between the various parties interested in the flow of the rivers would be a great help toward bringing about this conservation.

Respectfully submitted,
C. H. PIERCE,
District Engineer.

LAKE CHAMPLAIN AT BURLINGTON, VT.

Location. On south side of roadway leading to dock of Champlain Transportation Co., at foot of King St., Burlington, Chittenden County.

Records available. May 1, 1907 to September 30, 1922.

Gage. Staff. Comparisons of gage readings indicate that zero of gage at Burlington is at practically the same elevation as that of gage at Fort Montgomery, 92.5 feet above mean sea-level. Gage read by employee of the Champlain Transportation Co.

Extremes of discharge. Maximum stage recorded during year, 8.22 feet on April 19; minimum stage recorded, 0.18 foot, October 10.

1907-1922: Maximum stage recorded, 8.22 feet on April 19, 1922; minimum stage recorded, —0.25 foot on December 4, 1908.

Ice. Wider parts of Lake Champlain not usually frozen over until the latter part of January. Occasionally closure does not occur until February, and in some years it lasts only for a few days. The northern end of the lake above the outlet is usually covered with ice from the middle of December to the middle of April.

Accuracy. Gage read to hundredths once a day at irregular intervals. Gage readings made when the lake is rough subject to inaccuracies due to wave action.

Cooperation. Gage heights furnished through the courtesy of D. A. Loomis, General Manager of the Champlain Transportation Co.

DAILY GAGE HEIGHT, IN FEET, OF LAKE CHAMPLAIN AT BURLINGTON, VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922.

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1920-21												
1	1.78	1.62	...	...	3.14	2.52	6.30	...	2.70	1.68	...	0.76
2	2.08	...	...	...	...	2.52	6.36	4.78	2.67	1.65	1.18	.72
3	...	...	...	4.30	3.05	2.64	...	4.72	...	...	1.18	...
4	2.32	1.70	...	4.30	3.02	2.77	6.35	4.64	2.60	1.58	1.10	...
5	2.40	...	...	4.32	...	2.80	6.30	4.60	2.56	1.55	...	.72
6	2.40	1.76	...	4.32	...	...	6.18	4.50	2.50	...	...	.64

7	2.38	...	...	4.25	2.90	2.90	6.10	4.32	2.44	1.52	...	.64
8	2.34	1.74	3.48	4.18	...	2.92	5.95	...	...	1.50	.96	.62
9	...	...	3.58	...	...	3.17	5.92	4.25	2.34	1.46	.96	.60
10	...	1.72	3.56	4.07	2.82	3.70	5.84	4.16	2.28	1.42	...	...
11	2.28	...	3.64	4.00	...	4.12	5.82	4.07	...	1.50	...	.58
12	2.24	...	...	3.97	2.78	4.32	5.70	...	2.24	...	.92	...
13	...	...	3.64	3.92	...	...	5.60	3.87	...	...	...	.56
14	2.14	...	3.64	3.87	2.73	4.58	5.51	3.85	2.20	...	...	.56
15	2.10	1.66	4.05	3.82	...	4.75	5.35	...	...	1.50	.95	.54
16	2.06	1.64	4.55	...	...	4.79	5.30	3.70	2.16	1.50	...	.54
17	...	1.66	4.73	...	2.66	5.02	...	3.60	2.10	...	.88	...
18	2.00	...	4.80	3.72	...	5.20	5.33	3.53	2.14	...	...	...
19	1.98	1.74	...	...	2.64	5.20	5.30	3.46	...	1.35	...	.48
20	...	1.76	4.78	...	...	...	5.24	3.44	...	1.40	...	.50
21	...	...	4.75	3.60	2.66	5.28	5.20	3.30	...	...	...	...
22	...	1.82	4.70	3.58	...	5.68	5.25	...	1.88	1.42	.90	...
23	1.84	1.86	...	...	...	5.87	5.20	...	...	1.40	...	...
24	...	2.00	4.70	3.56	2.58	...	...	3.17	1.84	1.35	...	.35
25	1.76	...	...	...	2.52	5.90	5.12	...	1.78	1.32	...	...
26	...	1.98	...	3.40	2.50	6.04	5.12	3.02	...	...	.84	.26
27	...	...	...	...	...	...	5.10	2.95	1.72	1.30	.80	...
28	1.62	...	4.55	3.34	...	6.15	5.00	2.92	1.72	1.30	...	.26
29	1.70	1.98	4.52	3.28	...	6.36	...	2.86	1.72	1.32	.78	.26
30	1.64	1.98	...	...	...	6.36	4.92	2.78	1.70	...	.76	.26
31	...	...	4.42	3.22	...	...	...	2.76	...	...	...	...
1921-22												
1	0.26	...	1.54	...	...	...	5.44	6.98	...	5.30	3.30	...
2	...	0.54	...	...	1.54	...	...	6.85	4.38	5.43	3.26	...
3	.30	.50	...	1.80	1.52	...	5.50	6.75	4.35	5.44	3.22	...
4	.28	...	...	...	1.56	...	5.50	6.55	4.25	5.44	...	2.16
5	...	...	1.86	...	...	...	5.50	6.50	...	5.40	3.14	...
6	.22	...	...	1.84	1.57	1.84	5.57	6.50	...	...	...	2.12
7	.22	.50	1.92	...	...	1.84	5.62	...	4.25	...	...	...
8	...	...	1.94	...	...	2.20	5.78	6.43	4.18	5.18	...	2.04
9	...	.54	1.96	1.76	...	...	...	...	4.12	...	3.16	...
10	.18	.56	...	...	1.60	2.87	6.24	6.37	4.10	5.03	3.16	...
11	.30	...	...	...	...	3.07	6.57	6.25	...	4.88	3.10	...
12	.32	.61	1.92	...	...	...	7.05	...	...	4.83	3.02	1.94
13	.30	...	1.92	1.84	1.54	3.30	7.64	6.12	3.88	...	2.94	...
14	...	...	...	...	...	3.40	7.80	...	...	4.70	...	1.92
15	.28	.64	1.89	...	...	3.62	7.95	5.86	3.86	4.60	2.86	1.90
16	...	.64	1.88	...	...	3.92	8.10	5.80	3.86	...	...	1.90
17	.26	.66	...	1.73	...	3.95	8.18	...	3.72	4.40	2.78	...
18	.20	.60	...	...	...	4.10	8.20	5.52	...	...	...	...
19	.20	.70	1.96	1.75	...	...	8.22	5.48	4.12	4.22	...	1.82
20	.30	...	2.06	...	1.54	4.17	...	5.44	4.36	4.18	2.68	...
21	...	1.26	2.06	...	1.54	4.17	8.10	...	4.44	4.10	...	1.74
22	.30	1.32	...	...	...	...	8.03	5.34	4.65	3.98	...	1.70
23	...	1.38	...	1.64	...	4.26	...	5.28	4.82	...	...	1.68
24	.40	...	2.05	...	1.60	4.24	7.90	5.13	...	3.86	...	...
25	.48	1.48	...	1.64	...	4.24	7.72	...	5.02	3.84	2.40	...
26	...	1.56	...	...	...	...	7.60	...	4.98	...	2.38	1.58
27	.48	...	...	...	1.82	4.27	7.50	4.88	4.92	...	...	1.52
28	...	1.56	1.98	1.62	...	4.38	7.40	...	4.94	3.56	...	1.50
29	.46	1.56	...	...	...	4.72	7.25	4.66	4.96	3.52	...	1.45
30	...	1.56	1.94	1.58	...	5.10	...	...	5.18	...	...	1.43
31	.46	...	...	...	...	5.30	...	4.45	...	3.36	...	...

Lake frozen over Jan. 24.

WINOOSKI RIVER AT MONTPELIER, VT.

Location. One mile downstream from the Central Vermont Railway station in Montpelier, Washington County, about three-eighths mile above mouth of Dog River, and 1¼ miles below mouth of North Branch.

Drainage area. 420 square miles.

Records available. May 19, 1909 to September 30, 1922.

Gage. Gurley seven-day water-stage recorded on right bank, installed July 4, 1914; gage heights referred to datum by means of a hook gage inside the well; and outside staff gage is used for auxiliary readings. Recorder inspected by L. D. Smith.

Discharge measurements. Made from cable or by wading.

Channel and control. Channel deep and fairly uniform in section at the gage; control is formed by sharply defined rock outcrop about 500 feet below gage.

Extremes of discharge. 1909-1922: Maximum stage determined by leveling from flood marks preserved on building near present gage, 17.31 feet, April 7, 1912 (discharge not determined); minimum stage from water-stage recorder, 2.58 feet, September 30, 1921 (discharge, from extension of rating curve, 6 second-feet).

Ice. Stage-discharge relation affected by ice during the winter months. Discharge ascertained by means of gage heights, current-meter measurements, observer's notes and climatic records.

Regulation. Operation of power plants on main stream and tributaries above station cause diurnal fluctuations in stage.

Accuracy. Stage-discharge relation practically permanent except when affected by ice. Rating curve well defined between 30 and 5,000 second-feet. Operation of water-stage recorder satisfactory except for short periods indicated by footnote to daily discharge table. Daily discharge October 1, 1920 to March 31, 1921, and December 23, 1921 to April 30, 1922, determined from application of rating table to mean daily gage heights with corrections for effect of ice during winter; daily discharge during remainder of period ascertained by use of discharge integrator. Results good.

DISCHARGE MEASUREMENTS OF WINOOSKI RIVER AT MONTPELIER, VT., DURING THE YEARS 1921 AND 1922.

Date.	Made by	Gage height. Feet.	Discharge. Sec.-ft.
1921			
Jan. 4.	J. L. Lamson	4.54	667
Feb. 25.	J. L. Lamson	*4.20	312
Mar. 16.	J. L. Lamson	10.19	7,070
Dec. 11.	J. L. Lamson	4.14	429
1922			
Jan. 13.	J. L. Lamson	*4.66	345
Mar. 18.	J. L. Lamson	*7.26	1,060
June 12.	J. S. S. Jones	4.88	836

*Stage-discharge relation affected by ice.

DAILY DISCHARGE, IN SECOND-FEET, OF WINOOSKI RIVER AT MONTPELIER, VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922

Day.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1920-21												
1	7,500	560	420	584	290	510	2,200	560	186	118	164	95
2	1,880	566	1,200	590	285	560	1,480	445	182	106	124	72
3	1,070	1,140	900	846	285	1,040	1,260	410	156	74	114	72
4	811	664	685	620	290	1,260	1,120	400	172	75	90	37
5	685	494	1,550	560	290	760	1,060	350	176	100	80	43
6	542	440	2,530	584	310	720	1,000	325	184	98	76	81
7	476	345	1,380	572	320	1,380	900	285	140	86	58	61
8	430	360	1,070	512	300	1,260	820	265	120	82	152	52
9	420	380	888	566	300	3,350	870	275	110	93	198	47
10	365	602	839	518	300	4,710	900	275	110	95	134	53
11	340	435	804	476	300	2,530	710	250	112	144	110	21
12	312	370	762	450	300	2,380	630	235	230	164	245	71
13	308	300	678	385	300	3,050	580	225	250	126	300	55
14	296	296	1,730	482	320	2,480	560	280	350	116	175	58
15	296	300	4,320	578	325	2,380	550	265	290	97	215	62
16	320	280	1,880	578	325	5,230	690	265	210	124	168	64
17	310	395	1,300	460	475	3,590	1,120	220	150	140	126	60
18	300	650	1,100	370	570	2,230	1,160	205	138	146	320	27
19	290	500	930	360	440	1,500	910	225	84	155	465	91
20	280	400	804	350	375	2,640	670	184	130	510	220	73
21	260	300	748	415	370	6,770	570	170	126	200	250	51
22	250	500	632	430	340	4,190	820	146	100	154	220	97
23	240	550	650	445	325	2,230	760	280	112	96	164	58
24	210	600	720	420	320	1,830	1,440	210	110	75	132	42
25	231	500	720	380	285	3,530	1,220	180	100	104	106	30
26	210	345	720	355	290	2,700	830	192	90	83	96	84
27	250	370	680	345	265	2,130	700	192	180	65	85	53
28	500	300	680	330	325	2,580	600	144	200	116	50	75
29	400	450	650	320	...	2,380	530	126	160	300	86	68
30	300	500	620	310	...	1,460	500	140	155	305	77	50
31	250	...	590	305	...	1,460	...	162	...	156	81	..
1921-22												
1	70	132	310	290	200	170	1,420	602	200	1,440	155	156
2	100	275	320	300	200	170	1,340	590	400	1,550	237	123
3	86	310	1,360	290	230	165	1,220	590	650	1,140	233	96
4	100	230	1,180	290	210	160	1,220	590	930	1,290	174	133
5	53	200	740	310	210	210	1,300	1,540	455	979	177	156
6	72	192	590	320	200	280	1,640	1,910	350	727	167	131
7	72	190	500	300	200	400	1,880	1,310	740	596	602	126
8	64	166	475	300	190	3,500	5,230	1,720	510	470	1,010	135
9	86	158	395	290	190	2,300	6,210	1,110	312	518	362	110
10	144	168	385	300	185	1,850	8,100	874	300	420	235	61
11	184	200	390	290	185	1,500	9,010	706	500	330	220	125
12	445	220	405	280	170	1,400	11,800	608	675	304	156	125
13	400	230	345	290	180	1,200	4,970	524	500	304	135	205
14	220	225	385	290	175	1,400	3,110	524	350	276	157	162
15	180	220	280	280	180	1,550	3,110	410	345	186	141	455
16	118	210	245	290	180	1,750	2,990	350	330	201	128	905
17	114	270	270	240	175	1,400	2,750	325	560	225	135	318
18	106	850	1,220	230	175	1,100	3,470	320	2,120	198	167	227
19	116	1,720	1,200	230	185	1,000	2,530	1,250	1,890	210	176	187
20	160	2,500	700	240	210	860	2,030	750	1,040	190	132	158
21	480	1,180	530	230	230	1,050	1,680	500	1,700	168	155	146
22	255	650	295	240	220	930	1,340	440	2,600	139	121	129
23	196	480	300	220	220	811	1,220	375	2,700	142	134	120
24	168	290	320	230	200	832	1,100	330	1,420	190	112	95
25	182	330	320	230	200	937	1,040	310	986	181	81	160
26	168	335	310	220	185	1,550	1,040	375	734	160	573	138
27	160	310	310	220	175	2,330	1,040	290	590	133	380	108
28	150	290	300	210	185	4,070	930	231	1,140	136	251	119
29	140	330	290	210	...	6,910	755	225	1,930	136	216	128
30	106	330	300	210	...	3,230	692	205	2,680	98	182	110
31	136	...	290	200	...	2,030	....	175	....	122	183	...

NOTE.—Stage-discharge relation affected by ice Dec. 25-31, 1920, Jan. 19 to Mar. 9, 1921, and Dec. 23, 1921 to Mar. 21, 1922; discharge based on gage heights corrected for effect of ice by means of discharge measurements, observer's notes and weather records.

Operation of water-stage recorder unsatisfactory Oct. 17-23, 27-31; Nov. 20-30; Dec. 1-3, 24-28, 1920; Feb. 15, and June 24-29; Oct. 26-29; Nov. 21-23, 28-30, 1921; and May 15 to June 15, 1922; discharge during these periods estimated from observer's readings and comparison with records on tributary streams.

MONTHLY DISCHARGE OF WINOOSKI RIVER AT MONTPELIER, VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922.

(Drainage area, 420 square miles.)

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.	Per square mile.	Run-off. Depth in inches on drainage area.
1920-21.					
October	7,500	210	656	1.56	1.80
November	1,140	280	463	1.10	1.23
December	4,320	420	1,070	2.55	2.94
January	846	305	468	1.11	1.28
February	570	265	329	.783	.82
March	6,770	510	2,410	5.74	6.62
April	2,200	500	905	2.15	2.40
May	560	126	254	.605	.70
June	350	84	160	.381	.43
July	510	65	139	.331	.38
August	465	50	157	.374	.43
September	97	21	60.1	.143	.16
The year	7,500	21	594	1.41	19.19
1921-22.					
October	480	53	162	.386	.44
November	2,500	132	440	1.05	1.17
December	1,360	245	492	1.17	1.35
January	320	200	260	.619	.71
February	230	170	194	.462	.48
March	6,910	160	1,520	3.62	4.17
April	11,800	692	2,870	6.83	7.62
May	1,910	175	647	1.54	1.78
June	2,700	200	988	2.35	2.62
July	1,550	98	424	1.01	1.16
August	1,010	81	235	.560	.65
September	905	61	178	.424	.47
The year	11,800	53	701	1.67	22.62

MOLLYS BROOK NEAR MARSHFIELD, VT.

Location. At head of Mollys Falls, one-fourth mile above confluence with Winooski River, one mile from Marshfield village, Washington County.

Drainage area. 24 square miles (from surveys by engineers of Montpelier & Barre Light & Power Co.).

Records available. August 11, 1920 to September 30, 1922.

Gage. Inclined staff on right bank; vertical high-water section on left bank; read by Carroll George.

Discharge measurements. Made from cable or by wading.

Channel and control. Bed covered with gravel and alluvial deposits. Control is well defined at head of Mollys Falls; probably permanent.

Extremes of discharge. 1920-1922: Maximum stage recorded, 6.15 feet at 8 a. m., April 12, 1922 (discharge, by extension of rating curve, 680 second-feet); minimum stage recorded, 1.12 feet at 7.15 a. m., September 15, 1921 (discharge, by extension of rating curve, 2.2 second-feet).

Ice. Ice forms at the gage, and on rocks at the control; discharge relation somewhat affected.

Regulation. Storage in Peacham Pond has some effect on the distribution of flow.

Accuracy. Stage-discharge relation probably permanent except when affected by ice. Rating curve well defined between 5 and 250 second-feet. Gage read to hundredths twice daily. Discharge ascertained by application of rating table to mean daily gage heights, with corrections for effect of ice during winter. Results excellent.

DISCHARGE MEASUREMENTS OF MOLLYS BROOK NEAR MARSHFIELD, VT., DURING THE YEARS 1920-1922.

Date.	Made by	Gage height. Feet.	Discharge. Sec.-ft.
1920			
Aug. 12.	Lamson and Pierce	1.99	37.2
Sept. 5.	C. H. Pierce	1.61	17.5
16.	M. R. Stackpole	2.36	63
Oct. 16.	J. L. Lamson	1.92	30.3
Dec. 24.	J. L. Lamson	2.10	41.9
1921			
Feb. 24.	J. L. Lamson	*1.75	18.6
Mar. 15.	J. L. Lamson	2.81	102
15.	J. L. Lamson	2.91	110
17.	J. L. Lamson	3.70	221
May 26.	J. L. Lamson	1.68	17.6
26.	J. L. Lamson	1.68	17.5
June 25.	J. L. Lamson	1.37	6.1
1922			
Jan. 13.	J. L. Lamson	*1.64	12.4
June 13.	J. S. S. Jones	1.87	28.0

*Stage-discharge relation affected by ice.

DAILY DISCHARGE, IN SECOND-FEET, OF MOLLYS BROOK NEAR MARSHFIELD, VT., FOR THE YEARS ENDING SEPT. 30, 1920-1922.

Day. 1920-21	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
1	...	39	467	51	35	26	19	22	169	35	13	15	15
2	...	36	148	43	70	42	20	20	108	32	14	12	7.4
3	...	20	90	69	48	49	21	28	92	30	12	10	6.3
4	...	15	70	41	32	41	22	25	82	29	19	8.6	4.9
5	...	16	62	34	107	36	19	24	78	27	14	19	4.3
6	...	14	55	30	118	35	19	28	74	25	14	20	3.7
7	...	53	49	31	81	35	21	38	67	23	12	18	3.3
8	...	36	43	31	59	32	19	64	63	22	10	16	25
9	...	47	41	34	55	29	18	122	70	23	9.2	21	8.0
10	...	51	36	54	51	28	18	229	65	24	8.6	16	4.7
11	49	57	35	30	61	29	17	129	59	21	15	25	4.2
12	38	38	32	26	49	28	17	110	51	20	32	19	36
13	22	401	30	24	53	28	17	93	47	19	22	5.4	18
14	35	250	30	21	88	29	17	114	43	23	28	4.5	12
15	92	79	36	20	256	40	16	112	45	21	19	17	13
16	269	65	31	19	121	36	18	307	52	19	12	7.7	8.0
17	76	67	30	41	78	29	28	194	72	17	10	45	5.9
18	45	54	28	38	65	23	20	121	72	16	8.3	4.5	24
19	31	98	28	28	70	23	18	104	60	16	8.0	4.7	22
20	24	57	26	25	55	22	17	142	47	17	7.4	14	12
21	24	47	26	28	48	24	17	418	42	14	6.8	10	17
22	25	41	25	29	53	24	18	283	63	18	6.8	4.7	9.2
23	51	35	24	29	49	23	17	161	51	27	6.6	4.2	6.8
24	30	34	19	26	42	22	16	134	104	18	6.3	3.4	6.3
25	23	29	21	24	38	21	17	229	72	18	6.1	3.3	5.2
26	20	26	21	24	26	23	16	203	53	18	5.9	6.8	4.5
27	19	25	22	24	29	23	17	173	45	15	19	5.9	4.2
28	16	33	32	24	26	22	16	200	42	14	25	8.6	3.9
29	16	54	34	25	29	21	..	191	41	13	20	21	3.6
30	24	76	26	35	28	22	..	135	38	15	17	12	3.3
31	20	...	26	...	26	18	..	112	..	12	..	10	3.3

Day. 1921-22	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	5.9	7.4	8.0	17	12	11	8	76	61	11	113	8.0	10
2	4.9	3.3	25	22	12	12	8	92	57	34	121	8.0	20
3	4.5	2.7	16	45	12	13	8	78	55	62	87	10	24
4	4.0	4.2	16	63	13	11	8	69	55	69	112	10	21
5	3.4	2.9	12	46	14	11	11	74	112	27	81	11	18
6	3.0	3.9	11	29	16	11	22	88	112	28	65	10	17
7	2.9	2.9	8.3	25	12	10	50	94	112	53	56	36	14
8	2.6	5.6	7.4	18	13	10	184	261	135	26	49	47	11
9	2.4	16	6.8	21	12	10	155	314	85	19	45	18	9.2
10	2.4	12	9.6	25	13	10	141	510	64	22	38	15	8.6
11	2.6	9.6	11	22	12	9	66	516	59	32	34	12	6.8
12	3.3	67	13	20	12	8	62	594	50	51	32	11	24
13	3.4	24	14	20	11	8	45	330	49	32	29	10	27
14	2.6	15	12	19	11	8	56	245	45	23	27	8.9	24
15	2.6	10	12	10	11	8	66	224	41	23	24	8.3	61
16	4.2	7.4	12	14	11	8	63	218	36	22	21	11	53
17	3.1	6.8	14	20	11	7	47	220	24	53	20	28	22
18	3.3	5.9	29	74	10	7	35	251	24	113	24	29	17
19	3.0	6.3	94	49	10	7	35	218	65	105	23	25	14
20	2.8	21	145	33	10	8	32	188	41	60	19	18	14
21	3.1	30	82	30	10	9	41	145	29	72	17	13	12
22	4.3	7.4	35	15	10	8	34	123	27	155	15	9.6	10
23	3.4	11	18	14	10	8	30	112	22	162	15	10	8.3
24	3.0	8.3	5.6	12	10	9	36	94	19	87	20	12	8.6
25	3.6	13	5.9	12	10	10	45	92	19	68	15	27	24
26	6.3	12	18	12	10	10	67	92	24	53	14	83	24
27	4.2	8.3	8.9	12	10	10	107	92	19	44	13	38	20
28	2.9	6.8	12	12	10	8	197	85	16	103	12	14	19
29	2.8	6.8	20	12	9	..	355	74	15	178	11	13	19
30	2.6	6.8	20	12	9	..	209	66	14	240	9.6	9.6	17
31	..	7.1	..	11	11	..	122	..	10	...	8.6	7.4	..

MONTHLY DISCHARGE OF MOLLYS BROOK NEAR MARSHFIELD, VT., FOR THE YEARS ENDING SEPT. 30, 1920-1922.

(Drainage area, 24 square miles.)

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.	Per square mile.	Run-off. Depth in inches on drainage area.
1920					
August 11-31 ...	269	16	45.2	1.88	1.47
September	401	14	63.1	2.63	2.93
1920-21					
October	467	19	53.0	2.21	2.55
November	69	19	31.9	1.33	1.48
December	256	26	62.8	2.62	3.02
January	49	18	28.5	1.19	1.37
February	28	16	18.4	.767	.80
March	418	20	138	5.75	6.63
April	169	38	65.6	2.73	3.05
May	35	12	20.7	.862	.99
June	32	5.9	13.6	.567	.63
July	25	3.3	11.3	.471	.54
August	36	3.3	9.84	.410	.47
September	6.3	2.4	3.44	.143	.16
The year.......	467	2.4	38.3	1.60	21.69
1921-22					
October	67	2.9	11.3	.471	.54
November	145	5.6	23.4	.975	1.09
December	74	10	24.1	1.00	1.15
January	16	9	11.2	.467	.54
February	13	7	9.25	.385	.40
March	355	8	75.6	3.15	3.63
April	594	66	188	7.83	8.74
May	135	10	48.3	2.01	2.32
June	240	11	67.6	2.82	3.15
July	121	8.6	37.7	1.57	1.81
August	83	7.4	18.4	.767	.88
September	61	6.8	19.2	.800	.89
The year.......	594	2.9	44.5	1.85	25.14

JAIL BROOK AT EAST BARRE, VT.

Location. At ruins of old dam about one-fourth mile above highway bridge in village of East Barre, Washington County.

Dainage area. 38 square miles (approximate) including 13 square miles tributary to Orange Brook reservoir (see Diversions).

Records available. August 14, 1920 to September 30, 1922.

Gage. Inclined staff on left bank, read by Georg J. Dobbs.

Discharge measurements. Made from cable or by wading.

Channel and control. Bed covered with rocks and boulders. Control formed by rocks near gage; probably permanent.

Extremes of discharge. 1920-1922: Maximum stage recorded, 8.38 feet at 6 p. m., April 10, 1922 (discharge, by extension of rating curve, 1,350 second-feet); minimum stage recorded, 2.45 feet September 11, 1921 (discharge, by extension of rating curve, 0.5 second-foot).

Ice. Ice forms at the gage, and on rocks at the control; discharge relation somewhat affected.

Diversions. Water is diverted from about 13 square miles tributary to Orange Brook reservoir, and used for municipal supply of Barre. No records available as to quantity diverted or amount wasted back into Jail Brook.

Accuracy. Stage-discharge relation probably permanent except when affected by ice. Rating curve well defined between 1 and 60 second-feet, and by measurements at 859 and 873 second-feet. Gage read to hundredths twice daily. Discharge ascertained by application of rating table to mean daily gage heights, with corrections for effect of ice during winter. Results good.

DISCHARGE MEASUREMENTS OF JAIL BROOK AT EAST BARRE, VT., DURING THE YEARS 1920-1922.

Date.	Made by	Gage height. Feet.	Discharge. Sec.-ft.
1920			
Aug. 14.	J. L. Lamson	2.91	8.0
19.	J. L. Lamson	2.72	4.2
Sept. 5.	C. H. Pierce	2.70	3.0
16.	M. R. Stackpole	3.10	15.0
Oct. 16.	J. L. Lamson	3.02	11.8
1921			
Feb. 23.	J. L. Lamson	*3.20	13.7
Mar. 16.	J. L. Lamson	6.55	859
16.	J. L. Lamson	6.63	873
June 25.	J. L. Lamson	2.60	1.3
Oct. 21.	J. L. Lamson	3.56	57
21.	J. L. Lamson	3.50	43.2
1922			
Jan. 12.	J. L. Lamson	3.09	15.7
June 13.	J. S. S. Jones	3.26	27.4

*Stage-discharge relation affected by ice.

DAILY DISCHARGE, IN SECOND-FEET, OF JAIL BROOK AT EAST BARRE, VT., FOR THE YEARS ENDING SEPT. 30, 1920-1922.

Day. 1920-21	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
1	...	3.0	855	41	50	47	10	105	385	74	11	4.0	6.5
2	...	2.7	127	45	310	60	10	90	162	50	10	3.4	6.5
3	...	2.6	53	89	138	80	10	394	150	41	5.6	3.4	2.7
4	...	2.8	37	57	92	60	10	660	123	41	9.5	1.6	2.1
5	...	3.4	42	30	250	35	10	200	116	30	8.0	1.6	1.3
6	...	2.4	28	28	424	33	10	150	110	20	5.0	1.3	2.1
7	...	13	25	20	212	25	9	635	103	18	5.6	1.2	1.2
8	...	20	22	25	116	23	9	295	89	18	4.0	1.0	3.4
9	...	13	18	33	77	23	9	825	116	20	3.0	1.2	4.6
10	...	10	17	71	71	20	9	765	116	15	3.0	1.0	4.0
11	...	31	17	28	77	20	9	370	81	14	4.6	3.0	2.1
12	...	30	16	25	77	20	8	340	74	12	8.6	3.0	103
13	...	134	15	21	71	20	8	515	67	19	8.0	2.1	23
14	8.0	77	13	19	225	47	8	340	67	25	15	1.3	12
15	12	29	20	23	650	125	8	400	89	25	13	20	9.5
16	30	21	17	20	225	75	8	795	106	20	6.5	8.6	5.6
17	7.4	28	16	41	145	35	90	430	187	15	4.6	4.0	3.4
18	4.6	13	19	67	116	20	65	295	170	14	4.0	3.0	16
19	4.2	91	15	45	71	17	23	116	123	11	4.0	26	47
20	3.0	33	11	41	63	15	18	475	81	11	3.0	98	35
21	2.7	17	14	45	57	15	16	870	67	10	4.0	18	35
22	2.8	11	15	86	67	17	14	465	98	8.6	2.1	9.5	14
23	7.4	12	12	127	67	15	14	280	81	28	1.6	5.0	10
24	4.4	8.6	8	188	60	15	14	250	355	13	1.3	3.0	8.0
25	2.8	7.4	14	127	60	15	11	705	138	9.5	1.6	2.1	3.0
26	2.1	6.5	13	71	60	13	11	415	86	23	1.2	2.1	2.7
27	2.0	7.4	13	47	53	13	11	355	71	13	1.2	1.6	2.1
28	2.0	6.5	53	30	53	11	13	530	54	9.5	6.5	2.1	2.1
29	2.1	13	28	37	53	11	..	310	54	8.6	6.5	54	1.3
30	2.0	28	24	110	47	11	..	205	74	8.0	5.6	35	1.3
31	4.0	...	13	...	47	11	..	195	..	6.5	..	9.5	1.3

Day. 1921-22	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	1.3	8.6	13	41	14	8	9	175	73	10	60	2.8	7.4
2	1.2	4.6	41	60	13	10	9	132	77	11	123	41	5.6
3	1.0	3.0	28	635	13	12	10	123	75	47	92	10	4.2
4	1.0	4.6	20	127	11	14	10	132	103	74	185	11	3.0
5	1.0	4.6	21	98	15	13	11	170	286	25	87	9.8	2.8
6	1.2	3.0	13	86	12	10	47	190	325	25	50	6.2	6.5
7	1.2	3.0	13	80	11	11	280	220	185	45	30	190	6.2
8	1.0	4.0	12	78	11	11	590	882	187	18	33	157	5.6
9	.7	8.6	23	80	11	10	475	647	104	13	50	26	3.2
10	.7	7.4	14	98	11	10	237	1,150	77	17	25	14	2.7
11	.5	12	21	80	12	10	162	930	68	41	19	11	2.3
12	1.0	67	18	66	14	10	127	1,140	60	55	16	8.6	9.5
13	1.2	33	20	54	13	10	127	551	50	20	18	8.0	23
14	1.0	18	23	41	13	9	237	412	46	12	13	6.8	9.5
15	1.3	9.5	20	35	11	8	310	433	41	13	15	6.2	54
16	2.1	5.6	20	41	11	8	225	376	34	13	9.2	5.3	89
17	2.1	5.0	26	106	13	8	200	466	30	19	12	6.2	20
18	2.1	5.0	200	605	11	8	150	545	71	47	9.8	5.3	14
19	1.3	4.0	460	138	12	8	98	358	187	99	7.4	5.0	11
20	2.7	16	430	74	13	8	67	286	83	46	5.6	4.8	8.6
21	1.6	60	106	60	13	10	63	230	47	75	6.2	4.6	6.8
22	2.1	14	60	54	13	10	50	175	37	346	5.9	5.0	5.3
23	1.6	9.5	54	47	11	10	60	145	34	212	6.2	2.7	5.0
24	1.3	10	54	41	11	10	92	138	28	63	8.6	3.4	7.7
25	1.3	12	106	35	11	13	119	123	20	37	5.6	11	11
26	2.7	15	74	29	11	11	256	132	26	22	4.8	268	9.2
27	3.0	13	74	24	10	10	442	141	21	15	5.6	21	5.9
28	1.6	14	89	21	8	10	671	103	19	81	3.4	14	5.0
29	1.3	11	81	19	8	..	954	80	15	256	3.2	12	4.2
30	4.0	10	50	17	8	..	406	74	14	162	2.8	10	3.8
31	..	7.4	..	15	8	..	205	...	12	...	3.0	8.0	..

MONTHLY DISCHARGE OF JAIL BROOK AT EAST BARRE, VT., FOR THE YEARS ENDING SEPT. 30, 1920-1922.

(Drainage area, 38 square miles.)*

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.
1920			
August 14-31	30	2.0	5.75
September	134	2.4	22.6
1920-21			
October	855	8.0	51.3
November	188	19	54.6
December	650	47	132
January	125	11	30.5
February	90	8.0	15.9
March	870	90	412
April	385	54	120
May	74	6.5	20.3
June	15	1.2	5.59
July	98	1.0	10.7
August	103	1.3	12.0
September	2.7	.5	1.54
The year	870	.5	72.9
1921-22			
October	67	3.0	13.0
November	460	12	72.8
December	635	15	96.3
January	15	8	11.5
February	14	8	10.0
March	954	9	216
April	1,150	74	355
May	325	12	78.5
June	346	10	64.0
July	185	2.8	29.5
August	268	2.7	28.8
September	89	2.3	11.7
The year	1,150	2.3	82.4

*Includes 13 square miles tributary to Orange Brook reservoir from which diversion is made for municipal supply of Barre. No records available as to quantity diverted or amount wasted back into Jail Brook.

LAMOILLE RIVER AT CADYS FALLS, VT.

Location. About one-fourth mile below power plant of Morrisville Electric Light and Power Co., at what was formerly known as Cadys Falls, 2 miles downstream from village of Morrisville, Lamoille County.

Drainage area. 280 square miles.

Records available. September 4, 1913 to September 30, 1922.

Gages. Friez water-stage recorder in gage house on right bank, one-fourth mile below highway bridge at Cadys Falls. Gage heights are referred to gage datum by means of a hook gage inside the well; an outside staff gage is used for auxiliary readings. Recorder inspected by N. E. Cobleigh.

Discharge measurements. Made from a cable or by wading.

Channel and control. Channel smooth gravel; well defined gravel control 500 feet downstream from gage.

Extremes of discharge. 1913-1922: Maximum stage recorded, 11.63 feet October 1, 1920 (discharge, from extension of rating curve, 8,730 second-feet); discharge practically nil at various times in February, 1922 (water held back by dam).

Ice. River freezes over at gage during extremely cold weather, but control usually remains partly open.

Accuracy. Stage-discharge relation practically permanent, except when affected by ice. Rating curve well defined. Operation of water-stage recorder satisfactory except for short periods mentioned in footnote to daily discharge table. Daily discharge ascertained by discharge integrator. Results excellent.

DISCHARGED MEASUREMENTS OF LAMOILLE RIVER AT CADYS FALLS, VT., DURING THE YEARS 1921 AND 1922.

Date.	Made by	Gage height. Feet.	Discharge. Sec.-ft.
1921			
Dec. 9.	J. L. Lamson	2.58	258
9.	J. L. Lamson	2.62	288
1922			
Jan. 16.	J. L. Lamson	*2.58	235
Mar. 22.	J. L. Lamson	3.22	524
June 14.	J. S. S. Jones	2.82	355

*Stage-discharge relation affected by ice.

DAILY DISCHARGE, IN SECOND-FEET, OF LAMOILLE RIVER AT CADYS FALLS, VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922.

Day. 1920-21	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	5,750	475	230	350	325	148	1,760	310	255	90	100	140
2	1,520	530	990	405	300	305	1,120	280	200	68	96	154
3	740	1,120	700	600	255	425	900	265	160	62	82	136
4	630	770	530	510	225	520	810	260	235	62	92	87
5	500	580	1,220	440	200	420	730	235	162	73	106	130
6	420	510	2,180	425	170	390	650	225	160	66	100	158
7	355	420	1,140	410	290	600	620	220	152	57	58	102
8	315	410	780	395	285	680	560	146	128	62	85	106
9	255	420	630	350	205	2,000	560	162	128	56	92	100
10	230	560	540	350	154	2,550	600	250	114	40	100	118
11	245	460	530	355	132	1,560	480	156	142	102	89	54
12	210	390	510	340	122	1,560	425	118	225	116	122	93
13	220	350	450	340	138	2,000	380	136	210	87	152	102
14	182	305	1,130	340	146	1,600	380	126	190	86	100	114
15	192	320	2,940	395	136	1,520	360	71	180	80	88	73
16	210	280	1,360	435	130	3,300	420	104	152	92	126	80
17	180	410	910	360	205	2,300	730	110	132	65	122	100
18	220	520	720	330	315	1,500	760	120	126	82	104	48
19	198	420	610	355	265	980	710	140	80	82	104	110
20	176	365	550	345	215	1,900	530	126	116	68	166	104
21	182	300	500	330	210	4,450	440	130	114	118	110	112
22	225	330	385	360	166	3,350	850	110	102	100	150	78
23	205	320	465	370	166	1,720	800	280	96	95	106	82
24	142	325	455	350	160	1,340	1,400	195	94	70	88	80
25	205	290	355	365	168	2,550	900	168	104	86	94	48
26	190	283	275	350	150	2,350	660	162	72	82	140	130
27	182	272	315	320	110	1,750	530	180	72	86	130	138
28	305	244	330	305	150	2,200	435	156	64	68	42	136
29	405	265	415	305	...	1,940	395	116	64	120	120	128
30	355	255	370	245	...	1,260	340	114	78	110	108	112
31	285	...	380	305	...	1,120	...	130	...	61	126	...

Day. 1921-22	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	80	186	240	125	140	130	950	500	98	1,020	104	102
2	50	196	240	170	115	125	820	350	160	520	130	97
3	104	250	970	170	64	145	710	350	265	630	130	60
4	100	220	840	145	78	140	740	345	485	640	112	82
5	120	180	540	155	16	66	790	500	320	510	114	93
6	118	176	430	145	83	120	1,060	820	335	410	72	96
7	122	180	325	165	91	150	1,200	640	495	340	210	85
8	124	160	285	125	92	3,200	2,950	1,380	270	340	420	85
9	24	158	255	160	53	3,000	3,700	860	200	330	255	94
10	76	150	245	180	95	1,800	4,800	570	184	260	170	41
11	62	134	275	170	96	1,300	5,600	430	305	215	138	85
12	73	168	285	170	56	990	6,400	365	980	200	130	80
13	166	164	270	180	125	780	3,400	320	820	190	74	90
14	158	190	250	155	130	980	2,050	290	355	180	102	95
15	160	186	250	125	145	1,560	2,000	280	300	160	88	112
16	94	182	240	160	140	1,240	2,150	255	275	128	90	245
17	150	190	220	165	145	820	2,050	300	435	142	83	136
18	140	480	620	165	140	680	2,750	215	2,450	132	95	156
19	140	1,260	860	145	60	570	2,000	235	1,880	124	164	150
20	124	2,350	500	125	125	500	1,460	450	920	124	106	134
21	215	1,100	300	125	130	485	1,180	71	960	122	122	136
22	225	630	270	105	125	435	890	116	2,600	98	108	134
23	152	420	235	140	130	400	760	126	2,350	71	67	134
24	172	290	190	125	155	390	690	140	1,200	124	100	85
25	156	300	205	130	180	465	640	126	495	122	114	138
26	150	290	230	125	82	730	590	198	435	106	340	114
27	184	225	215	135	135	1,280	740	160	420	117	200	78
28	176	280	205	135	140	2,300	610	140	580	97	172	100
29	156	275	200	98	...	3,600	495	120	1,240	104	138	111
30	106	275	220	140	...	1,980	430	100	1,550	69	118	114
31	164	...	194	140	...	1,340	...	98	...	82	104	...

NOTE.—Stage-discharge relation affected by ice Jan. 26-28, 121; Jan. 2 to Feb. 4 and Feb. 11 to Mar. 7, 1922; discharge for those periods based on gage heights corrected for effect of ice. Operation of water-stage recorder unsatisfactory Nov. 26-30, 1920; Apr. 23-25, and Sept. 24-26, 1921; May 1-5 and May 27 to June 2, 1922; discharge estimated for those periods.

MONTHLY DISCHARGE OF LAMOILLE RIVER AT CADYS FALLS, VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922.

(Drainage area, 280 square miles.)

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.	Per square mile.	Run-off. Depth in inches on drainage area.
1920-21					
October	5,750	142	498	1.78	2.05
November	1,120	244	417	1.49	1.66
December	2,940	230	739	2.64	3.04
January	600	245	369	1.32	1.52
February	325	110	196	.700	.73
March	4,450	148	1,620	5.79	6.68
April	1,760	340	674	2.41	2.69
May	310	71	171	.611	.70
June	255	64	137	.489	.55
July	120	40	80.4	.287	.33
August	166	42	106	.379	.44
September	154	48	105	.375	.42
The year	5,750	40	429	1.53	20.81
1921-22					
October	225	24	130	.464	.53
November	2,350	134	375	1.34	1.50
December	970	190	342	1.22	1.41
January	180	98	145	.518	.60
February	180	16	110	.393	.41
March	3,600	66	1,020	3.64	4.20
April	6,400	430	1,820	6.50	7.25
May	1,380	71	350	1.25	1.44
June	2,600	98	779	2.78	3.10
July	1,020	69	249	.889	1.02
August	420	67	141	.504	.58
September	245	41	109	.389	.43
The year	6,400	16	464	1.66	22.47

MISSISQUOI RIVER NEAR RICHFORD, VT.

Location. About three miles downstream from Richford, Franklin County, 3 miles below mouth of North Branch, and 2 miles above mouth of Trout River.

Drainage area. 445 square miles.

Records available. May 22, 1909 to December 3, 1910, and June 26, 1911 to September 30, 1922.

Gage. Gurley water-stage recorder on left bank, about one-fourth mile above highway bridge, inspected by Harry Jenne. Chain gage on highway bridge used from June 26, 1911 to July 31, 1915. From May 22, 1909 to December 3, 1910, gage was just below plant of the Sweat-Comings Co. in Richford.

Discharge measurements. Made from highway bridge or by wading.

Channel and control. Channel deep, banks not subject to overflow; stream bed composed of gravel, boulders and ledge rock. Control is sharply defined by rock outcrop about 100 feet below gage.

Extremes of discharge. 1911-1922: Maximum stage recorded, 17.64 feet April 1, 1918 (stage-discharge relation affected by ice), (maximum discharge occurred on March 26, 1913, approximately 10,200 second-feet); minimum discharge occurred on July 14, 1911 (approximately 8 second-feet), (water held back by dams).

Ice. Stage-discharge relation usually affected by ice, from December to March; discharge determined from gage heights corrected for effect of ice by means of current-meter measurements, observer's notes, and weather records.

Regulation. Considerable daily fluctuation at low stages caused by operation of power plants at Richford.

Accuracy. Stage-discharge relation practically permanent except when affected by ice. Rating curve fairly well defined below 6,000 second-feet. Gage house wrecked by ice March 8, 1921 and rebuilt June 14; operation of water-stage recorder generally satisfactory during remainder of period. Daily discharge ascertained by applying rating table to mean daily gage heights determined by inspection of recorder sheets, with corrections for effect of ice during the winter. Results good for open water periods, and fair for the winter.

DISCHARGE MEASUREMENTS OF MISSISQUOI RIVER NEAR RICHFORD, VT., DURING THE YEARS 1921 AND 1922.

Date.	Made by	Gage height. Feet.	Discharge. Sec.-ft.
1921			
Jan. 7.	J. L. Lamson	*5.02	687
June 14.	J. L. Lamson	3.04	284
Sept. 9.	W. E. Armstrong	1.94	20.4
9.	W. E. Armstrong	1.90	15.9
1922			
Jan. 17.	J. L. Lamson	*4.05	217
Mar. 23.	J. L. Lamson	*7.72	937
Oct. 30.	W. E. Armstrong	2.99	250

*Stage-discharge relation affected by ice.

DAILY DISCHARGE, IN SECOND-FEET, OF MISSISQUOI RIVER NEAR RICHFORD, VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922.

Day. 1920-21	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	6,480	575	560	800	480	350	...	...	...	132	60	58
2	6,248	830	2,740	1,050	460	380	...	...	...	125	58	58
3	2,690	1,970	1,970	1,650	420	860	...	...	...	84	58	58
4	1,240	2,200	1,280	1,400	460	960	...	...	...	92	58	58
5	860	1,560	3,060	1,150	500	920	...	...	...	90	54	50
6	770	1,170	5,160	960	500	960	...	...	...	82	50	52
7	662	925	3,720	740	460	1,050	...	...	...	80	42	55
8	575	800	2,020	650	440	1,300	...	...	...	66	53	45
9	500	860	1,520	600	420	...	...	...	...	58	47	50
10	451	1,320	1,100	550	400	...	...	...	...	66	45	52
11	351	1,030	860	500	380	...	...	...	...	82	37	42
12	307	674	995	500	380	...	...	...	...	80	60	50
13	314	650	1,030	580	400	...	...	...	...	55	61	55
14	307	615	2,440	650	420	...	...	...	265	75	63	58
15	300	585	5,400	770	380	...	...	...	240	125	165	45
16	300	541	4,270	680	350	...	...	...	209	107	145	66
17	279	770	2,340	600	500	...	...	...	157	86	157	61
18	268	1,280	1,640	530	700	...	...	...	140	130	132	63
19	251	960	1,280	530	600	...	...	...	135	110	145	56
20	244	770	1,060	530	500	...	...	...	132	152	170	64
21	272	605	925	550	440	...	...	...	107	233	165	60
22	289	550	710	600	380	...	...	...	100	206	160	53
23	289	600	995	680	340	...	...	...	115	152	110	48
24	331	630	995	650	320	...	...	...	97	90	90	61
25	296	595	960	600	300	...	...	...	92	105	84	61
26	237	550	880	550	280	...	...	...	84	95	70	63
27	331	541	920	530	260	...	...	...	79	56	58	60
28	575	527	1,000	530	300	...	...	...	79	55	64	88
29	555	500	1,050	530	...	...	...	...	70	55	66	68
30	505	487	1,000	500	...	...	...	...	160	55	63	68
31	442	...	920	500	...	...	...	...	...	55	61	...

Day. 1921-22	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	68	237	428	320	200	200	2,150	710	179	2,840	95	173
2	77	407	455	300	200	185	1,560	625	197	1,920	100	188
3	100	575	1,200	280	220	170	1,520	595	970	1,560	132	162
4	86	478	1,440	260	220	170	1,560	580	1,740	1,360	130	155
5	80	469	1,140	260	220	170	1,720	710	890	1,100	162	179
6	102	500	740	300	220	200	2,020	1,170	550	830	185	191
7	79	442	560	280	200	860	2,340	1,140	460	650	594	165
8	95	335	560	260	185	3,900	3,500	1,760	399	527	1,200	145
9	115	328	560	260	170	3,100	5,040	1,720	328	469	536	132
10	150	293	580	250	155	2,600	6,360	1,060	296	428	310	112
11	224	328	600	230	155	1,950	7,740	830	300	339	227	110
12	375	324	580	230	155	1,500	8,170	710	668	307	218	142
13	532	335	560	230	155	1,400	7,480	686	1,360	300	203	185
14	437	343	520	220	155	1,700	4,490	575	890	296	179	203
15	300	328	500	220	155	2,700	3,280	478	590	254	170	209
16	221	343	480	220	145	1,950	3,390	451	545	215	157	162
17	182	371	500	200	145	1,550	2,950	424	650	212	142	120
18	165	1,440	1,250	195	145	1,300	4,270	379	6,000	200	1,030	140
19	135	3,390	1,000	190	145	1,150	3,940	335	8,000	176	2,200	122
20	176	5,040	780	200	145	1,100	2,540	375	4,930	167	890	115
21	1,030	3,720	620	200	170	1,050	1,880	395	2,060	162	437	127
22	995	1,800	560	195	170	960	1,480	451	4,700	165	324	112
23	800	1,140	480	185	200	860	1,240	395	6,600	155	282	95
24	692	710	460	200	340	820	1,240	331	4,820	224	233	102
25	523	469	440	170	400	920	1,170	300	2,290	240	212	84
26	437	698	420	170	340	1,100	1,100	321	1,320	209	808	82
27	391	692	400	170	260	1,400	1,320	331	1,030	152	545	75
28	347	580	380	185	230	2,500	1,320	303	2,760	160	355	102
29	317	565	380	185	...	6,200	1,030	240	4,080	152	282	82
30	265	500	360	185	...	5,800	830	203	4,270	135	265	71
31	237	...	340	185	...	3,700	....	197	....	142	224	...

MONTHLY DISCHARGE OF MISSISQUOI RIVER NEAR RICHFORD, VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922.

(Drainage area, 445 square miles.)

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.	Per square mile.	Run-off. Depth in inches on drainage area.
1920-21					
October	6,480	237	887	1.99	2.29
November	2,200	487	856	1.92	2.14
December	5,400	560	1,770	3.98	4.59
January	1,650	500	698	1.57	1.81
February	700	260	420	.944	.98
March 1-8	1,300	350	848	1.91	.57
April	....	...	...	...	...
May	....	...	...	...	...
June 14-30	265	70	133	.299	.19
July	233	55	97.9	.220	.25
August	170	37	85.5	.192	.22
September	88	42	57.5	.129	.14
1921-22					
October	1,030	68	314	.706	.81
November	5,040	237	906	2.04	2.28
December	1,440	340	622	1.40	1.61
January	320	170	224	.503	.58
February	400	145	200	.450	.47
March	6,200	170	1,720	3.87	4.46
April	8,170	830	2,950	6.63	7.40
May	1,760	197	606	1.36	1.57
June	8,000	179	2,130	4.79	5.34
July	2,840	135	518	1.16	1.34
August	2,200	95	414	.930	1.07
September	209	71	135	.303	.34
The year	8,170	68	893	2.01	27.27

CLYDE RIVER AT WEST DERBY (NEWPORT), VT.

Location. Just below plant of Newport Electric Light Company at West Derby (Newport), Orleans County, about 1 mile above mouth of river.

Drainage area. 150 square miles.

Records available. May 25, 1909 to September 30, 1919, and May 24, 1920 to August 15, 1922.

Gages. Water-stage recorder on right bank; referenced to gage datum by a hook gage inside the well; chain gage fastened to tree is used for auxiliary readings. Recorder inspected by F. R. Sherwell.

Discharge measurements. Made by wading near gage or from highway bridge one-half mile downstream.

Channel and control. Stream bed rough and irregular; covered with boulders and ledge rock; fall of river rapid for some distance below gage.

Extremes of discharge. 1909-1922: High water of March 25-30, 1913, reached maximum stage of 5.8 feet, as determined from high-water marks (approximate discharge, 6,300 second-feet); minimum discharge practically nil at various times when water held back by dams.

Ice. The river usually remains open at the control; stage-discharge relation seldom affected.

Regulation. Flow at ordinary stages fully controlled by two dams at West Derby; distribution of flow affected also by several dams above West Derby. Seymour Lake and several small ponds in the basin afford a large amount of natural storage, but at the present time there is little if any artificial regulation at these ponds.

Accuracy. Stage-discharge relation subject to occasional changes; individual current-meter measurements occasionally plot erractically, probably because of rough measuring section. Rating curve fairly well defined. Operation of water-stage recorder satisfactory except for periods indicated in footnote to daily discharge table. Daily discharge ascertained by applying rating table to mean daily gage heights. Results good when water-stage recorder was in operation.

DISCHARGED MEASUREMENTS OF CLYDE RIVER AT WEST DERBY (NEWPORT), VT., DURING THE YEARS 1921 AND 1922.

Date.	Made by	Gage height. Feet.	Discharge. Sec.-ft.
1921			
Jan. 7.	J. L. Lamson	2.60	280
June 17.	J. L. Lamson	2.24	130
1922			
Mar. 24.	J. L. Lamson	2.54	256
24.	J. L. Lamson	2.53	250
Oct. 28.	W. E. Armstrong	2.20	93
28.	W. E. Armstrong	2.18	86
29.	W. E. Armstrong	2.18	83

DAILY DISCHARGE, IN SECOND-FEET, OF CLYDE RIVER AT WEST DERBY (NEWPORT), VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922.

Day. 1920-21	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	248	145	175	286	171	141	1,040	360	93	62	61	59
2	498	200	156	286	167	152	930	322	93	64	59	61
3	653	196	164	298	145	152	890	286	102	51	60	60
4	670	227	152	304	91	110	790	264	131	55	60	60
5	632	243	156	304	69	83	720	248	160	74	60	61
6	532	269	160	298	59	91	646	232	145	61	50	61
7	430	322	204	292	110	182	613	222	141	59	43	60
8	380	328	360	275	149	218	548	218	152	58	53	61
9	340	328	507	204	156	248	532	212	152	59	54	62
10	328	334	540	196	156	540	507	196	152	55	55	59
11	264	322	498	218	156	820	474	196	145	62	55	52
12	238	310	460	227	164	870	452	191	134	62	57	71
13	204	298	415	218	160	890	422	182	123	62	58	64
14	196	218	430	182	128	770	394	182	145	60	53	64
15	196	269	565	149	85	690	374	178	107	61	62	64
16	200	259	613	134	83	720	367	175	116	59	60	64
17	209	269	632	156	126	710	415	167	126	54	60	61
18	196	298	639	160	160	690	430	164	123	62	64	54
19	191	298	613	164	160	639	467	164	116	61	62	71
20	191	304	532	167	149	646	490	160	107	58	57	76
21	191	204	474	175	107	770	490	160	113	57	50	71
22	204	269	422	156	91	890	515	160	128	57	59	64
23	167	222	387	152	91	1,050	515	167	131	57	61	62
24	152	286	353	145	119	1,120	532	171	102	50	60	60
25	145	119	340	164	156	1,050	507	171	102	58	67	53
26	196	187	292	164	116	980	507	171	76	58	60	55
27	200	232	269	160	58	1,060	482	175	76	59	60	43
28	191	204	292	160	152	1,150	452	178	74	60	49	33
29	196	275	286	160	...	1,180	422	141	79	58	58	25
30	204	196	292	156	...	1,180	387	128	71	56	59	35
31	145	...	280	164	...	1,120	...	110	...	50	60	...

Day. 1921-22	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	38	91	175	123	71	81	760	730	164	532	97	...
2	42	88	175	120	69	79	680	670	146	565	85	...
3	46	85	218	117	71	79	603	603	164	548	89	...
4	47	81	248	114	81	91	548	548	173	574	85	...
5	48	91	259	113	58	64	523	515	160	540	100	...
6	46	62	264	119	79	99	532	507	173	507	110	...
7	48	91	264	113	74	91	565	482	182	467	125	...
8	53	91	243	93	71	131	710	474	164	415	140	...
9	48	107	213	113	71	218	860	482	146	394	120	...
10	56	99	204	110	71	380	1,100	490	133	316	100	...
11	57	99	191	107	76	422	1,390	498	133	275	54	...
12	58	99	178	113	58	415	1,970	367	125	248	93	...
13	59	81	171	113	79	407	2,270	212	137	222	44	...
14	59	113	167	107	81	422	2,210	101	178	202	82	...
15	58	85	160	85	81	460	1,970	322	212	182	76	...
16	51	96	134	113	81	474	1,740	353	217	173	...	...
17	59	99	167	105	81	452	1,500	328	264	160	...	...
18	61	116	218	107	79	460	1,420	304	452	151	...	...
19	76	182	227	102	56	452	1,470	292	460	117	...	...
20	110	334	248	107	79	394	1,560	286	474	113	...	...
21	128	387	259	102	67	360	1,470	292	490	110	...	...
22	145	467	243	85	71	328	1,320	264	612	112	...	...
23	149	482	218	116	71	298	1,210	259	650	120	...	...
24	138	452	191	107	81	259	1,040	243	622	160	...	...
25	113	380	191	107	85	243	910	243	603	170	...	...
26	138	286	167	107	71	269	820	227	540	150	...	...
27	171	264	164	113	91	316	780	212	507	140	...	...
28	138	222	145	91	81	437	740	217	507	133	...	...
29	123	204	141	71	..	641	710	187	507	120	...	...
30	64	196	128	96	..	720	740	164	532	54	...	...
31	88	...	126	83	..	760	...	169	...	105	...	...

NOTE.—Water-stage recorder not in operation Oct. 2-3, 1921; Jan. 1-4; Apr. 16; July 21-27, 29; Aug. 5-10; and Aug. 16 to Sept. 30, 1922. Discharge estimated for these periods, except Aug. 16 to Sept. 30, for which no estimates were made.

MONTHLY DISCHARGE OF CLYDE RIVER AT WEST DERBY (NEWPORT), VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922.

(Drainage area, 150 square miles.)

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.	Per square mile.	Run-off. Depth in inches on drainage area.
1920-21					
October	670	145	283	1.89	2.18
November	334	119	254	1.69	1.89
December	639	152	376	2.51	2.89
January	304	134	202	1.35	1.56
February	171	58	126	.840	.87
March	1,180	83	675	4.50	5.19
April	1,040	367	544	3.63	4.05
May	360	110	195	1.30	1.50
June	160	71	117	.780	.87
July	74	50	58.7	.391	.45
August	67	43	57.6	.384	.44
September	76	25	58.2	.388	.43
The year	1,180	25	247	1.65	22.32
1921-22					
October	171	38	81.1	.541	.62
November	482	62	184	1.23	1.37
December	264	126	197	1.31	1.51
January	123	71	106	.707	.82
February	91	56	74.5	.497	.52
March	760	64	332	2.21	2.55
April	2,270	523	1,140	7.60	8.48
May	730	101	356	2.37	2.73
June	650	125	328	2.19	2.44
July	574	54	260	1.73	1.99
August 1-15	140	44	93.3	.622	.35

CONNECTICUT RIVER AT WHITE RIVER JUNCTION, VT.

Location. At the railroad bridge between Westboro, Lebanon township, Grafton County, New Hampshire, and White River Junction, Hartford township, Windsor County, Vermont. Mascoma River enters from the east about a mile below the gage.

Drainage area. 4,120 square miles.

Records available. November 1, 1902 to September 30, 1922. Prior to 1912 the readings were discontinued during six months, May to October of each year.

Gages. Graduations painted on downstream end of pier nearest the west end of bridge used from November 1, 1902 to June 15, 1918; chain gage over west channel installed June 16, 1918. Gage read by F. H. Chipman.

Discharge measurements. Made at highway bridges about one-fourth mile above the gage, the flow in White River and in

Connecticut River above the confluence of the two streams being measured separately, the sum of the two being the discharge at the gage.

Channel and control. Channel deep, bed covered with alluvial deposits, gravel and rock ledge; control formed by rock outcrop extending across river at various places below the gage; control for high water is probably at Quechee Falls, 7 miles downstream.

Extremes of discharge. 1912-1922: Maximum stage recorded, 26.8 feet April 12, 1922 (approximate discharge, from extension of rating curve, 80,000 second-feet); minimum stage recorded, 2.8 feet September 8, 1913 (discharge, from extension of rating curve, 560 second-feet).

Ice. River covered with ice each winter, usually from December to March; stage-discharge relation seriously affected.

Regulation. Distribution of flow not seriously affected by power plants, except for low water on Sundays caused by Sunday shutdown of paper mill at Wilder, two miles above the gage. About 4,100 million cubic feet of storage at Connecticut lakes and tributary streams above Pittsburg, N. H., has some effect on the low water discharge.

Accuracy. Stage-discharge relation apparently permanent except when affected by ice. Rating curve well defined between 900 and 32,000 second-feet. Gage read to tenths once a day, prior to November 27, 1919, and twice a day thereafter. Daily discharge ascertained by applying rating table to daily or mean daily gage heights. For periods when stage-discharge relation was affected by ice see footnotes to tables of daily and monthly discharge. Results good.

DISCHARGE MEASUREMENTS OF CONNECTICUT RIVER AT WHITE RIVER JUNCTION, VT., DURING THE YEARS 1919-1922.

Date.	Made by	Gage height. Feet.	Discharge. Sec.-ft.
1919			
July 30.	Stackpole and Bigwood	4.08	1,520
1920			
Sept. 15.	M. R. Stackpole	7.50	7,780
1921			
May 19.	J. L. Lamson	5.58	3,940
Sept. 14.	W. E. Armstrong	3.40	959
1922			
Jan. 20.	J. L. Lamson	*5.95	1,790
Mar. 17.	J. L. Lamson	9.52	13,600
31.	J. L. Lamson	14.56	31,400
Apr. 2.	J. L. Lamson	11.62	20,500
June 9.	J. S. S. Jones	6.43	5,340

*Stage-discharge relation affected by ice.

MONTHLY DISCHARGE OF CONNECTICUT RIVER AT WHITE RIVER JUNCTION, VT., FOR THE YEARS ENDING SEPT. 30, 1912-1922.

(Drainage area, 4,120 square miles.)

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.	Per square mile.	Run-off. Depth in inches on drainage area.
1911-12					
October	.....	....	*5,730	1.39	1.60
November	10,300	4,600	5,810	1.41	1.57
December	20,800	4,790	10,200	2.48	2.86
January	.....	....	*4,140	1.00	1.15
February	.....	....	*1,890	.459	.50
March	23,200	....	7,150	1.74	2.01
April	65,100	10,900	30,900	7.50	8.37
May	30,000	11,100	16,500	4.00	4.61
June	38,700	2,530	13,700	3.33	3.72
July	3,150	1,110	2,110	.512	.59
August	7,930	1,600	3,210	.779	.90
September	14,800	2,670	5,670	1.38	1.54
The year	65,100	....	8,900	2.16	29.42
1912-13					
October	24,700	4,040	7,440	1.81	2.09
November	18,000	5,180	8,840	2.15	2.40
December	12,000	4,040	6,850	1.66	1.91
January	20,800	6,050	10,700	2.60	3.00
February	12,000	3,500	5,010	1.22	1.27
March	77,100	1,850	22,800	5.53	6.38
April	36,300	12,600	18,300	4.44	4.95
May	21,100	5,830	9,850	2.39	2.76
June	18,000	3,320	6,830	1.66	1.85
July	6,270	1,300	3,350	.813	.94
August	4,220	890	1,920	.466	.54
September	3,680	560	1,580	.383	.43
The year	77,100	560	8,650	2.10	28.52
1913-14					
October	11,400	1,200	4,230	1.03	1.19
November	10,000	3,150	5,690	1.38	1.54
December	6,050	....	4,260	1.03	1.19
January	.....	....	*1,650	.400	.46
February	.....	....	*1,660	.403	.42
March	18,700	....	6,600	1.60	1.84
April	63,100	11,100	27,400	6.65	7.42
May	34,300	4,220	15,100	3.67	4.23
June	7,200	1,400	3,430	.833	.93
July	4,980	1,720	2,800	.680	.78
August	2,980	1,110	1,980	.481	.55
September	7,200	1,110	2,180	.529	.59
The year	63,100	....	6,420	1.56	21.14

*Based on comparison with records at Fairlee-Orford.

MONTHLY DISCHARGE OF CONNECTICUT RIVER AT WHITE RIVER JUNCTION, VT., FOR THE YEARS ENDING SEPT. 30, 1912-1922.—*Continued.*

(Drainage area, 4,120 square miles.)

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.	Per square mile.	Run-off. Depth in inches on drainage area.
1914-15					
October	2,820	1,110	1,820	.442	.51
November	4,790	1,300	2,710	.658	.73
December	5,610	....	2,910	.706	.81
January	.....	....	*2,870	.697	.80
February	41,900	....	6,530	1.58	1.64
March	19,000	2,980	5,810	1.41	1.63
April	32,700	3,150	13,000	3.16	3.53
May	14,800	3,860	6,910	1.68	1.94
June	6,050	1,200	3,010	.731	.82
July	23,900	2,530	10,000	2.43	2.80
August	11,700	3,680	6,760	1.64	1.89
September	6,050	890	2,860	.694	.77
The year	41,900	....	5,430	1.32	17.87
1915-16					
October	4,040	1,850	3,060	.743	.86
November	5,390	2,670	3,730	.905	1.01
December	.....	....	4,880	1.18	1.36
January	.....	....	†6,400	1.55	1.79
February	.....	....	†6,910	1.68	1.81
March	.....	....	†5,040	1.22	1.41
April	39,900	14,500	23,100	5.61	6.26
May	25,000	7,200	13,100	3.18	3.67
June	16,100	7,440	11,600	2.82	3.15
July	14,500	3,320	6,950	1.69	1.95
August	14,100	890	4,160	1.01	1.16
September	4,220	890	2,480	.602	.67
The year	39,900	....	7,600	1.84	25.10

*Based on comparison with records at Fairlee-Orford.
†Based on comparison with records at Fairlee-Orford and West Hartford.

MONTHLY DISCHARGE OF CONNECTICUT RIVER AT WHITE RIVER JUNCTION, VT., FOR THE YEARS ENDING SEPT. 30, 1912-1922.—*Continued.*

(Drainage area, 4,120 square miles.)

Month.	Observed discharge in second-feet.			Discharge corrected for storage in Connecticut lakes. (Second-feet.)		Run-off.
	Maximum.	Minimum.	Mean.	Mean.	Per square mile.	Inches.
1916-17						
October	7,200	1,500	4,100	3,980	.966	1.11
November	11,700	1,980	4,500	4,360	1.06	1.18
December	20,800	....	†7,790	7,690	1.87	2.16
January	.....	....	†3,630	3,540	.859	.99
February	.....	....	†2,430	2,390	.580	.60
March	26,900	....	†7,190	7,210	1.75	2.02
April	38,700	11,100	22,600	22,800	5.53	6.17
May	21,500	10,900	14,300	14,900	3.62	4.17
June	31,500	7,200	15,600	15,600	3.79	4.23
July	11,700	1,400	5,150	5,100	1.24	1.43
August	12,900	1,980	6,170	6,210	1.51	1.74
September ...	7,200	1,110	3,420	3,330	.808	.90
The year	38,700	....	8,080	8,100	1.97	26.70
1917-18						
October	28,100	2,250	6,400	6,190	1.50	1.73
November	31,900	2,820	7,800	7,960	1.93	2.15
December	.....	....	†2,590	2,300	.558	.64
January	.....	....	†1,910	1,680	.408	.47
February	.....	....	†2,710	2,620	.636	.66
March	.....	....	†6,960	6,950	1.69	1.95
April	44,700	14,500	22,200	22,500	5.46	6.09
May	24,300	5,180	12,800	13,100	3.18	3.67
June	6,730	2,820	5,190	5,090	1.24	1.38
July	5,830	1,300	3,260	3,320	.806	.93
August	11,400	1,030	3,080	2,800	.680	.78
September ...	22,200	1,200	5,890	5,810	1.41	1.57
The year	44,700	1,030	6,730	6,700	1.63	22.02
1918-19						
October	31,100	6,050	11,500	11,900	2.89	3.33
November	31,500	5,610	12,500	12,600	3.06	3.41
December	18,300	4,600	8,010	8,020	1.99	2.29
January	7,900	3,500	5,630	5,500	1.33	1.53
February	4,600	2,000	2,970	2,510	.609	.63
March	40,300	3,800	12,900	12,800	3.11	3.58
April	35,100	12,000	19,300	19,700	4.78	5.33
May	25,000	7,200	12,700	12,900	3.13	3.61
June	6,730	2,390	4,330	4,120	1.00	1.12
July	4,600	1,030	1,970	1,730	.420	.48
August	1,850	890	1,360	1,220	.296	.34
September ...	11,400	890	3,540	3,530	.857	.96
The year	40,300	890	8,080	8,070	1.96	26.61

†Based on comparison with records at Fairlee-Orford and West Hartford.
NOTE.—Beginning October, 1916, monthly mean discharge corrected for effect of storage in Connecticut lakes.

MONTHLY DISCHARGE OF CONNECTICUT RIVER AT WHITE RIVER JUNCTION, VT., FOR THE YEARS ENDING SEPT. 30, 1912-1922.—*Concluded.*

(Drainage area, 4,120 square miles.)

Month.	Observed discharge in second-feet.			Discharge corrected for storage in Connecticut lakes. (Second-feet.)		Run-off.
	Maximum.	Minimum.	Mean.	Mean.	Per square mile.	Inches.
1919-20						
October	9,230	2,250	5,890	5,980	1.45	1.67
November	20,800	7,200	11,100	11,400	2.77	3.09
December	14,800	2,820	6,730	6,780	1.65	1.90
January	.....	....	†2,050	1,510	.367	.42
February	.....	....	†1,410	1,230	.299	.32
March	38,700	....	†11,900	11,900	2.89	3.33
April	45,900	13,800	30,500	31,000	7.52	8.39
May	31,900	6,270	15,700	16,000	3.88	4.47
June	7,680	1,300	4,250	4,040	.981	1.09
July	6,960	2,110	4,010	4,100	.995	1.15
August	6,050	1,400	2,800	2,520	.612	.71
September ...	7,680	1,300	3,800	3,570	.867	.97
The year	45,900	....	8,340	8,340	2.02	27.51
1920-21						
October	21,500	1,300	5,700	5,620	1.36	1.57
November	10,300	3,500	5,580	5,690	1.38	1.54
December	30,300	4,220	10,900	11,100	2.69	3.10
January	7,200	....	4,340	4,380	1.06	1.22
February	.....	....	2,740	2,560	.621	.65
March	38,300	....	22,900	23,400	5.68	6.55
April	28,400	8,690	14,100	14,100	3.42	3.82
May	12,300	2,250	4,940	4,660	1.08	1.24
June	2,820	1,110	1,950	1,890	.459	.51
July	2,250	960	1,390	1,330	.323	.37
August	3,860	1,110	2,140	1,790	.434	.50
September ...	1,110	820	1,010	950	.231	.26
The year	38,300	820	6,510	6,490	1.58	21.33
1921-22						
October	4,040	995	2,210	2,280	.553	.64
November	20,400	1,980	5,570	5,730	1.39	1.55
December	10,900	3,500	5,780	5,790	1.41	1.63
January	3,700	2,000	2,730	2,530	.626	.72
February	3,000	1,700	2,350	2,240	.544	.57
March	43,100	1,800	12,900	13,000	3.16	3.64
April	77,500	13,500	32,000	32,700	7.94	8.86
May	21,500	3,860	10,400	10,600	2.57	2.96
June	32,300	3,500	12,000	12,100	2.94	3.28
July	27,700	1,720	7,710	7,660	1.86	2.14
August	7,200	1,850	3,770	3,770	.915	1.05
September ...	6,270	1,850	2,950	2,540	.617	.69
The year	77,500	995	8,350	8,410	2.04	27.73

†Based on comparison with records at Fairlee-Orford and West Hartford.
NOTE.—Beginning October, 1916, monthly mean discharge corrected for effect of storage in Connecticut lakes.

WHITE RIVER AT WEST HARTFORD, VT.

Location. About 500 feet above the highway bridge in the village of West Hartford, Windsor County, 7 miles above mouth of river.

Drainage area. 687 square miles.

Record available. June 9, 1915 to September 30, 1922.

Gage. Inclined staff on left bank; read by F. P. Morse.

Discharge measurements. Made from cable 1,500 feet below the gage or by wading.

Channel and control. Channel wide and of fairly uniform cross-section at measuring section; covered with gravel and small boulders. Control formed by rock ledge 100 feet below the gage; well defined.

Extremes of discharge. 1915-1922: Maximum stage recorded, 16.9 feet, April 12, 1922 (discharge, by extension of rating curve, 24,500 second-feet); minimum stage recorded, 2.33 feet at 6 a. m., August 29, 1916 (discharge, by extension of rating curve, 26 second-feet). The highwater of March 27, 1913, reached a stage of 18.9 feet, as determined from reference point on scale platform opposite gage (discharge not determined).

Ice. River freezes over at the gage; control usually remains partly open, although ice on the rocks and along the shore affects the stage-discharge relation.

Regulation. There are several power plants on the main stream and tributaries above the station, the nearest being that of the Vermont Copper Co. at Sharon; when this plant is in operation it causes some diurnal fluctuation in discharge at low stages. The effect of power plants farther upstream is practically eliminated by the large amount of pondage at Sharon.

Accuracy. Stage-discharge relation practically permanent, except when affected by ice. Rating curve well defined between 130 and 5,000 second-feet. Staff gage read to quarter-tenths twice daily. Daily discharge ascertained by applying rating table to mean daily gage heights, with corrections for effect of ice during winter. Results good.

DISCHARGE MEASUREMENTS OF WHITE RIVER AT WEST HARTFORD, VT., DURING THE YEARS 1921 AND 1922.

Date.	Made by	Gage height. Feet.	Discharge. Sec.-ft.
1921			
Jan. 12.	J. L. Lamson	*4.56	922
Feb. 17.	J. L. Lamson	*3.97	570
May 18.	J. L. Lamson	4.14	704
1922			
Jan. 10.	J. L. Lamson	*4.21	617
Feb. 25.	J. L. Lamson	*4.98	639
June 8.	J. S. S. Jones	4.22	769
Aug. 18.	J. S. S. Jones	3.01	175

*Stage-discharge relation affected by ice.

DAILY DISCHARGE, IN SECOND-FEET, OF WHITE RIVER AT WEST HARTFORD, VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922.

Day. 1920-21	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	8,320	370	620	820	500	780	5,110	5,500	305	215	345	142
2	2,080	620	1,550	960	470	880	3,300	2,700	285	247	170	140
3	1,200	1,370	1,280	1,200	500	1,050	2,700	2,320	265	345	170	112
4	960	1,200	1,120	1,100	500	1,450	2,440	2,080	265	162	150	126
5	820	855	1,200	1,050	500	1,200	2,200	1,860	247	146	150	94
6	717	717	5,110	960	540	1,200	1,970	1,650	230	146	126	130
7	620	530	2,440	880	540	2,400	1,860	1,460	215	146	134	130
8	530	590	1,860	880	540	2,800	1,750	1,370	200	140	130	126
9	445	590	1,550	860	445	5,500	1,750	1,120	215	170	170	114
10	395	820	1,370	860	440	12,100	1,860	890	200	215	162	86
11	395	890	1,370	855	480	5,900	1,550	960	187	325	130	90
12	345	785	1,200	960	440	5,300	1,460	1,040	305	305	395	102
13	285	620	1,200	820	440	6,300	1,370	890	500	265	620	140
14	285	500	1,860	750	560	5,300	1,280	1,370	345	247	305	130
15	265	560	8,950	1,200	445	5,300	1,200	1,120	345	187	265	140
16	247	530	4,000	1,200	500	9,370	1,460	1,040	265	230	230	126
17	305	560	2,840	920	660	8,110	1,650	890	247	200	146	120
18	325	530	2,320	750	920	5,900	2,440	785	187	187	285	114
19	247	590	1,860	620	760	3,640	1,860	750	162	160	620	165
20	230	560	1,650	780	720	5,300	1,550	717	200	685	500	150
21	200	370	1,650	820	720	13,600	1,460	685	170	717	305	146
22	215	445	1,370	880	620	9,160	1,550	560	155	395	420	150
23	200	590	1,200	860	660	5,300	1,550	620	155	247	265	140
24	200	590	1,050	780	600	4,180	2,570	560	146	175	170	162
25	247	620	860	620	540	6,700	2,200	472	140	142	200	140
26	200	652	620	500	500	6,100	1,750	685	126	155	162	126
27	230	590	560	540	560	4,730	1,550	620	120	146	146	155
28	285	560	560	500	560	4,540	1,460	560	146	155	106	140
29	620	620	660	500	...	4,360	1,280	445	175	247	120	150
30	472	560	680	500	...	2,990	2,990	325	215	560	142	134
31	395	...	680	500	...	2,700	....	345	...	305	140	...

Day. 1921-22	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	134	215	685	580	460	500	3,820	1,550	530	2,200	247	247
2	325	305	620	580	520	480	3,470	1,460	560	4,920	325	230
3	100	620	2,440	560	580	470	2,990	1,370	1,040	2,570	265	230
4	150	500	2,320	520	640	440	2,840	1,370	1,970	2,700	285	247
5	146	395	1,370	580	580	520	2,700	3,470	1,120	2,080	265	305
6	140	345	1,460	660	560	700	3,300	4,540	820	1,750	247	230
7	146	395	1,120	820	520	880	3,820	3,330	1,120	1,460	370	230
8	138	305	855	700	520	8,200	7,500	3,470	855	1,280	1,200	230
9	134	305	760	680	470	7,500	10,000	2,570	750	1,550	717	215
10	200	370	660	660	440	4,730	13,400	2,200	925	1,200	500	215
11	200	500	620	620	460	3,140	15,200	1,860	1,120	960	370	187
12	265	445	600	600	440	2,200	20,500	1,650	960	890	325	230
13	685	420	560	620	440	2,080	10,000	1,550	890	785	305	345
14	445	445	540	600	420	2,080	7,500	1,370	785	717	215	285
15	305	420	470	620	400	4,920	6,500	1,280	685	620	230	285
16	265	345	472	580	390	3,470	6,500	1,120	717	560	215	620
17	215	445	750	560	370	2,320	6,100	1,040	717	500	247	445
18	187	685	1,370	560	370	1,860	11,000	1,040	1,200	560	247	345
19	155	2,440	2,570	540	380	1,750	6,700	2,200	2,440	620	265	265
20	200	5,900	1,370	540	380	1,970	5,110	2,700	1,750	530	305	247
21	685	2,570	925	540	540	1,860	4,000	1,860	1,650	420	187	230
22	652	1,650	620	540	580	1,650	3,140	1,460	5,900	370	215	230
23	395	1,280	560	520	490	1,550	2,840	1,280	3,140	370	215	230
24	395	820	560	500	540	1,650	2,570	1,120	2,080	445	215	215
25	305	855	560	490	620	2,080	2,320	1,040	1,550	472	215	175
26	345	890	560	480	540	2,440	2,320	1,040	1,200	370	420	200
27	265	750	560	480	540	4,730	2,320	890	1,040	370	652	200
28	265	590	540	480	500	8,740	2,080	820	1,280	325	395	200
29	265	820	540	470	...	15,500	1,860	750	3,300	305	370	215
30	325	785	540	440	...	8,320	1,750	620	4,000	325	345	187
31	230	...	500	480	...	5,500	...	590	...	230	265	...

MONTHLY DISCHARGE OF WHITE RIVER AT WEST HARTFORD, VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922.

(Drainage area, 687 square miles.)

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.	Per square mile.	Run-off. Depth in inches on drainage area.
1920-21					
October	8,320	200	719	1.05	1.21
November	1,370	370	646	.940	1.05
December	8,950	560	1,780	2.59	2.99
January	1,200	500	820	1.19	1.37
February	920	440	559	.814	.85
March	13,600	780	4,970	7.23	8.34
April	5,110	1,200	1,970	2.87	3.20
May	5,500	325	1,170	1.70	1.96
June	500	120	224	.326	.36
July	717	140	257	.374	.43
August	620	106	238	.346	.40
September	165	86	131	.191	.21
The year	13,600	86	1,130	1.64	22.37
1921-22					
October	685	100	279	.406	.47
November	5,900	215	894	1.30	1.45
December	2,570	470	906	1.32	1.52
January	820	440	568	.827	.95
February	640	370	489	.710	.74
March	15,500	440	3,360	4.89	5.64
April	20,500	1,750	5,800	8.44	9.42
May	4,540	590	1,700	2.47	2.85
June	5,900	530	1,540	2.24	2.50
July	4,920	230	1,050	1.53	1.76
August	1,200	187	343	.500	.58
September	620	175	257	.374	.42
The year	20,500	100	1,430	2.08	28.30

SECOND BRANCH OF WHITE RIVER AT NORTH RANDOLPH, VT.

Location. Near school house about one-fourth mile below North Randolph, Orange County.

Drainage area. Approximately 27 square miles. (Estimated from sketch map.)

Records available. October 16, 1920 to September 30, 1921.

Gage. Inclined staff on right bank; vertical staff on left bank for high stages.

Discharge measurements. Made by wading or from farm bridge.

Channel and control. Stream bed covered with gravel and alluvial deposits; control formed by ledge rock and gravel, probably permanent.

Extremes of discharge. Maximum stage recorded during period, 4.6 feet at 5 p. m., March 21 (discharge from extension of rating curve, 650 second-feet); minimum stage recorded, 0.9 foot at 6.30 a. m. and 5 p. m., September 11 (discharge from extension of rating curve, 0.8 second-foot).

Ice. Channel seriously obstructed by ice during the winter; stage-discharge relation seriously affected.

Regulation. Operation of saw-mill at North Randolph causes large fluctuation in discharge at low stages. As the mill has but a small amount of pondage, the flow during the morning hours probably corresponds to natural conditions.

Accuracy. Stage-discharge relation probably permanent, except when affected by ice. Rating curve fairly well defined between 5 and 300 second-feet. Gage read to half-tenths twice a day. Daily discharge determined by application of rating table to mean daily gage heights, except for periods when saw-mill caused fluctuations in stage the rating table was applied to morning gage heights only. Results fair.

DISCHARGE MEASUREMENTS OF SECOND BRANCH OF WHITE RIVER AT NORTH RANDOLPH, VT., DURING THE YEARS 1920 AND 1921.

Date.	Made by	Gage height. Feet.	Discharge. Sec.-ft.
1920			
Oct. 15.	J. L. Lamson	1.40	13.8
15.	J. L. Lamson	1.54	23.7
1921			
Jan. 5.	J. L. Lamson	2.01	56
Mar. 18.	J. L. Lamson	3.00	256
June 25.	J. L. Lamson	1.44	20.9
Oct. 21.	J. L. Lamson	1.37	14.4
21.	J. L. Lamson	1.56	24.6
21.	J. L. Lamson	1.20	6.8

DAILY DISCHARGE, IN SECOND-FEET, OF SECOND BRANCH OF WHITE RIVER AT NORTH RANDOLPH, VT., FOR THE YEAR ENDING SEPT. 30, 1921.

Day.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	..	21	30	51	27	23	268	105	21	8.9	7.6	3.5
2	..	30	47	62	26	24	230	55	18	10	7.6	3.5
3	..	55	40	51	24	27	194	51	11	8.9	6.8	3.5
4	..	40	33	62	25	32	170	55	14	8.9	6.8	3.5
5	..	21	62	53	26	29	185	51	11	6.8	6.8	3.5
6	..	24	115	55	27	34	155	47	11	6.8	6.8	3.5
7	..	24	85	49	27	47	141	44	8.9	3.5	6.8	1.0
8	..	33	44	53	26	65	105	47	6.8	3.5	17	1.0
9	..	30	47	40	23	125	135	47	6.8	4.2	11	1.0
10	..	24	47	44	21	195	95	47	7.6	4.2	5.2	1.0
11	..	24	62	47	20	206	105	40	8.9	11	6.1	.8
12	..	24	47	47	20	230	89	40	12	22	20	3.5
13	..	21	33	51	20	239	76	40	15	14	14	3.5
14	..	16	105	62	18	268	68	47	12	6.8	10	3.5
15	..	16	200	44	18	260	62	41	10	14	7.6	3.5
16	16	16	165	47	18	432	55	44	8.9	14	6.8	3.5
17	11	11	145	36	40	520	85	40	6.8	10	6.8	3.5
18	16	24	115	35	29	485	68	34	8.9	6.1	16	3.5
19	16	36	51	33	26	268	55	33	7.6	10	14	3.5
20	16	44	55	33	21	268	51	32	6.8	68	6.8	3.5
21	16	30	51	33	21	592	55	17	6.8	27	6.8	3.5
22	11	24	76	33	21	525	51	17	6.8	14	6.8	3.5
23	11	44	55	31	24	420	47	22	5.2	8.9	6.8	3.5
24	11	36	62	30	21	382	82	18	15	8.9	6.8	3.5
25	11	21	51	30	21	370	76	24	6.8	7.6	6.8	3.5
26	11	40	51	30	21	305	47	32	5.2	6.8	6.8	3.5
27	16	27	53	28	21	284	40	18	12	3.0	3.5	3.5
28	21	16	53	27	21	280	40	15	11	6.8	3.5	3.5
29	27	16	51	28	..	245	33	16	16	18	3.5	3.5
30	27	21	51	31	..	260	33	15	11	14	3.5	3.5
31	21	..	51	27	..	275	..	16	..	10	3.5	..

NOTE.—Stage-discharge relation affected by ice Dec. 26-31; Jan. 10-12; and Jan. 18 to Mar. 7; discharge for these periods based on gage heights corrected for effect of ice.

MONTHLY DISCHARGE OF SECOND BRANCH OF WHITE RIVER AT NORTH RANDOLPH, VT., FOR THE YEAR ENDING SEPT. 30, 1921.

Month. 1920-21	Discharge in second-feet. Maximum.	Minimum.	Mean.
October	...	11	40.0
November	55	11	27.0
December	200	30	68.8
January	62	27	41.4
February	40	18	23.3
March	592	23	249
April	268	33	96.6
May	105	15	37.7
June	21	5.2	10.3
July	68	3.0	11.8
August	20	3.5	8.0
September	3.5	.8	3.1
The year	592	.8	51.8

NOTE.—Average discharge October 1-15, 1920, estimated 66 second-feet by comparison with records of White River at West Hartford.

WEST RIVER AT NEWFANE, VT.

Location. At covered highway bridge 1¼ miles northeast of village of Newfane, Windham County.

Drainage area. 310 square miles.

Records available. September 13, 1919 to September 30, 1922.

Gage. Chain on downstream side of highway bridge.

Discharge measurements. Made from highway bridge or by wading.

Channel and control. Gravel and ledge; well defined riffle just above island 800 feet below gage; probably permanent.

Extremes of discharge. 1919-1922: Maximum stage recorded, 12.0 feet April 12, 1922 (approximate discharge, by extension of rating curve, 8,120 second-feet); minimum stage recorded, 3.55 feet September 10, 1921 (discharge, by extension of rating curve, 35 second-feet).

Ice. River freezes over and stage-discharge relation seriously affected.

Regulation. A few small mills above the station do not seriously affect the distribution of flow.

Accuracy. Stage-discharge apparently permanent except when affected by ice. Rating curve fairly well defined between 70 and 2,000 second-feet. Gage read to half-tenths twice daily. Daily discharge ascertained by applying rating table to mean daily gage heights, with corrections for effect of ice during the winter. Results good.

DISCHARGE MEASUREMENTS OF WEST RIVER AT NEWFANE, VT., DURING THE TWO YEARS ENDING SEPT. 30, 1922.

Date.	Made by	Gage height. Feet.	Discharge. Sec.-ft.
1920			
Oct. 8.	J. L. Lamson	4.13	183
1921			
Jan. 21.	J. L. Lamson	*5.89	358
Mar. 23.	J. L. Lamson	6.04	1,810
May 16.	J. L. Lamson	4.57	460
1922			
Jan. 10.	J. L. Lamson	*5.30	332
June 15.	J. S. S. Jones	4.57	438

*Stage-discharge relation affected by ice.

DAILY DISCHARGE, IN SECOND-FEET, OF WEST RIVER AT NEWFANE, VT., FOR THE YEAR ENDING SEPT. 30, 1921 AND 1922.

Day. 1920-21	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	3,440	230	399	430	200	230	4,470	5,190	100	1,220	87	43
2	1,070	477	916	470	190	290	2,040	2,190	90	1,110	90	43
3	477	3,340	754	720	180	490	1,400	1,400	80	627	87	40
4	320	1,120	586	520	160	1,000	1,130	1,080	80	276	77	40
5	245	712	1,210	520	175	580	977	890	80	188	67	39
6	230	477	2,820	460	270	430	873	763	80	150	59	40
7	197	352	1,530	470	290	490	771	644	71	127	63	39
8	170	333	1,050	500	260	2,350	669	515	71	106	87	39
9	142	352	754	460	220	3,340	703	455	63	950	85	39
10	130	822	771	430	240	5,300	822	385	61	530	71	38
11	109	522	686	430	150	2,720	635	346	63	1,490	63	38
12	112	434	562	440	125	2,350	522	298	87	763	59	43
13	112	339	477	410	140	3,540	462	359	118	385	63	52
14	106	292	1,350	400	125	2,240	420	678	127	276	65	55
15	106	260	4,370	840	120	2,140	406	703	115	1,110	59	52
16	109	250	2,140	740	120	3,540	831	448	85	1,150	55	49
17	103	399	1,400	420	220	3,130	763	333	71	455	55	47
18	95	333	1,060	235	680	2,240	1,000	276	59	265	95	47
19	97	292	856	205	310	1,440	1,000	240	55	206	455	47
20	103	260	678	205	240	2,350	941	215	52	192	162	52
21	95	292	580	310	190	5,610	695	179	52	276	95	52
22	95	270	540	280	140	3,340	746	154	47	225	75	71
23	95	378	520	290	145	1,940	746	154	46	170	67	73
24	92	420	520	300	130	1,440	1,580	162	46	124	59	77
25	85	365	450	310	120	2,660	1,310	154	43	106	55	65
26	100	352	440	280	125	2,560	882	225	47	100	55	80
27	118	292	410	300	125	2,240	695	170	44	80	52	90
28	413	292	430	270	170	1,990	594	138	43	80	49	80
29	339	292	410	240	...	1,680	500	124	276	124	49	65
30	210	314	420	220	...	1,180	2,300	112	1,680	106	43	59
31	174	...	440	220	...	1,010	....	112	....	100	44	..

Day. 1921-22	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	63	71	225	280	170	210	1,490	339	188	309	75	100
2	59	162	265	260	190	190	1,120	326	158	320	71	87
3	55	225	1,400	240	380	190	1,000	309	562	255	71	71
4	55	146	1,110	220	310	160	1,150	406	3,130	265	124	75
5	53	124	712	260	240	240	1,090	3,750	1,180	240	80	87
6	52	124	594	400	220	360	1,360	2,510	839	179	75	80
7	52	115	455	520	210	480	1,680	1,580	546	138	75	115
8	52	95	430	420	195	4,300	4,160	1,310	346	115	162	100
9	59	95	420	360	190	3,750	3,750	848	265	115	206	87
10	71	106	440	320	180	3,130	4,270	538	1,490	124	115	80
11	85	124	430	290	170	2,720	4,470	462	1,990	106	95	75
12	100	138	380	270	170	2,090	6,480	392	1,790	95	75	100
13	106	138	350	270	160	1,940	3,030	352	1,150	87	71	100
14	100	118	320	260	155	3,440	2,040	339	586	80	65	100
15	80	118	310	250	150	2,920	2,350	326	434	75	71	95
16	67	115	310	260	150	1,940	2,190	270	372	71	59	399
17	65	154	380	240	145	1,220	2,240	230	309	65	55	276
18	63	995	1,700	230	145	890	3,030	281	797	59	130	192
19	59	1,180	1,490	260	140	822	2,350	5,610	1,220	162	265	124
20	80	1,490	780	260	140	1,160	1,740	2,660	848	138	115	100
21	170	848	652	260	190	1,360	1,310	1,360	1,580	124	100	95
22	150	455	594	220	240	977	1,080	1,020	2,350	115	75	87
23	106	333	540	220	210	907	882	703	1,490	95	75	80
24	87	240	490	210	260	865	746	492	907	80	71	75
25	85	225	460	190	320	1,190	686	462	695	106	87	75
26	85	265	380	190	280	2,350	712	462	570	170	206	71
27	82	206	350	185	240	3,340	729	406	455	240	333	59
28	85	225	320	190	220	3,650	635	326	372	138	179	59
29	77	255	290	185	...	3,130	462	250	320	162	240	55
30	75	255	280	175	...	2,920	372	206	455	95	150	55
31	67	...	280	170	...	1,740	...	179	...	100	130	...

MONTHLY DISCHARGE OF WEST RIVER AT NEWFANE, VT., FOR THE YEARS ENDING SEPT. 30, 1921 AND 1922.

(Drainage area, 310 square miles.)

Month.	Discharge in second-feet. Maximum.	Minimum.	Mean.	Per square mile.	Run-off. Depth in inches on drainage area.
1920-21					
October	3,440	85	300	0.968	1.12
November	3,340	230	495	1.60	1.78
December	4,370	399	953	3.07	3.54
January	840	205	398	1.28	1.48
February	680	120	199	.642	.67
March	5,610	230	2,120	6.84	7.89
April	4,470	406	1,030	3.32	3.70
May	5,190	112	616	1.99	2.29
June	1,680	43	131	.423	.47
July	1,490	80	422	1.36	1.57
August	455	43	82.2	.265	.31
September	90	38	53.1	.171	.19
The year	5,610	38	571	1.84	25.01
1921-22					
October	170	52	78.9	.255	.29
November	1,490	71	305	.984	1.10
December	1,700	225	553	1.78	2.05
January	520	170	260	.839	.97
February	380	140	206	.665	.69
March	4,300	160	1,760	5.68	6.55
April	6,480	372	1,950	6.29	7.02
May	5,610	179	926	2.99	3.45
June	3,130	158	913	2.95	3.29
July	320	59	143	.461	.53
August	333	55	119	.384	.44
September	399	55	105	.339	.38
The year	6,480	52	611	1.97	26.76

MINERAL RESOURCES.

G. H. PERKINS.

Inasmuch as the various metals which are to be found in Vermont and the uselessness of attempting to mine any of them to the least profit were considered in the last Report, it would seem unnecessary to devote space to the discussion of this subject. As has been stated more than once in these volumes, it is simply a waste of money and labor to start a mine of gold, copper, or whatever the metal anywhere in Vermont.

For more than a hundred years mines have been opened in different parts of the State and, while a few, very few, of them have paid for a short time, all have ultimately proved failures. As has been stated in former Reports, there are deposits of several kinds of metal, but always in too small quantities to permit profitable mining, that is, it has always cost more to get the metal than it was worth when obtained. For further comment the reader is referred to the Twelfth and other Reports of this series.

Vermont can never be a mining State, but it is, and always will be a great quarrying State. In the quarries of slate, granite and marble must always be found the wealth of the State.

During the years 1920 and 1921 the output and sales of granite, marble and slate have been more or less irregular, because of building conditions and strikes. These conditions have affected some of the industries, as granite and slate considerably, marble, which has been free from strikes, much less. Still, so far as I have been able to ascertain, all have done better than during the years of the great war, as would be expected. I am inclined to believe that the business of these industries, which are so vitally important to the prosperity of the State, has been improving during the last three years.

As in all business, the greatly increased expense of producing has made it necessary that the quarrying companies raise the price of the finished material and, of course, this affects the amount sold. Hence, taking all the conditions into account, there is apparently no reason for discouragement on the part of the numerous stone producing firms. Often, if not usually, though the quantity of stone produced and sold is less, the higher prices necessarily charged and obtained bring the money value to a high figure.

As during a number of years past, Vermont leads the country in the amount and value of granite and marble and is second only to Pennsylvania in slate.

It has not been thought necessary to reproduce in this Report the map showing the distribution of the above named rocks. It may be said, however, that all the quarries of marble and slate now worked are west of the Green Mountains. The granite is all east of the mountains.

GRANITE.

As the list of granite quarries shows, this stone is quarried and worked in a large number of so-called sheds or, rather, while the quarries are not very numerous the buildings in which this stone is cut into such shapes as are desired are very numerous.

In seeking accurate information as to granite I have, as in years past, been very greatly helped by the Secretary of the Granite Manufacturers' Association, at present Mr. Athol R. Bell. It is obvious that because of his position, Mr. Bell is the best authority on the Barre District, which includes not only Barre, city and town, but a large territory round about, as Williamstown, Montpelier, Northfield and Waterbury.

Most of the quarries are at Millstone Hill, though there are a few elsewhere. In the number as a glance at the list shows, there only were ten, or perhaps a dozen, quarries in operation in the Barre District. But when it comes to cutting plants we find them very numerous. A few of these quarry their own stone, but the far greater number buy the rough stone from the near-by quarries.

As to the value of the output in this district the letter written by Mr. Bell in response to enquiries gives the latest facts better than I can present them in any other way, therefore, with Mr. Bell's consent, I am glad to quote as follows:

May 2, 1923.

Mr. G. H. Perkins, State Geologist,
Burlington, Vt.

Dear Mr. Perkins:

Obedient to your suggestion of March 20 we have at length revised the list of granite manufacturing and quarry concerns in the Barre District. You will note that a number of changes have taken place since the list was last submitted to you.

For the years 1921 and 1922 we can give you very reliable figures on the valuation of manufactured granite shipped from the district. We are unable, however, to include such other data as in our mind would make up an ideal report. This is due largely to the fact that our industry has been in an unsettled state for nearly two years. The year 1921 was a period of depression in this business. In fact, many of our manufacturers closed their plants in the late fall of 1920, not to reopen them until well into 1922, and in some cases not until 1923. Then in the early part of 1922 a serious labor difficulty resulted in an open shop declaration on the part of a great majority of manufacturers and quarry owners. Inasmuch as very few of the union men returned to work under open shop conditions, the change entailed the employment of largely inexperienced men, a factor which naturally cut down production. At the present time a respectable number of manufacturers are once more operating on the union basis, while a majority of the others are adhering to the American plan or open shop. In the case of the union manufacturers, they have skilled mechanics at their disposal. American plan manufacturers, on the other hand, are now beginning to get efficiency out of their employees, and so between the two groups, production in both the quarries and the cutting plants will be far larger in 1923 than during the previous two years. It may even approach the record production of 1919 and 1920. Using the gross shipments of all of our members and estimates in the case of manufacturers who are not members of the Association, we find that in 1921 the Barre District manufactured Barre granite memorials to the value of $6,350,000. In 1922, due to causes already described, this total slumped to $3,450,000.

Yours very truly,
Granite Manufacturers' Association, Inc.,
Athol R. Bell, Sec'y.

ARB/N.

Although the Barre District is the main granite center of the State, yet, as the following list shows, there are important granite works elsewhere in Vermont. While the attempt has been made to complete the list as fully and as accurately as possile, it is very likely that, outside of the Barre District, there are some errors. Some companies may be passed over which should be included and vice versa.

Especially outside of the Barre District business has in most cases been rather dull. There appears some difference in the activity of different companies. Some have temporarily closed, some have had business, though less than they could gladly have cared for, a few have had enough to at least keep them busy.

LIST OF GRANITE COMPANIES IN VERMONT, 1923.

BARRE.

Anderson & Johnson.
Anderson-Friberg Co.
A. Barclay & Co.
Barclay Brothers.
Barre Granite Quarry Co., Quarries.
Barre Memorial Co.
E. J. Batchelder & Co.
Beck & Beck.
J. O. Bilodeau & Co.
George E. Bond Co.
Boutwell, Milne & Varnum, Quarries.
Crescent Granite Co.
Brown & DeMerell.
Bruza Brothers.
Hinman-Bugbee Co.
Burke Brothers.
Buzzi Granite Co.
Canizo & Co.
Canton Brothers.
Capitol Hill Granite Co., Quarries.
Carroll Brothers.
Carswell-Wetmore Co.

Caslani Brothers.
Celente & Bianchi.
Central Granite Co.
Chioldi Brothers Granite Co.
Ciresoli & Co.
William Cole & Son.
Cook-Watkins Manufacturing Co.
Comolli & Co.
J. P. Corskie & Son.
Davis Brothers, West Berlin.
Dessureau & Co.
Freeman & Wasgat.
Gelpi Granite Co.
Genest & Beaulieu.
Gerrard-Barclay Granite Co.
E. C. Glysson & Co.
Grearson & Lane Co.
Guidici Co.
Guidici Brothers Co.
Harrison Granite Co.
Hebert & Ladrie.
Hedburg & Gustafson.
Hoyt & Mine.
Industrial Granite Co.
Johnson & Gustafson.
Jones Brothers Quarry Co., Quarries.
Jones Brothers.
Kent & Russell.
Robert Kyrock.
LeClair & McNulty.
Littlejohn & Milne Quarry Co., Quarries.
Littlejohn, Odgers & Milne
Lion Granite Co.
Marr & Gordon.
Marrion & O'Leary.
Martinson Estate Co.
Paul Mascitti.
Alexander Milne.
Milne Granite Co.
Mutch & Loranger.
McDonnell & Sons., also Quarries.
McGovern Granite Co.
McMillan Granite Co.
T. J. Newcomb.
Nelson & Mattson.
North Barre Granite Co.
Novelli & Calcagni.
Oleson & Nelson.
Olliver Granite Co.
Parnigoni Brothers.
Parry & Jones Co.
Peerless Granite Co.
J. K. Pirie Estate, Quarries.
Pratt Granite Co.
Provost Granite Co., Inc.
Provost & Son, West Berlin.
Puente Granite Co.
Redmond & Hartigan.
Rizzi Brothers.
L. G. Rizzi.
James C. Robertson.
Robins Brothers.
E. N. Rock & Co.
Frank Ross & Co.
Ross & Ralph.
Rossi & Casellini.
Roux Granite Co.
Royal Granite Co.
Russell & Brand Granite Co.
Saldi & Rossi.
Sanguinetti & Co.
J. P. Saporiti & Co.
Saporiti Granite Co.
James Sector & Co.
E. L. Smith & Co., Quarries.
South Barre Granite Co.
Standard Granite Co., Quarries.
Steele Granite Co.
George Straiton.
E. Tosi & Co.
Union Granite Co.
Valz Granite Co.
Verde Mountain Granite Co.
Vermont Manufacturing & Quarry Co.
Victory Granite Co.
Wetmore & Morse Granite Co.
Young Brothers Co.
Zampieri & Brothers.
Zorsi Giovanni.

MONTPELIER.

These are all Cutting Plants.
U. Aja Granite Co.
Ariole & Co.
Barre Granite Co.
Beaudette & Doucette.
Belluli Granite Co.
Artistic Granite Co.
Bonazzi & Bonazzi.
Bianchi Granite Co.
Boutwell-Milne-Varnum Granite Co.
A. Canas.
Capitol Granite Co.
Doucette Bros.
H. C. Emmons.
Excelsior Granite Co.
C. P. Gill & Co.
Higuera Granite Co.
Johnson Granite Co.
Robert Lawrence.
R. A. LeClerc.
Lillie Granite Co.
Maloney & Clossey.
Menard & Erno.
Mills & Co.

National Granite Co.
E. Ray Granite Co.
Sheridan & Poole.
George Sievewright.
St. Onge & Son Granite Co.
Star Granite Co.
Wetmore & Morse Granite Co.

NORTHFIELD.

Cross Bros.
Pando Granite Co.
Pelaggi & Co.
Phillips & Slack.

BETHEL.

Woodbury Granite Co.

WATERBURY.

Drew Daniels Granite Co.
O'Clair Granite Co.
Union Granite Co.

GROTON.

A. Checci.
Groton Quarry Co.

SOUTH RYEGATE.

American Gray Granite Co.
Beaton Granite Co.
Blue Mountain Granite Co.
Jas. Craigie.
Newbarre Granite Co.
Ryegate Granite Works Co.

BARTON.

Crystal Lake Granite Co., Quarries.
Barton Granite Co., Quarries.
L. R. Lewis.
T. F. Roy.
M. J. Smith.
Ward & Co.

CONCORD.

Kirby Mountain Granite Co.
Lillecrop & Son.
Moose River Granite Co.
L. E. Smith Granite Co.

HARDWICK AND WOODBURY.

M. Ambrozini, Hardwick.
American Granite Co., Hardwick.
Ainsworth & Ainsworth, Hardwick.
O. H. Bailey, Hardwick.
Buck Lake Quarry, Hardwick.
Calderwood, Hardwick.
M. J. Couhig, Hardwick.
Caledonia Granite Co., Hardwick.
Eureka Granite Co., Hardwick.
E. R. Fletcher, Woodbury, Quarry.
Floyd Fuller, Hardwick.
P. Good, Hardwick.
Grant & Adams, Hardwick.
John Hay, Hardwick.
Hardwick Polishing Co.
C. Hamilton, Hardwick, Quarries.
Hardwick Granite Co.
L. P. Heney, Hardwick.
O. G. Kimball, Hardwick, Quarries.
Nunn & Fordyce, Hardwick.
E. T. Leach, Hardwick.
G. W. Merriam, Hardwick.
E. R. Murch, Hardwick.
Paz & Canales Brothers, Hardwick.
E. P. Purdy, Hardwick.
Standard Granite Co., Hardwick.
A. B. Thomas, Woodbury, Quarries.
Vermont Quarries Co., Hardwick.
Woodbury Granite Co., Hardwick, Woodbury, Quarries.

OTHER LOCALITIES IN THE STATE.

Eureka Granite Co., Adamant, Quarries.
Patch & Co., Adamant, Quarries.
C. S. Haselton, Beebe Plain, Quarries.
Presby Leland Co., Dummerston, Quarries.
Stanstead Granite Co., Beebe Plain.
A. J. Goss, West Danville, Quarries.
Newport Granite Co., Derby, Quarry.
Union Granite Co., Morrisville.

MARBLE.

Unlike the granite industry which, as has been shown, is distributed among a large number of companies, the marble of Vermont is handled by a few companies and most of it by one.

In marble, as in most other materials, while the amount sold was more in 1921 and 1922 than during the two preceding years, the rise in price brought the total value nearer what it had been than it otherwise would have been. As to the situation this year, 1923, and that preceding, 1922, Mr. D. H. Bixler of the Vermont Marble Company, writes as follows:

"The marble business like most other classes of business has suffered considerably during the last few years. The costs of labor and of supplies have risen as elsewhere. This has necessitated an increase in price. On this account the demand for exterior and interior building marble was considerably checked; besides, owners and architects have resorted a great deal to cheaper substitutes, such as limestone and terra cotta for exterior work and to substitutions or omissions entirely for interior treatment; again very keen competition is met with from various other parts of the country—this referring both to exterior and interior marble. There would seem to be though somewhat of a revival in building operations and prospects look reasonably good for the marble business in these lines.

"All the above is to a large extent true with respect of the monumental marble. There has been the set-back and our costs have gone up in line with other industries, but we are looking for a reasonably good demand for the coming season."

The following is a list of marble companies now doing business in Vermont:

Clarendon Marble Company, Quarries and Mill, Clarendon.
Eastman Marble Company, rough stock only, Quarries at West Rutland.
Manchester Marble Company, Quarries and Mill, Dorset.
Meadow Brook Marble Company, Quarry and Mill, Brandon.
Middlebury Marble Company, Quarries at Middlebury, Office at Brandon.
Vermont Marble Company, Main Offices at Proctor,
Quarries at Proctor, West Rutland, Florence, Brandon, Danby, Dorset, Swanton, Isle La Motte, Roxbury, Rochester.
Mills at Proctor, Center Rutland, West Rutland, Florence, Middlebury, Swanton.
Lime Plant at West Rutland.

In the last Report sundry considerable additions to some of the mills of the Vermont Marble Company were mentioned. These are reported as finished and in operation.

In the Ninth Report of this series the whole marble industry is very fully considered and those especially interested in this stone are referred to that volume, which can be obtained from the State Library, Montpelier.

The total value of all marble sold in Vermont, rough or finished, during 1920 and 1921 cannot be given with absolute accuracy, but probably was not less than $4,000,000 for each year.

SLATE.

Though far behind Pennsylvania in the amount of slate produced, Vermont much exceeds any other State in this material.

Below is a corrected list of slate companies now doing business in Vermont, 1921-1922:

CASTLETON.

P. F. Hinchey and Company, Hydeville. Quarries. Mill stock only. Colors green, mottled and purple.
Penrhyn Slate Company, Hydeville. Quarries. Mill stock only. Hydeville Plant, Lake Bomoseen Plant, Scotch Hill Plant. Mottled, green and purple.
Hydeville Slate Works, Hydeville. Mill stock only. Mottled, green, purple.
John Jones Slate Company, Castleton. Quarry. Mill stock only. Mottled, purple.
Lake Shore Slate Company, West Castleton. Quarry. Mill stock only. Mottled and purple.

FAIR HAVEN.

Clark and Flanagan Slate Company. Quarries. Mill stock and roofing. Unfading green, purple, mottle, gray.
Durick, Keenan and Company. Quarry. Mill stock only. Mottled and purple.
Eureka Slate Company. Quarries. Roofing slate. Unfading green, mottled, purple.
Fair Haven Marble and Marbleized Slate Company. Quarry. Mottled purple, green.
Locke Slate Products Corporation. Mottled, green and mottled purple.
McNamarra Brothers Slate Company. Electrical slate only.
Mahar Brothers Slate Company. Quarries. Mill stock and roofing. Mottled, green and mottled purple.
Old English Slate Company. Quarry. Roofing. Mottled and purple. Office, Boston, Mass.
W. H. Pelkey Slate Company. Quarry. Roofing. Green.
Vermont Milling and Products Corporation. Ground slate only for roofing. Mill at Poultney; Office, Fair Haven.
A. B. Young Slate Company. Mill stock only.

POULTNEY.

Auld and Conger Company. Quarries in Vermont and Pennsylvania. Roofing. Weathering green, unfading green, sea green, purple, mottled.
Donnelly and Pincus Slate Company. Quarries. Roofing. Unfading green, purple, mottled.
General Slate Company. Quarries. Roofing. Sea green, mottled, purple, gray.
Vendor Slate Company. Quarries. Roofing. Sea green, mottled, purple, gray and unfading.
Staso Milling Company. Ground slate only.
Owen O. Jones Slate Company. Quarries. Mill stock and roofing. Unfading green, mottled, purple, gray.
New York Consolidated Slate Company. Quarries. Roofing. Green, purple, unfading green, mottled.
F. C. Sheldon Slate Company. Quarries. Roofing. Purple and sea green.

WEST PAWLET.

Rising and Nelson Slate Company. Quarries. Roofing. Sea Green.

WELLS.

O'Brien Brothers Slate Company. Quarries. Roofing. Purple and sea green.
Burdette and Hyatt. Quarries in Wells; Office in Whitehall, N. Y.

Norton Brothers Slate Company. Quarries in Vermont and Granville, N. Y.; Office in Granville, N. Y. Roofing. Green, purple, red.
O. W. Owens and Sons Slate Company. Quarries in Vermont and New York; Office in Granville, N. Y. Roofing. Green, purple, red.
Progressive Slate Company. Quarries in Vermont and New York; Office in Granville, N. Y. Purple, green, red.
F. C. Sheldon Slate Company. Quarries in Vermont; Office in Granville, N. Y. Roofing. Sea green.
Vermont Slate Company. Quarries in Vermont; Office in Granville, N. Y. Sea green, purple, red.
H. G. Williams Slate Company. Quarries in Vermont and New York; Office in Granville, N. Y. Roofing. Purple, red, green.

Like most other kinds of business, this suffered during the lull in building, but has since been improving, especially during the last three years, each year being reported better than the last.

Ordinarily Vermont produces about two-thirds as much slate as Pennsylvania, that is about $2,500,000 for Vermont.

TALC AND SOAPSTONE.

Talc is produced in Vermont in considerable amount by the following companies:

LIST OF COMPANIES PRODUCING TALC.

American Mineral Company, Johnson.
Magnesia Talc Company, Waterbury.
Eastern Talc Company, East Granville, Rochester; Office, International Trust Company Building, Boston, Mass.
Vermont Talc Company, Chester Depot.
American Soapstone Finish Company, Chester Depot.

The value of talc annually sold is about $500,000.

So much has been stated by Professor E. C. Jacobs in regard to these deposits and the modes of working, in Reports immediately preceding this, that it seems unnecessary to take up the subject here at any length.

A little soapstone is also quarried and manufactured at Chester Depot.

LIME AND LIMESTONE.

Very little limestone is used from Vermont quarries for building, most of the limestone quarries being burned for use as lime.

The few lime plants in operation in the State were fully discussed by Professor Jacobs in the Eleventh Report of this series

and to this article those especially interested are referred.

There have been of late years a half dozen companies which made lime. Some of these have not been active continuously and some are not at present, but most are doing something. The companies are:

LIST OF LIME KILNS IN VERMONT.

Amsden Gray Lime Company, Amsden. This company has been continuously active for many years. Of late, however, it has taken several important steps forward, involving considerable new machinery and will soon, if not already, be able to add largely to its output. Besides abundance of limestone, the company owns large tracts of woodland from which to obtain fuel and material for barrels.
Missisquoi Lime Works, Highgate Springs.
Fonda Lime Kilns, St. Albans.
Swanton Lime Works, Swanton.
Champlain Valley Corporation, Winooski.
Green Mountain Lime Company, New Haven Junction; Office, Worcester, Mass.
Brandon Lime and Marble Company, Leicester Junction.
Vermont Marble Company, Proctor.
Pownal Lime Company, Pownal; Office, 92 State St., Boston, Mass.

The value of lime annually sold is about $500,000.

The quarries at Leicester Junction are not in operation, nor are those at New Haven Junction.

The Vermont Marble Company does not quarry stone for burning, but utilizes the great quantity of waste from the ordinary work in marble, making in rotary kilns a hydrated lime. It is the only plant of its kind in the State and will be found to be fully described in the Tenth Report of this series.

ASBESTOS.

Asbestos has been mined in Vermont for more than twenty years, with several intervals of inaction. All the mines have been opened on Belvidere Mountain in the town of Eden. Some accounts of these efforts to obtain commercially valuable asbestos was given in the Report immediately preceding this and need not be repeated here. So far as I know, there has been no work done at any of these mines during the last two years.

CLAYS.

There is a good deal of clay in the State, but it has never been carefully studied. Professor Jacobs has taken up an investigation of the Vermont clays and, as a result of his examination, it is expected that the character, use, location, etc., of this material will ere long be more satisfactorily known than in the past. At present only the following companies are engaged in producing clay:

LIST OF COMPANIES WORKING CLAY.

Horn, Crockett Company, Forestdale, (Brandon).
Rutland Fire Clay Company, Rutland.
American Paper Clay Company, Rutland.
S. C. Lyon Brothers, Bennington.
E. F. Rockwood, Bennington.
E. L. Sibley, Bennington.

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