REPORT

OF THE

STATE GEOLOGIST

ON THE

MINERAL INDUSTRIES AND GEOLOGY

OF

VERMONT

1925-1926

FIFTEENTH OF THIS SERIES

GEORGE H. PERKINS
State Geologist

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STAFF OF THE VERMONT GEOLOGICAL SURVEY, 1925-1926.

GEORGE H. PERKINS, *State Geologist, Director.*
University of Vermont.
ELBRIDGE C. JACOBS, *Assistant Geologist.*
University of Vermont.
CHARLES H. RICHARDSON, *Assistant Geologist.*
Syracuse University.
CLARENCE E. GORDON, *Assistant Geologist.*
Massachusetts Agricultural College.
E. J. FOYLES, *Field Assistant.*
Rochester University.
G. W. BAIN, *Field Geologist.*
Amherst College.

CONTRIBUTING GEOLOGISTS.

G. H. HUDSON, Plattsburg, N. Y.
ROBERT BALK, Columbia University.
B. F. HOWELL, Princeton University.
W. L. BRYANT, Providence, R. I.

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STATE OF VERMONT.

OFFICE OF STATE GEOLOGIST.

BURLINGTON, VT., December 1, 1926.

To His Excellency, Franklin S. Billings, Governor:

Sir:—In compliance with Act 405 of the General Laws of Vermont, I herewith present my Fifteenth Report as State Geologist.

As required, this Report covers the Biennial Period, 1925-1926.

Those areas of the State which have been studied are indicated in the Introduction, which follows.

As will be seen by the following pages, the Geologist has been greatly aided in carrying on his investigation of the geology of the State by several geologists who have studied different areas in Vermont and have furnished the reports of their work which are contained in this volume.

Respectfully submitted,

GEORGE H. PERKINS,
State Geologist.

INTRODUCTION.

The present Report, which is the fifteenth of this series, differs from former volumes in that it contains more technical material of value to geologists and a real contribution to the geology of Vermont, but less interesting to the general reader. Still, much of that which must be called technical will be found useful to teachers and others especially interested in the geological structure of our State.

The writer has in former volumes had occasion to notice the great complexity and metamorphism found in the Green Mountain region and, while many difficult problems yet remain unsolved, and while some of them may not be settled for a long time, yet through the efforts of several geologists who have been working in Vermont and, as may be hoped, will continue their investigations, difficulties in interpretation of perplexing rock masses are becoming less and it seems not too much to hope that in due time the geological history of Vermont, the entire State, may be clearly stated. Several of the articles in this Report are valuable contributions toward this end. Nevertheless, not a few very perplexing problems remain for the investigation of future students of Vermont geology. As an examination of previous Reports will show, little by little the problems are being solved, slowly of necessity, but with good assurance that many, at least, of the problems have been correctly solved and thus permanent additions to geological knowledge have been made. When a full and clear account of the geological history of Vermont may be written cannot be told, but it is coming in due time and when complete it will be a most interesting story and will present nearly all known geological processes.

As will be seen by the reader, the following pages include a variety of articles by a number of geologists, treating of some investigation of this or that part of the State.

In the first of these, the Geologist attempts to reply to numerous inquiries which have come to his office, not only from towns in the State, but from many other states, asking what are the

facts concerning peat in Vermont. The title indicates sufficiently the scope of this paper.

The second article by Dr. Robert Balk, at present of Columbia University, gives the result of an extended and careful study of the granite areas of Bethel, Barre and Woodbury. The method of examination adopted by Dr. Balk, while it has been used for several years in Germany, has not before been applied on this side of the ocean and, though in some parts quite technical, the article will be read with interest and profit by those interested in the structure and formation of our granites.

The third article by Professor G. H. Hudson, of the Plattsburg Normal School, is a very thorough and careful study of the species of Crinoid which is considered, and must be of value to paleontologists.

In the fourth article Mr. E. J. Foyles, of Rochester University, continues his work in Vermont, accounts of which are given in previous Reports, on the geology of the Champlain valley, taking up here the towns of Addison, Panton and Ferrisburg.

The fifth article gives an account of a discovery in the Lower Cambrian near St. Albans, by Professor B. F. Howell of Princeton University, of a most interesting fossil which is thought to be a "fish plate," such as occur on the surface of the skin of many of the older fishes. If, as seems most probable, this is a veritable "fish plate," then it is older than any indication of these animals hitherto found, by millions of years. Dr. W. L. Bryant of Providence, R. I., a specialist and authority in this branch of paleontology, follows Professor Howell's account with a plate and description of the fossil. It is certain that whatever this fossil proves to be (so far all experts pronounce it a plate from a fish) it is unlike any form hitherto found in our rocks.

Professor C. H. Richardson, of Syracuse University, who for many years has studied the geology of Vermont, beginning at the north line of the State, has now reached the towns of Barnard, Pomfret and Woodstock, thus adding to our knowledge of the geology of eastern Vermont.

In the next article Mr. E. L. Perry, of ~~Princeton University~~, gives a brief summary of investigations in the towns of Plymouth and Bridgewater. A much fuller discussion of this region by Mr. Perry will be included in the next Report.

As the ninth article, Mr. E. J. Foyles publishes a list of known paleozoic fossils found in the Vermont limestone, sandstone and shale beds. This list will be very useful not only to students interested in our rocks, but especially to collectors.

For several years Professor E. C. Jacobs, of the University of Vermont, has spent considerable time in the study of the clay deposits of the State. In this volume he summarizes the results of his work.

A paper which must be of great interest to students of the Green Mountain region is by Professor G. W. Bain, of Amherst College. This article adds to the constantly accumulating history of the Green Mountains, as does the following more technical article by the same author on some of the changes that are found in such rocks as those of these mountains as a result of contact metamorphism.

The usual summary of the Mineral Resources of Vermont is prepared by the State Geologist and will be found useful for reference.

This volume closes with a very interesting paper by Professor C. E. Gordon, of the Massachusetts Agricultural College, who, as readers of these Reports will remember, has for several years investigated Vermont geology. In this report Professor Gordon takes up the towns of Bristol, Lincoln and Warren. The extremely metamorphosed condition of most of the rocks in the area studied renders the interpretation of their history very difficult, and in parts uncertain. Because of this the present paper is to be regarded as the result of a preliminary rather than final study.

The Topographical Survey of Vermont, which has been carried on for several years by the State in cooperation with the United States Geological Survey, has been advanced during the past two years and several new Quadrangles completed and a large part of the area of Vermont has now been mapped, but a strip along the eastern border still remains to be surveyed.

THE PRESENT STATE OF OUR KNOWLEDGE OF PEAT.

G. H. Perkins

As is proper in a Vermont report, while some of the facts concerning peat in other localities will be given, this paper refers especially to the peat which exists in our Vermont bogs. Enquiries about the peat deposits of this State and the character of the material found in these bogs have come to this office from various parts of the United States, as well as from towns in Vermont, and it is with the hope that some, at least, of these enquiries may be answered that this paper is written.

Especially during and since the great war, because of new conditions mainly, much greater interest appears to have been taken in this subject than ever before in this country. Of late years the greatly increased cost of other materials used for fuel and, also, so far as coal is concerned, the uncertainty of obtaining a sufficient supply, because of strikes, has, as is well known, caused a large number of our people to seek to find some substitute that could satisfactorily take the place of coal and, to some extent, wood, and for this reason many of our Vermont farmers are asking if by some possibility the peat bogs, which they see on every hand, cannot be utilized as they have not been. There are peat deposits of greater or lesser dimensions in almost every town in the State and very naturally many people, knowing as they must, of the long and extensive use of peat in Europe, have raised the inquiries which have been mentioned. Although, as will be seen in what follows, satisfactory replies cannot be found to many of the questions which arise in this connection, nevertheless, it will be useful to some if what it is at present possible to say by way of answer be brought before them.

In Europe a considerable number of publication on peat have appeared during the last twenty or thirty years and some are earlier, but not nearly as much has appeared on this side of the Atlantic. As the conditions in the many localities where peat has been and still is used in Europe are in many important respects very different from those here, it is not wise to draw conclusions hastily from the results obtained in any of the foreign countries and apply them to our own peat bogs. As will be shown when later the history of peat is considered, this material has been used and experimented with for centuries in the old world, but very little attention seems to have been given it in this country until within the last twenty years or perhaps somewhat longer.

The Canadian government has done far more than our own by way of investigating peat, especially during the last ten years as will be shown later. By reason of the numerous trials which have been carried forward in both the United States and Canada, it is possible at this time to make far more intelligent and complete statements as to the use of peat and its value for fuel and numerous other purposes, than at any time heretofore. It is well to remark at the outset that the author of these pages does not claim to be able to present much that is new in regard to peat. His main object now is to gather into convenient form a summary of what has up to this time been found to be true as a result of the investigations of others in order that those interested in this material may have before them the principal facts which have been ascertained.

As has been indicated, it will not be necessary nor useful that we take up the older published reports nor European literature to any extent, and those articles and reports that have been published within the last twenty-five years that need be discussed are not numerous. Most of the material included in the following pages has been taken from a half dozen Bulletins, beginning with 1911.

In 1911 there appeared *Bulletin No. 16, Bureau of Mines, U. S.*, by C. A. Davis. At the time of its publication, this Bulletin was the most important work, taken as a whole, that had been issued in this country. The title of this Bulletin, *"The Uses of Peat for Fuel and Other Purposes,"* shows its general scope. The supply of this Bulletin, a work of 214 pages, has long since been exhausted. Copies should be found in all libraries having files of Government publications. Because this work is not accessible to most of our Vermont farmers, liberal quotations are given on the following pages. As this Bulletin considers the peat deposits of the whole United States, it very naturally contains much that is not of special interest to Vermonters, but it also includes much useful information which is applicable in this State as well as elsewhere.

In his Introduction Mr. Davis writes: "The Bulletin sets forth the results of an investigation that was undertaken to determine whether peat as a fuel widely used in other countries could be made available in the United States where, though labor and economic conditions differ from those in the peat-using countries, there are opportunities for the introduction of a fuel selling at prices that should make the mining and shipment of peat to near-by markets profitable. In connection with the investigation of the possibilities of using peat as fuel, attention was incidentally given the possible development of other uses with the view of increasing the value of a material that hitherto has not

been generally considered an important natural resource of the United States."

As one would expect from the above Introduction, a considerable part of this Bulletin is devoted to a consideration of peat as fuel, but numerous other uses to which this material has been put, are also discussed more or less fully. There is also a map showing the location and distribution of peat deposits in the United States.

A Bulletin of especial value to Vermonters is number 165, by J. L. Hills and F. M. Hollister, published by the State Experiment Station, 1911, entitled, *The Peat and Muck Deposits of Vermont*. This Bulletin is still to be had from the Station at Burlington, and is in many respects very complete and were it not for the fact that very important experiments and much investigation of the subject has been carried on since this Bulletin was published, those inquiring about peat, especially Vermonters, might be referred to its pages and such an article as this would be superfluous. However, since 1912 several important Bulletins have been sent out by our own Government and more by our neighbors in Canada, and while the general status of the matter is not greatly changed by the findings of recent investigators, the summary of the findings which can be now given is well worth looking into. For this reason, as well as for others, a brief summary of those publications issued up to the present time in the United States and Canada cannot fail to be of value.

The Vermont Bulletin necessarily devotes most of its attention to Vermont peat, its characteristics, uses, location, composition, etc. Numerous quotations from the pages of this Bulletin will be found in pages which follow.

Of interest to the people of this State are pages 179 to 194 of the Bulletin, these pages giving the location, county by county, of numerous peat bogs, and more or less brief notes on the extent, depth of peat, physical features, etc. From these bogs two hundred and forty-four samples were collected. The samples were taken from forty-two towns, in twelve counties. On pages 197 to 221 chemical analyses of many of the samples are given. "The most extensive and valuable bogs were found to be located in Addison, Franklin, Grand Isle, Chittenden, Windham and Orleans Counties."

During the past ten years peat as a fuel has been much more extensively investigated in Canada by the Government much more extensively investigated in Canada by the Government and also by numerous corporations than in the United States, and several important and valuable Bulletins have been published. These Bulletins, Reports, etc., are of interest to us in Vermont because the conditions, at least in southern Canada, are similar to those in our own State.

The writer has quoted freely from some of these, since they are valuable in themselves and some are not readily accessible to Vermont farmers. A few of the Canadian Bulletins, those of most value to students of peat in Vermont will be considered.

In 1915 Bulletin number 11, Canadian Department of Mines, by Aleph Anrep, was issued. *"Peat Bogs and the Peat Industry."* Though not published till 1915, the investigations reported were carried on in 1913 and 1914. As will be seen by later quotations, this Bulletin treats some phases of the peat question, such as "Botany of Peat Bogs" and various kinds of machinery by which peat is prepared for fuel very fully. It is a work of over two hundred pages in all and is illustrated by ninety-two plates and sixty-five cuts.

In 1922 the United States Geological Survey published Bulletin 728, *"On the Occurrence and Uses of Peat in the United States,"* by E. C. Soper and C. C. Osbon. This Bulletin, a pamphlet of two hundred and seven pages, a large folding map of the United States, showing the location of peat deposits, and thirty-two illustrations. This publication, while treating of other matters pertaining to peat, is especially occupied with the numerous deposits over the United States. The Vermont peat bogs are enumerated and briefly described.

In 1924 the Canada Mines Branch issued Bulletin 614, *"Facts About Peat,"* by B. F. Haanel. In this Bulletin the topics which were taken up in previous Bulletins are discussed and the results of investigations made later than those before given are presented. There are also tables giving analyses of different peats from numerous bogs.

In 1926 the United States Bureau of Mines published a Bulletin entitled, *"Possibilities for the Commercial Utilization of Peat,"* by W. W. Odel and O. F. Hood. It is numbered Bulletin 253, Bureau of Mines. The Bulletin is a late result of an Act of Congress passed in February, 1919. The delay in publication was caused mainly by the inclusion of lignite and, as lignite, as a fuel is of much greater importance than peat, the appropriation was so largely expended upon lignite that too little remained for the proper investigation of peat, but what there was available after the lignite had been investigated was applied to the study of peat.

Other bulletins besides those mentioned have been issued, especially by the Canadian Government, but I think that those listed above contain all that is of interest to the readers of this article. As will appear, extensive extracts have been taken from all of the Bulletins named in course of the following pages.

The Bibliography at end of this article is intended to include all important publications on American peat that have been issued since 1910.

WHAT IS PEAT?

Before going further it will be well to understand what is the character of the material we are to study. What is peat? Later, muck, which is very often associated with peat will be defined. Most people have at least a general idea of what peat is and how formed, but it may not be out of our way to enlarge upon this somewhat.

In Bulletin 614, Mines Branch, Canada, on peat, Mr. Haanel defines peat as follows: "Peat is a combustible substance formed by humification or carbonization of plants under certain conditions. It is, like coal, a stratified mineral, and intermediate in nature between plant fiber and coal."

Mr. Davis writes in Bulletin 16, U. S. Bureau of Mines, page 8: "Peat is the partly decomposed and disintegrated vegetable matter that has accumulated in any place where ordinary decay or chemical decomposition of such material has been more or less suspended, although the form and a considerable part of the structure of the plant organs are more or less destroyed."

In the Vt. Exp. Station Bulletin 165, p. 145, we find peat defined "as the yellow, brown to black, more or less fibrous residue of a partly decomposed and disintegrated vegetable matter derived from mosses, sedges, and water plants in general, which have accumulated mostly under water and consequently away from air under conditions which have served in part to arrest ordinary processes of decomposition."

In the U. S. Bulletin 728 we find, page 4, "Peat is the partly decomposed organic residuum produced by an arrest in the decomposition of roots, trunks of trees, shrubs, mosses and other vegetation covered or saturated with water. It contains a large proportion of the original vegetable matter, and its vegetable structure is generally visible without a microscope. It is usually acidic, and it contains less inorganic than organic matter. In fact, some pure peats contain less than four percent of inorganic material. If the material will ignite and burn freely when dry it is usually considered peat."

The Century Dictionary defines peat as "partly decomposed vegetable matter produced under various conditions of climate and topography, and of considerable importance in certain regions as fuel. Peat occurs in many countries and in different latitudes, but always either in swampy localities or in damp and foggy regions, and its formation illustrates the conditions under which coal has originated."

The above definitions refer to northern regions, or to regions as in some parts of India, where by reason of elevation, the climate is cool. As would be expected, in tropical regions, except in a few peculiar and limited localities, peat is not found and, when found, the peat is not composed of the same species of plants as is usually the case. As peat is formed under different circumstances, it necessarily follows that the material in different bogs or even in the same bog, varies not only in its chemical composition, but also in its physical structure.

In U. S. Bulletin 728, page 8, attention is called to three kinds of peat deposits, *viz.:* "As classified according to topography, there are three great types of peat deposit-filled basin in which the peat accumulates in marshes, ponds and lakes; the built-up depository and its corollary, the climbing bog, in which the peat forms on flat or gently sloping moist areas not covered with water; the composite area consisting of built-up peat underlain by peat of the filled-basin type. * * * * * * Although deposits of all three kinds are found throughout the peat regions, the filled-basin type predominates. Built-up peat forms on areas where the drainage is greatly interrupted so that the soil becomes saturated with moisture. As shown by deep borings, large areas now covered by built-up peat are underlaid by fine-grained peat composed of the remains of aquatic plants, showing that the built-up stage was preceded by a long period of subaqueous peat formation. The most extensive deposits of lake and built-up peat are in the Great Lakes region and the New England States, and the most extensive deposits of marsh peat are in the Atlantic Coast States. Large climbing bogs are found in Maine; some are found in other New England States."

While the larger part of the peat found is of fresh-water origin, there is salt-water peat also. As will be shown later, fresh-water peat, taking all localities together, is, or may be composed of the remains of a great variety of plants, but salt-water peat is usually made from a comparatively small number of species, as most of the plants found in fresh-water bogs will not live in salt water. Most salt-water peat is made from a relatively few species of rushes, grasses, and sedges. Salt-water peat also contains a much greater proportion of inorganic matter, mostly sand, brought in by the daily tides, than fresh-water peat. It is much less valuable as a fuel than fresh-water peat. As Vermont has no sea shore and, therefore, no salt marshes, these may be left out of this discussion.

In Bulletin 253, U. S. Bureau of Mines, page 4, we find a classification of the different kinds of peat that is worth noticing. This is not a new arrangement, but I have seen none better, so far as physical characters go. There is turfy peat, fibrous peat, earthy peat and pitchy peat. By turfy peat is meant that sort in which the decomposition of the vegetable matter has been incomplete. It is spongy, elastic, light in weight as compared with other peat. Davis gives the specific gravity as "from 0.11 to 0.26," the full cubic foot weighing 7 to 16 pounds. It is yellow or light brown

color. Fibrous peat is of more completely decomposed vegetable matter, darker in color, black or dark brown, and has a specific gravity, "0.24 to 0.67," a cubic foot weighs 15 to 42 pounds. When peat grades into muck it is black, not fibrous, like earth when dry, specific gravity 0.41 to 0.90, a cubic foot weighs 25 to 56 pounds. Pitchy peat is more hard and dense than the other varieties, specific gravity 0.62 to 1.03.

The peat most commonly found in Vermont is of the fibrous sort, though turfy peat is not uncommon.

PEAT-FORMING PLANTS.

As peat can form only under water, or in very moist places, it necessarily follows that the plants from which it is formed must be of those kinds that thrive in such places, that is, aquatic or at least semi-aquatic plants. Notwithstanding this limitation, the total number of kinds is not small. As we shall see in the northern peat areas, where indeed most of the peat of the world is found and used, some species of plants are much more abundant than others. So far as the writer knows, a thorough botanical study of any given peat bog has not been made, but some have been investigated to a considerable extent.

In Vermont, and also in southern Canada, Sphagnum moss is the largest peat producer. This moss, which must be familiar to anyone who knows peat bogs, is the large moss of, usually, a light green color, sometimes reddish at the top, which often covers a large part of the surface of a bog. Rarely, however, does this plant alone occupy the whole of a bog, at least for any long time, for soon after a bog is started other plants, flowering plants and, after a time, even trees, appear coming up through and above the Sphagnum. The collector of wild flowers knows that some of our choicest and most beautiful wild flowers, especially orchids and heaths, as Arethusa, Cypripedium, Calopogon, Calypso and a number of other species are only to be had when sought for in a peat swamp. Bushes of various species and trees such as larch, firs, spruce, red maple, etc., are not uncommon in some peat bogs.

There is variety in bogs, some affording many species, others few. I suppose that some of our Vermont bogs if carefully examined would produce not less than a hundred species, perhaps more, large and small.

Beginning at page 58 of his Bulletin No. 11, Mr. Anrep has introduced excellent halftone plates of most of the more common Canadian plants of the peat bogs (Plates XVI to LXXIII, inclusive). Anyone having these plates at hand can readily identify these plants, and all are found in our Vermont bogs.

In Bulletin 16, U. S. Bureau of Mines, this variety of peat-forming plants is discussed in an interesting manner by Mr. Davis and also the conditions of climate, soil, etc., which are most favorable to the growth of such plants. While, as has just been shown, some plants are found in peat bogs and, therefore, contribute mainly to the formation of peat, it is obvious that the character of the peat formed and, therefore, its value, depends mostly upon the nature of the vegetation from which the material is formed.

In Vermont, as has been seen, Sphagnum moss is more commonly and abundantly found in our peat bogs than any other plant and probably supplies more largely than other species the material of our peat.

Mr. Haanel says that "Grass peat, particularly that formed from Eriophorum, when well humified, gives a black, heavy and compact fuel with small ash content and is the best raw material for the manufacture of peat fuel." Eriophorum is the very common cotton grass well known by anyone who has seen our peat bogs. Perhaps the origin and formation of peat will be more completely understood if we review the various essential stages in the growth of a peat deposit.

HISTORY OF A PEAT BOG.

Incidentally a part of this story has been touched upon in preceding pages, but it may be well to give a more complete and full account of how such a bog begins and develops. Necessarily the story is not precisely the same for all parts of the world, or for all bogs, but most if not all of our Vermont peat bogs have practically identical history.

We must go back into late geological time, though not very far back. As everyone would suppose, the possibility of a peat bog in any given locality, climate being left out of account, must depend upon the nature of the surface of the country, it must necessarily be more or less irregular, that is, there must be elevations from which water may run off and depressions into which water may run. If the climate and other conditions are right, peat bogs are very likely to form in many of the depressions. Without a full and detailed account of the agencies by which irregularity of the land surface are produced, it will be sufficient here to notice that which has been more than any other the cause of such low places as those in which peat bogs are found.

When the great glacier, of which all geology takes cognizance, moved from the north southward over the then surface of the land, it would come upon areas, greater or lesser, which would by reason of softness yield more readily to the action of the ice and this as it moved on, would necessarily scoop out some of the material over which it passed and to a greater depth than would be possible where the underlying material was harder and thus

after the ice had melted and disappeared, some of the depressions, the shallower ones, would result and in them water could drain from the land surrounding. In this way many and, in Vermont most, of the basins in which we now find water, or swamps or peat bogs have been produced, if we refer only to those of small size. The larger lakes and ponds often are due to more profound movements in the crust of the earth, but these larger and deeper bodies of water are never peat bogs and are not considered here. There is another cause for the present existence of ponds and swamps and a cause not uncommon in Vermont.

When a glacier moves down a valley it always carries with it débris, stones in pieces of considerable size, or broken or ground even to fine powder, and deposits this finally along the sides or elsewhere in its course or, when it melts, at the end. Here and there this material is left across a valley, forming a dam, and should a stream flow through a valley thus dammed, of course a pond is formed. Elsewhere there are other causes which have operated to form ponds which have finally become peat bogs, but in Vermont the two mentioned can account for all.

Ponds or lakes formed in one or another of the ways above mentioned may always remain ponds or lakes, and if the water is deep they usually do, but if the water is not too deep, or later a pond is partly filled by various kinds of débris washed into it from the surrounding land, it is taken possession of by vegetation and gradually filled up. At first only the shallowest portion, near the shore would be thus occupied, then this with very likely addition as time went on, would occupy more and more of the water area until the whole was filled with plants of many sorts and at a distance no water would be visible, though very evident if one tries to walk on its surface.

The various stages of the process may be seen even now from the tops of some of our New England mountains. Here is an apparently clear pond, near it perhaps a pond with clear water in the middle, but a border of moss and other vegetation. Sometimes, as if arranged for a museum exhibition, one may see in the landscape below, here a pond or little lake glistening in sunlight, over there is another with its border of aquatic plants, perhaps there are several borders of different shades of green, and a small body of bright water in the center, then beyond there is another similar, but with wider border, and often there may be others, bordered more widely, and over there one or more in which no water is to be seen, but only a more less circular area of light green, and this, as the years pass becomes a true peat bog, which was once a pond. The zones of plant life often seen in a forming peat bog are well stated by Mr. Davis, "In basins where the conditions of plant growth are favorable and certain kinds of plants become established, the aquatic vegetation arranges itself in well defined zones, more or less concentric around the deepest parts of the lake. Each zone is characterized by some dominant group of plants, which in the northern part of the United States are, broadly speaking, as follows, beginning with the zone in the deepest water and progressing shorewards: 1, the pond weeds, Potamogeton; 2, the yellow and white pond lilies, Castalia and Nymphea; 3, the lake bulrushes, Scirpus; 4, the amphibious sedges, Carex, Eleocharis, etc., especially the turf-forming sedge Carex filiformis. In the open water of any depth may grow the unattached algæ and certain rootless seed plants. Plants of each of these zones contribute to the vegetable accumulations, and as the mass of débris is spread into the deeper parts of the basin, if these exceed the depth of fifteen feet, and the bottom is raised sufficiently, so that the plants may grow upon it they move into the newly made territory in the same order in which they have occupied the old."

In this way, in time, there may be formed over the former pond a thick mat of sedges and like plants and soon among these grow other plants than have yet appeared and also some of the water-loving shrubs, as some of the heaths. To quote further from Mr. Davis, "Sooner or later * * * * * * the so-called peat moss appears, generally following the shrubs—more rarely with them. Sphagnum is the large, grayish green, whitish and pinkish moss, widely distributed in swamps and bogs, especially in the northern part of the United States and Canada. The plants (of Sphagnum) grow continually at the top and die below, and in favorable places individual plants may be found that have made a growth of more than a foot in length before the lower part of the stem is lost in the disintegrated mass below. * * * * * * The moss grows rapidly and quickly raises the surface of the peat. Following the shrubs and Sphagnum appear a variety of coniferous trees. They appear first as scattered individuals and subsequently form a zone near the shore. Following the coniferous species (larch, spruce, etc.) certain broad-leaved deciduous trees secure foothold and in their turn displace the conifers. * * * * * * The deciduous trees form the end of the cycle. By the time they have become dominant the surface of the peat has reached such a height above the level of the ground water that the decomposition and disintegration go on each year at about the same rate as accumulations made at the surface by the trees and thus the conditions of the soil are kept stable."[1]

It is to be noted that while in general the above account holds in case of Vermont peat bogs, yet numerous exceptions are found in number of zones of plants, kinds of plants, etc.

Mr. Davis further writes by way of a summary, "In general it may be said that ponds and lakes are often filled with peat

[1] No. 5, Mines Department, Bulletin 16, pp. 25 and 26.

nearly to water level by the accumulation of the remains of aquatic plants which vary definitely in type according to the depth of the water, that from near the water's surface to slightly above it, sedges are the most important contributors to the peat and that because of the slow elevation of the water level from any cause, or because of the slight sinking of the turf which they form, their remains may constitute several feet of the top of the plant deposit. After the surface of a peat accumulation is raised so far above the water that it no longer is overflowed, herbs of many kinds may replace the sedges. When it is permanently from six inches to a foot above the water level, shrubs and Sphagnum usually take possession. When the peat accumulation has reached a depth of a few inches more, trees become the dominant plants. With their appearance the peat practically ceases to increase in depth unless there is an elevation of the water level. The chief points to be noted are: 1st. That peat which has been formed in basins is largely built up by aquatic plants. 2nd. That the vertical range of the growth of such plants is from the surface to a depth rarely exceeding fifteen feet, at which depth the formation of peat by plants attached to the bottom practically ceases. Peat of greater depth than this below a water level that has been constant since the filling began is generally made up of the remains of floating organisms mixed with fine organic and mineral salt and other mineral matter brought down by streams, etc."[1]

It should be noticed that in all countries the above would not in all respects be an exact account of the manner in which peat is formed, but in northern latitudes, where nearly all peat is found, the process is as above described. In tropical regions and in salt bogs the material and process are somewhat different. As will be inferred from some of the facts given, the character of the peat in any bog might differ considerably from that in another bog because of the difference in the vegetation of each. In some bogs the peat is formed largely of sedges, in another of mosses and so on. In some there are no trees, in others, as the great swamp on Alburg or Pearl Swamp on Grand Isle, trees cover the swamp and, of course, there is great addition of woody material to that from lesser plants. Some bogs are so completely filled that though there may be a large deposit of peat, the surface is covered by green sod and there is moist meadow.

GEOGRAPHICAL DISTRIBUTION OF PEAT.

While peat is found in many parts of the world, it is mostly limited to the northern and, therefore, colder regions, where all the large bogs are found. In Russia, Germany, Sweden, Denmark, Ireland in large quantities, and in other European countries to a less extent, peat has long been used successfully for fuel and

[1] U. S. Bulletin, Bureau of Mines, No. 16.

for other purposes. In Canada and the United States there are immense quantities. To a small extent peat is found in South America and much more in Asia. In the United States peat is found, especially in the northern states, though by no means confined to these localities, for it also occurs as far south as the Everglades of Florida.

In Bureau of Mines Bulletin 253 it is stated that "About half the total peat resources are in Minnesota; Wisconsin, Florida and Michigan combined possess about 79 percent of the remainder." Nevertheless, New England possesses a not inconsiderable amount. The amount of peat in the available bogs of New England is estimated to be 124,000,000 tons, and of this Vermont is credited with 8,000,000 tons. While these are only estimates, and necessarily so, still it is probable that the quantity would be increased as development was carried on.

In Vermont the peat deposits are distributed all over the State, though many are small. The largest number of bogs, as ascertained by the enquiries of the State Experiment Station, are found in Addison County, where there are at least fifteen; Chittenden and Windham, each of which reported eleven; and Windsor, ten. Other counties possess a smaller number. None of these, however, is as large as the great swamp on Alburg in Grand Isle County, and there are deposits of considerable size in the towns of South Hero, Grand Isle, Franklin, Richford, Highgate, Isle La Motte, and elsewhere in the State. In the Experiment Station Bulletin no county reported less than seven, and in the whole State one hundred and twenty-nine were reported. In addition to these there are, probably, a not negligible number of others which were not reported and very likely some of them not recognized as peat deposits.

THICKNESS OF PEAT DEPOSITS.

Of course the amount of peat in any bog or locality depends upon the surface area and the depth and these are both very variable in different bogs. To quote from Mr. Davis in Bulletin 16: "Peat which has been formed in basins is largely built up by aquatic plants; the vertical range of the growth of such plants is from the surface to a depth rarely exceeding fifteen feet, at which depth the formation of peat by plants attached to the bottom practically ceases. Peat of greater depth than this below a water level that has been constant since the filling began is generally made up of the remains of floating organisms mixed with fine organic and mineral salts, and other mineral matter brought in by streams, etc. These facts have a definite bearing on commercial exploitation in that they point out the limits of depth at which certain kinds of peat may be expected to occur in filled basins. Since water retards carbonization and decomposition, the

peat found below the water level in basins will be only slightly decomposed, although thoroughly disintegrated," page 28.

On pages 176 to 240 of Vermont Bulletin 165, F. M. Hollister who examined many of the peat deposits of this State, gives much detailed information as to the character, kinds of peat, etc., found. There are also a few good illustrations of peat swamps. The depth of the peat in many is not given, but in many it is. Naturally the depth varies very greatly in different bogs, that is, from two feet to over twenty, and in some it was found to be "very deep."

RATE OF FORMATION OF PEAT.

Like all the other conditions found in a peat deposit, the rate of deposition varies greatly, but it is always slow. Partly because of the often great differences in different localities and partly because long continued and thorough observation has not been made, no definite statements can be given as to the average rate of deposition. "Even under the most favorable conditions it is too slow to be measured by ordinary observation." (Bulletin 728, page 12.) "Persons who have lived near peat-forming basins for half a century are unable to see the slightest change in the appearance or depth of the peat, although careful examination shows that it has been forming continuously." l. c. 12.

Various opinions, estimates, have been expressed by various authors as to the rate of peat formation, but as they are all based upon entirely uncertain data they are, as it seems to the writer, of very little value. That the process of peat formation is always slow, sometimes very slow, is certain, a very few inches in depth may be formed in a century, and this is all that it is safe to say.

This is interesting, as every coal bed must begin as a peat deposit and to the time which must be assigned to the formation of any coal bed must first be assumed the time needed in the formation of the initial peat bed. This helps us to appreciate the immense duration of geological time. Rarely is a single bed of coal found, usually there are several, it may be sixty or seventy or more, and between these layers of coal there may be many feet of rock, sandstone, limestone, etc. It should be added that in some localities, in which it may be assumed that conditions for rapid formation were exceptionally favorable, the depth formed annually is reported to be very much greater than is indicated above.

Mr. Haanel, Canada Bulletin 614, says that "On a bog in Warmbruchen, Hanover, the depth is stated to have increased nearly three feet in thirty years, while on certain bogs in Switzerland peat formation is estimated to have proceeded at the rate of between two and three feet in a century." Mr. Haanel gives no authority for these statements and, if true, they must be considered quite exceptional.

PROPERTIES OF PEAT.

Some of the properties of ordinary peat have already been mentioned, but there are several others that should be enumerated. A classification of peat based upon its texture has already been given.

A very noticeable property is its capacity for taking up and holding water. When freshly dug, though the water content varies somewhat, average peat is by weight, nine parts water and one part vegetable matter, mixed with more or less inorganic matter. Of course its bulk is very different, and when dry a block may be as large as when dug or larger. The water may some of it be dried out, but as will be seen when the fuel use is considered, it cannot all of it be removed. So, too, if peat is exposed to rain it takes up water readily and in large amount.

In color peat may vary, as has been seen, from very light to black.

CHEMICAL COMPOSITION OF PEAT.

When we remember the variety of plants that in one place or another form peat, it is obvious that the chemical composition of different peats must be, to some extent at least, variable. In an area like that of Vermont, where the material forming peat is everywhere much the same, or not greatly unlike, the different peats would be more alike than in many other localities, but even here there is variety. But it is not only in peat from different bogs that variety in composition is found. In some deposits there are different layers as one goes from top to bottom; also on one side of a bog there may be drainage from adjacent land which brings into the bog various extraneous substances. Thus it is not possible to find an analysis that could be called a fair average as an analysis of Vermont peat. If it is to be successfully used as fuel, it is evident that any peat must contain certain elements needed for combustion. Basing their conclusions upon a detailed study of five hundred samples of peat from different parts of this country, Soper and Osbon in Bulletin 728, U. S. Geological Survey, write as follows, page 16: Although the exact atomic relations of the principal elements are not known, and probably are not constant, the formula, Carbon 62, Hydrogen 74, Oxygen 24, is typical.

The composition of peat is illustrated by the following analysis (ash and moisture omitted):

Carbon	62 percent
Hydrogen	6 percent
Oxygen	30 percent
Nitrogen	2 percent
	100 percent

The quantity of free carbon generally ranges from 10 to 60 percent, the remainder being combined with other elements.

Mr. Haanel in his Canadian Bulletin gives as an analysis, based on European peat:

Carbon	57 to 59 percent
Hydrogen	5 to 6 percent
Oxygen	24 to 38 percent

More useful than any other analyses can be to Vermonters are the numerous results of analyses made by F. M. Hollister in the Vermont Experiment Station laboratories, as given in Vt. Bulletin 165.

Dean Hills writes as follows: "The actual chemical make-up of the organic matter is but slightly understood, particularly as to the transition and decomposition products which occur. It is a heterogeneous mixture of substances, some known, some guessed at, complex and highly variable. To list the various organic acids, many more or less mythical, as well as the sundry organic compounds, and to mention the derivatives which are obtained from dry distillation would take many words. However, its elemental composition is the usual carbon, hydrogen, oxygen, nitrogen and a little sulphur, in varying proportions. Ordinarily the more completely decomposed the peat, the more its carbon and nitrogen and the less its oxygen and nitrogen content. Peat ash is variable, both in quality and quantity. The purest peats carry barely three percent and good ones rarely more than ten percent ash."[1]

The chemical analyses mentioned were taken in forty-two of the Vermont towns located in twelve of the fourteen counties.

Beginning at page 222 of the Vermont Bulletin is a very interesting "Discussion of the analytical results." In the following pages each county is considered and usually there is some comment on the particular bog from which samples were taken. The writer advises anyone interested to secure a copy of the Bulletin and carefully read pages 222 to 240. Pages 197 to 220 give numerous analyses of Vermont peats.

PEAT USED AS FUEL.

Various uses of peat, of which there are many other than as fuel, will be mentioned later. As is well known everywhere, peat

[1] Vt. Bulletin, p. 150.

if available, has been to some extent used as fuel and certainly no other use has become of anything like so important. The use of peat for heating purposes is very ancient in Asia and also in Europe. Everyone associates peat with Ireland and probably peat has been for many years of very great importance to the Irish peasants. Indeed it is difficult to see how, for centuries, many of the people could have lived without it.

Apparently, peat, or turf as the Irish usually call it, is in some parts of Ireland the only available fuel for the poorer classes. So much is this the case that it is probable that some areas in this island could never have been inhabited, at least to any extent, had not the climatic conditions been favorable for the formation of peat bogs, from which abundant and cheap fuel could be obtained.

While peat has long been used in Ireland more than elsewhere, it has and is now used in most of the countries of Europe, not perhaps as exclusively for fuel as in Ireland, but in many ways. It is estimated that as fuel alone not less than twenty millions of tons of peat are annually used by the different European countries. Especially has peat been long in use in Denmark, Russia, parts of Germany and Sweden. Of course the fuel situation in any locality must have an important influence upon the need for and use of peat.

Dry peat will always burn, but, as will be shown, coal and even wood are better at the same cost. Evidently the main reason why peat has been and is used so much more extensively in Europe than in our own country is because the better sorts of fuel have been abundant and cheap here as compared with those countries. Of late years, however, the relative cost of different kinds of fuel has changed and no one can tell how much more than now other fuels will cost. Here in Vermont, there never can be coal mines for geological reasons given in former Reports, wood is almost certain to increase in price and the time may come when the great stores of peat which lie idle in this State and more in some of the others, can be profitably used. This being undoubtedly true it must be of consequence that our supplies of peat and the material which they contain be investigated, even if under present conditions peat cannot, in most localities, be profitably dug and prepared for use. Increase in the prices of coal and wood and increase in efficiency of methods of obtaining and especially preparing peat, both of which may very likely occur, may cause peat to be more largely used in this country as it is in Europe.

As has been intimated, the present paper is only designed to furnish to those interested in the subject a convenient summary of what has, up to the present time, been ascertained as to the use of peat. It is not at all designed to recommend to owners of

peat deposits in Vermont that they at once begin to use peat, unless it be in a small way that shall not involve much expense.

So far as the United States are concerned, or at least so far as the writer can discover, very little peat is used for fuel, but the fact that enquiries as to the character and possible use of peat have greatly increased during the last few years show that more than usual attention is being given to its possibilities. The latest Government report declares, "The quantity of peat used as fuel in 1923 was negligible, though 57,907 tons are reported as used as fertilizer." As fertilizer it is quite certain that in one way or another, many thousand tons are used on many farms which are not reported. As will be shown, in Canada many thousands of tons of peat are annually used as fuel, and in Europe many millions.

Notwithstanding the many failures and the great sums of money already spent it seems desirable that attention be called to the possibilities in the case, even if it does not appear that peat is at present available in Vermont. As will appear, it does not now seem ordinarily possible to dig and prepare peat at such cost as permits competition with other fuel to advantage. As all peat is formed under water, or at least where it is very wet, it is impossible to use it as a fuel when first dug. Mr. Davis says, "Even in drained bogs, a short distance away from the ditches the water content seldom falls below 80 percent, as the falling rain is quickly absorbed by the mass of the peat through which it drains very slowly. This slow movement of water to the ditches in peat beds is shown by the fact that for a considerable distance above the water level in ditches, even when no water is standing in them, water can usually be squeezed from the material taken from the walls."[1]

From this it is obvious that the first process through which peat must pass is one which will dry it so far as possible. In Ireland, or elsewhere, peat used by the poorest people can only be dried by a simple and inexpensive process and in this case all peat is simply air dried. That is, it is piled up in some dry place and the sun and air cause the water to evaporate in part. In a dry climate this is easy, but not in moist regions. However, in most localities it has been found possible to dry out much water by exposure to sun and air, but as will be shown, it is very difficult to employ any artificial method by which the water can be wholly removed.

Yet the importance of removing as much of the held water as possible, and the necessity of getting rid of a certain amount are plainly shown by investigation. For example:

"Dry peat with no ash may produce 6,500 calories.

Dry peat with 30 percent ash may produce 4,500 calories.

[1] Bulletin U. S. Mines Bureau, p. 37.

Peat with 25 percent water may produce 4,700 calories.
Peat with 30 percent water may produce 4,700 calories.
Peat with 50 percent water may produce 2,700 calories."

Several methods have been more or less successfully employed to effect the evaporation of the water in order that peat may be used for fuel. Naturally the most obvious method is that of simply piling blocks of peat in the sun, after thoroughly draining the bog and, as we have seen, this is most commonly used everywhere. In many climates this is, to a certain extent effectual, that is peat can be air dried so that it burns readily and, therefore, can be used, but all that apparently should be gotten from the material cannot by any means be obtained in this way.

Peat does hold water like a sponge, but this is not all. "The water present in peat appears to be held in three ways, two of which are mechanical. Of the mechanically held water, a part only is removed by pressure or other mechanical means. Prolonged trials made by many competent experimenters show that only a relatively small percent of water can be pressed from peat having 90 percent of moisture at the outset. * * * * * * The remainder of the enclosed water resists the greatest hydraulic pressure and the best centrifugal machines and can be removed only by evaporation. If the quantity present is below 90 percent, the percentage removable by pressure is correspondingly reduced. In other words the water that can be pressed from peat does not reduce the water content below 70 percent and the rest can only be drawn off by heat derived from the sun and air or, more expensively, from an artificial source. This residual water is held largely in the cell walls and the minute cavities of the plant remains. It is clearly not held in chemical combination as it can be entirely removed by heat without destroying the nature and structure of the peat."[1]

In Bulletin 643, Canada Mines Branch, Mr. Haanel gives a summary of results of experiments carried on in Canada to discover some method of artificial drying as follows: "The artificial drying of peat is not a process which simply involves the evaporation of so many pounds of water. Peat has peculiar physical properties which make the problem difficult. An important one is poor conductivity of heat. When peat is subjected to a comparatively high temperature, as in a drying oven, the surface may become charred before even a small portion of the moisture has been evaporated. Pieces of peat dried in this manner have been found on inspection to be completely charred on the outside when the moisture contained on the inside was in the vicinity of 75 cent. Even assuming a thermal efficiency of 70 percent in the drier, where peat has a moisture content of 86 percent, in order to obtain 100 percent of dry substance an equal amount of dry peat, or its equivalent, must be burned to produce the heat required for the evaporation of the water contained, leaving a net product of zero. To obtain one hundred pounds of 25 percent moisture peat, consumption of the same amount of 25 percent moisture peat is necessary. Therefore, any process of removing the water from raw peat by evaporation alone is impracticable."

[1] Bulletin 16, Bureau of Mines, pp. 42, 43.

"Assuming again, that by the costly operation of pressing out the water by hydraulic pressure the moisture content of the peat can be reduced to 70 percent to produce one hundred pounds of dried peat product, forty pounds, or its equivalent of such product must still be used to operate the driers."

"In Europe, where air-dried peat fuel has long been produced in millions of tons annually, many processes have been advanced by inventors involving the substitution of mechanical pressure and artificial drying for what may be called the natural process of air drying."

The failure of all these attempts has been recorded in a recent and authoritative work on the subject by A. Hausding, published in Germany and translated for the British Fuel Board. The conclusions arrived at by Hausding, after a general survey of the European industry, are important. "Every artificial drying plant up to the present, no matter how promising it seemed to be, has always proved too expensive, both as regards plant costs and running expenses. Whoever values his money should never attempt the artificial drying of raw peat. The heat, or other energy corresponding to it required to evaporate the water is so great that from the commercial standpoint complete failure must be inevitable, even when the technical contrivances are assumed to be as perfect as possible."[1]

Various processes have been devised and tried thoroughly to treat peat so that it should be a more efficient fuel and all these have failed mainly because the contained water could not be economically removed. The general conclusion reached by all those who have investigated the question seems to be that air drying is, in any country, the only method by which peat can be economically prepared for use as fuel. As to this, Mr. Hausdig says, "During the past twenty-five years not a single one of the many discoveries or inventions in the domain of peat winning has attained any considerable importance or any success worth noting except the peat dredgers, the automatic spreaders, or peat-pulp distributors, and the cut peat machine. Millions have been invested in so-called new solutions of the peat problem and have been lost." All the peat used in Ireland, 6,000,000 to 8,000,000 tons annually, and the 7,000,000 tons used in Russia and that used in other European countries is only air dried.

Our near neighbor, Canada, under condition in many locali-

[1] Canada Bureau of Mines, Bulletin 614, p. 12.

ties like those found in Vermont, has, as already noticed, given much attention to the use of peat and many millions of dollars have been invested by various corporations in attempts to make its use possible as compared with other fuels. The Government of Canada has also expended large sums in similar work.

Mr. Haanel states that "In the year 1908 the Director of the Mines Branch of the Department of Mines undertook to have the status of the peat industry in Europe thoroughly investigated in order to determine whether an economic process for manufacturing peat fuel could be found in those countries and one which could be successfully employed in this country and at the same time he began the systematic investigation of the peat resources of Canada, paying especial attention to those peat bogs which were favorably situated with respect to transportation facilities as well as to inhabited districts. As a result of the investigation conducted in Europe a small commercial plant of 30 tons daily capacity was imported from Sweden and erected on a portion of the Alfred bog, which had been prepared for its reception, and was operated for two years * * * * * to demonstrate to those who might be interested how peat fuel could be manufactured economically. At the conclusion of these two seasons' work, the Swedish engineer, who was brought over for the purpose of operating the plant, showed how peat fuel, with that plant, could be manufactured on a small scale at a cost which would permit it to be sold on the market as a domestic fuel in competition with coal."[1]

Other machinery and other experiments were installed by the same authorities, but because of the European war these were not used until 1918, a joint Committee was appointed by the Canadian Government and that of Ontario "to conduct an investigation concerning the utilization of peat resources of Ontario for fuel purposes. This Committee after carefully considering all processes which had been devised for manufacturing peat fuel decided that the air-dried-machine-process was the only one which could in any sense be termed economic."[2]

On page 18 of this Bulletin Mr. Haanel gives the following information as to peat fuel prepared in the above manner. "In the manufacture of air-dried peat fuel, excavation must be discontinued in time to permit the fuel to dry below 50 percent moisture before severe frost sets in. Peat which is frozen while it contains more than this percentage of moisture will disintegrate and become useless as a domestic fuel."

The steps in the process are given as follows, page 18:

"(a) Excavation of raw peat.
(b) Pulping or maceration.
(c) Conveying the peat pulp to the drying field.

[1] Bulletin 614, Mines Branch, Canada, p. 17.
[2] Bulletin 614, Mines Branch, Canada, p. 17.

(d) Spreading and cutting into blocks.
(e) Turning the partially dried blocks.
(f) Harvesting."

By pulping is meant putting the raw peat through a machine which by means of knives cuts or tears the turf into small bits and also mixes it thoroughly so that the whole is homogeneous. This is found to be a very important process.

The extent of the Canadian experiments, as well as the confidence that in some way peat could be made valuable as an economical fuel is shown by the fact that besides the work of the Canadian Government, which was not inconsiderable, more than forty companies engaged in similar experiments and some of these invested large capital, several millions. Nevertheless, none of these efforts appear to have been sufficiently successful to warrant long continuance. At any rate I do not find that any are now in operation.

The necessary equipment is costly, as Mr. Haanel estimates the cost of a properly equipped plant of a size equal to turning out ten thousand tons of prepared peat fuel during one season to be $1,000,000.

After studying the results of the Canadian experiments, which were certainly very thorough, one might say that they were sufficiently conclusive to warrant us in the conclusion that peat fuel was proved a failure in this country, whatever may be true of some European countries, but it does not seem to me that this is the true view of the case. Were the subject investigated in detail, it would appear evident that many of the Canadian experiments were not performed in the wisest manner and were foredoomed to fail. Many others were so nearly successful as to give a good deal of encouragement as to future investigations. Some of the reports as to the use of peat in domestic service are surely well worth considering.

Although, as noticed elsewhere, we find no very encouraging results in any of the peat investigations that have thus far been carried on in the United States or Canada, yet we do find results that make it seem probable that methods will yet be discovered that will enable us to realize something of value in the product of our peat bogs.

It has been said that the moisture in dried peat may be reduced to 25 percent, but it has been found that somewhat more water is rather an advantage than otherwise. Mr. Haanel says, "Peat fuel containing 30 percent moisture or slightly more is tougher and stands handling better than the drier fuel." Drier peat than 39 percent moisture is likely to burn too fast. Exposure to rain does not seem to injure peat fuel to any great extent.

Canadian experience shows that in very cold weather, when a steady, hot fire is needed, peat is not as good a fuel as coal, since it at first burns more rapidly and then goes down. It serves well as kindling for coal and in moderate weather, that is, most ordinary winter and especially spring and fall weather, it is excellent and economical. Peat as manufactured at Alfred is an ideal fuel for open grates, and in many ways preferable to cannel coal. It burns quietly with a very cheerful yellow flame and then subsides into a red glow which lasts a long time." Haanel, l. c., page 22.

Mr. Haanel also says, "For cookstoves, and especially for baking where an intense steady heat is required for a comparatively short time, peat fuel is unexcelled. It is more easily ignited than coal, requires less draught except just as the fire is being started, and a much less quantity should be used to make a fire, though it must be renewed more frequently." Haanel, l. c., page 23.

"Peat does not clinker and burns to a light clean ash. 'The ash content of peat is infusible under ordinary conditions, thus high temperatures can be maintained without the production of troublesome clinkers.' When covered with ashes a peat fire can easily be kept over night, and by merely opening the dampers and adding a small quantity of fresh fuel, a surprisingly active fire is quickly rekindled." Haanel, l. c., page 22.

VALUE OF PEAT AS FUEL COMPARED WITH OTHER FUELS.

This is an interesting matter and one of the first questions which, in this part of the world, one would ask is how peat compares with well-known fuels. Many and careful experiments have been carried on in investigation of this question and the results of these experiments are interesting.

Some of the advantages in using peat have been mentioned above and if there were no disadvantages to offset these, the utility of peat would be settled. It has already been estimated that peat does not give as hot nor as long continued a fire as some other fuel. As compared with various kinds of coal and good wood, the relative value is about as follows:

Wood	5,760	B. t. u.[1]
Good anthracite coal	12.523	"
Bituminous coal, best	13.365	"
Bituminous coal, good	11.686	"
Coke	12.366	"
Air-dried peat	8.920	"

The above table is compiled from tables given by Mr. Davis, Bulletin Bureau of Mines, 16, page 53. Mr. Davis and other writers on peat give many more figures, but these are enough to

[1] B. t. u.—British thermal unit, *i. e.*, heat sufficient to raise one pound of water one degree Fahrenheit.

show that the best peat is much less in heating power than a fair quality of coal.

Mr. Haanel writes as to this "Standard peat fuel as manufactured at Alfred has a gross heating value of about 6.630 B. t. u. per pound, while the average anthracite now coming into Canada has a gross heating value of about 12.500 B. t. u. per pound. Standard peat fuel has a moisture content of 30 percent. Theoretically, therefore, it takes about two pounds of peat to give as much heat as one pound of anthracite. This is based on a comparison of the theoretical value of the two fuels. In practice, however, a large portion of the coal passes through the grates unburned and is entirely lost, while in case of peat, complete combustion results. In mild weather, owing to the difficulty of controlling the coal fire, a great deal of heat is wasted or the fires go out. With the peat fuel this is not the case. According to actual experience about four pounds of peat will, in mild weather furnish as much heat as three pounds of coal when burned in the ordinary furnace or surface heaters. For open fireplaces and domestic ranges the comparison is even better." Haanel, l. c., page 23.

In consequence of the attention which was given to the Canadian peat bogs, the Government and also some private companies distributed many tons which were used in various trials in different parts of Canada. "Over 600 tons were sold in Montreal and vicinity and several hundred tons were sold locally and drawn directly from the plant to purchasers." This was in one year, 1922. Besides this over 2,000 tons were used in different Canadian towns.

A Peat Committee was appointed by the Government and thorough investigation of the possibility of a profitable use of the material resulted. This Committee manufactured and sold at a nominal price 8,000 tons of peat. They later sent out a questionnaire to several hundred who had used the peat as prepared and the replies to these "Indicated general satisfaction with the fuel and a demand for much larger quantities." Haanel, page 22.

The cost of installing a plant with necessary machinery, transportation charges, and other drawbacks have prevented extensive use of peat fuel during the last two years. So much has been quoted from the last Canadian Bulletin for obvious reasons, *viz.:* The extensive investigation which Canadian authorities have made and the fact that conditions in Canada are very similar to those in Vermont. Coming to the States south of Canada we find that very much less interest has been taken in this subject.

As compared with Canada, the United States has at no time shown great interest in the use of peat for any purpose, nor has very much money been expended in preparing it for use. A small number have been engaged in manufacturing peat, especially for use as fuel and for agricultural use, but so far as reported, no results of importance have been reached. As far as reported, about a dozen companies in the United States have worked with peat within the last few years. All of these, or at least nearly all, prepared peat for use agriculturally. None, so far as I know, prepared it for fuel.

The latest Report of the U. S. Geological Survey that is published gives the amount used as fuel as "negligible." "The quantity of peat produced in the United States in 1923 was 61,355 short tons, valued at $376,834." This was entirely used for other purposes than fuel. Twenty-two plants, scattered over the country, only two in New England, reported for that year.

Coming now to the State in which we are most interested we find that, while as has been stated, peat bogs abound in Vermont there has never been any considerable effort made by Vermont farmers to use peat other than as a fertilizer or ingredient of fertilizers. The Vermont Bulletin (Experiment Station 165) gives a full account of one effort to make use of some of this material and, so far as I can ascertain, this is the only considerable effort of the sort in Vermont on record, though possibly there may be others.

A deposit of peat covering about fifty acres in Franklin was worked by Mr. John Webster. As described in the Bulletin, page 186, this was formerly a beaver meadow and thickly wooded. When Mr. Webster began operations the bog "was quite dry and covered with small trees and shrubs." "The peat as excavated was black at the top, brown near the middle and liver-colored near the bottom." The peat was six feet thick and was underlaid by a layer of shell marl. No machinery was installed, but a drying shed was built. At first considerable dry peat was sold, but after using it people found that the great quantity of ash produced made it necessary to clear out the ash pan of a stove several times a day. At the outset the swamp was not drained, but later ditches were dug.

As quoted, Mr. Webster says, "The next year and for nine succeeding years I cut and dried from five to ten cords annually, using it in the cookstove and open grate with good success. Of course I had to learn how to use it and what kind of stove was best suited to make an economical fire." This was written in 1910. As others owning or having access to a peat bog may be willing to try peat, though only in a small way, some further account of Mr. Webster's work may be interesting and useful. Mr. Webster says that he used only common tools, such as would be found at any farm, except that he added a peat spade made for use in a peat swamp. He did not cut the peat over wide areas, but cut ditches "twelve rods apart from the edge to the stream which flowed through the center of the marsh. These ditches were twelve feet wide, taking off the sod six inches deep." As it is always best that a bog be drained before work is attempted, the above method may in many cases be most convenient, as it serves to at least start ditches for drainage and also obtains peat. In this bog three layers were commonly taken out, but sometimes five or six.

Detailed directions are given by Mr. Webster for properly taking out the peat. (See Vermont Bulletin, page 159.) These directions are not quoted here as each bog may require somewhat different treatment. Of course any bog or swamp must first be cleared of trees, shrubs or grass, and any swamp should be at first drained as completely as possible for the best results. At any rate that portion which is to furnish peat should be well drained and if this can be done some time previous to taking out the peat so much the better. Naturally, the first process undertaken after the peat has been taken from the bog is to dry it as thoroughly as possible. The manner in which it is piled in the open air is important. Of course it is necessary that the sods, or blocks, be piled up in such a loose manner that the air can have free access. "A week's exposure to sun and wind vaporizes about one-half of the moisture. The blocks should then be turned. After another week or ten days of fine weather the blocks should be cobbled up to remain until dry enough to put in a shed, which in fine weather will be about one week."

"As to building the stack: Only after several trials did I learn how. Lay down a bottom of rails and old boards so as to allow air circulation. * * * * * * Begin the stack five or six feet wide and as long as needed. Lay a tier of blocks on the bottom across and another the other way, keeping the blocks about an inch apart. * * * * * * After three or four tiers are laid, leave, once in four feet, a hole through the stack at least four inches wide and four blocks high. * * * * * * Build up in this way about three feet and draw in and top off so that it will be about six feet high when finished. Twelve feet of such a stack will hold two cords. * * * * * * It is always best as soon as the fuel is in good condition to place it under cover where it will keep for any length of time. When dry enough to burn it will weigh about thirty pounds to a heaped bushel. A cord will weigh about a gross ton and is equal to or better than good wood." (Mr. Webster in Bulletin 145.)

As has been noticed, Mr. Webster used peat for nine or ten years and, for a time at least, he seems to have been well satisfied with the results of his trial. He considers a cost of production at $1.14 per cord as "a safe estimate." He considers the peat worth, as compared with other fuel, several times this. And yet I find on inquiry that he gave up producing peat some years ago because of the expense of getting it out. I do not have this information from Mr. Webster himself, as he died several years ago, but the above is the impression of residents of Franklin.

A caution which Mr. Webster gives may be properly added to the above. This refers to the time to cut peat. He says, "In northern Vermont, any time after mid-May. Frost injures it badly when it is first taken out, * * * * * * It may be cut any time during the summer, even as late as September first, with good prospect of securing it before winter. My experience indicates that freezing it does no harm when it is dry enough to stack."

The qualities to be looked for in a peat bog from which peat is to be taken are mainly as follows, as stated by Mr. Haanel:

"It must be convenient to shipping point and accessible to markets. The peat content of a bog must be sufficient to warrant the erection of the necessary plant. Shallow bogs and those portions of deep bogs of a depth less than from three to five feet are generally unsuitable for commercial production of peat fuel.

Peat for fuel purposes must be well humified and have comparatively low ash content. Degree of facility in drainage and freedom from stumps and roots are also points which may have a material bearing upon the success of operations to produce fuel commercially."[1]

Much of the above does not apply to peat production on a small scale, but it is given as a whole that each may use such part as he may think best. From the facts and results given on foregoing pages it will be readily seen that Vermont owners of peat bogs, however good they may be, are not advised to invest much money in them by way of putting in machinery to get out and prepare peat for fuel. And yet, notwithstanding many failures in various localities and at different times in the immediate past, success has in many cases been so nearly attained, and the relative cost of coal and wood has so constantly been increasing, that it does seem that inexpensive experiments might be tried here.

When we find, as has been shown, that in Europe many millions of tons of peat fuel have been and are being used and though largely for domestic fuel, yet some is used for fuel in manufacturing plants and in one country at least, for fuel in railroad locomotives, and successfully, when we find this to be true there is certainly a temptation to try still further to make use of it on this side of the ocean. So far as analyses and tests go, much of our peat seems equal to the best found in Europe. It is true that in this country there has hitherto been no such scarcity in other fuels as in Europe and probably this is a factor not to be overlooked. There is also no doubt that a great deal of money and labor has been expended, especially in Canada, in methods that

[1] Canada Bulletin 614, p. 5.

were unwise and doomed to failure from the start. In fact the best methods do not seem to have as yet been discovered.

As wages now are in most localities in this country, even considering the present price of coal, it does not appear that it is possible to dig and dry peat at such cost that it can compete with other available fuel. It should be understood that we are discussing the cost when all the work is done by hand. Estimates like the following would of course vary in each locality, but an estimate given by the U. S. Bureau of Mines may be of interest and it is a fairly reasonable one, for most places in New England at any rate. On page 11 of Bulletin 253, Bureau of Mines, we find, "Three men can cut and spread enough peat in one week to give twenty tons of air-dried peat."

Mr. Webster, from whose account in the Vermont Bulletin quotations have already been made, says that, "* * * * two men can easily throw out in an eight-hour day, after the sod is removed, eighteen to twenty feet in length, about eight solid cords." Of course these blocks would shrink in drying, giving, as Mr. Webster estimates, about seven dry cords.

What is said to be a cheaper mode of getting out peat is given in U. S. Mines Bulletin 253, page 11. "The Dutch method of winning peat for fuel and litter is said to result in a larger output per man, because the use of cutting tools permits taking out blocks 20 x 6 x 6 inches. A good workman is said to cut and spread in one day a strip of peat 300 feet long, 2 feet wide and 2 feet high, which is the equivalent of about four tons of air-dried peat fuel. In order to obtain four tons of peat containing 20 percent moisture from peat that contained 85 percent of moisture in the bog it is necessary to cut, remove and spread more than twenty-one tons of peat and it is not probable that the average workman will do this amount of work in eight hours. One ton of air-dried peat per man per day seems a fair estimate of what might be expected."

The suggestion which might well be considered by some Vermont farmers, is that "it might be more feasible for individuals, particularly farmers, with some peat on their farms, to utilize their time during the quiet months of the year in preparing their own fuel." It should be noticed that while for many purposes it is undoubtedly better to use a stove or furnace especially fitted for burning peat, peat can be burned in almost any sort of stove, etc., that will burn wood. There can be no doubt that there is a large amount of good peat which without very elaborate methods can be made good fuel, but at present and as long as present conditions continue, any required number of thermal units can be obtained more cheaply from other fuels.

A process which differs from those named is the "Hydropeat process." This is a European process and, so far as I know, has not been tried in this country. In some of the many kinds of peat bogs here, this process might not improbably be successfully used. Where, as in Germany, it has been tried, it has been found to be especially adapted to bogs in which there are great tangles of roots and much wood. In the Hydropeat process an abundance of water is thrown upon the bog, or that part of it which is being worked. A somewhat high pressure (75-100 pounds to the square inch) is used. By this the peat is washed away from roots, logs, or whatever such material there may be. The peat is thus washed into some sort of reservoir from which it is removed by pumps, or as may be most convenient, and spread over a well drained part of the bog. In the better machinery some provision for maceration is made as it is pumped out of the tanks.

In the Bulletin of the Mines Branch a somewhat more detailed account of this process is given (page 23, Bulletin 253). Where it can be conveniently used this process has been found to be much more economical than others and apparently is adopted in an increasing number of localities. As an example, I quote the following from the Bulletin:

"A plant in Germany is reported to have produced 6,500 tons of air-dried peat—9 tons per ton—in seventy-five ten-hour working days with nine men working the plant in a root-free bog, or eleven men when roots were confronted. The plant used two hundred kilowatt hours of electric current per hour. Under the above conditions the cost of the air-dried peat was less than $2.25 a ton. Of course the cost of labor, electricity, etc., would vary in each locality, but the above shows what can be done under what may be considered ordinary conditions."

"Dried peat differs from lignite and coal in this important particular—it does not tend to ignite spontaneously when stored in piles. It is readily kindled, however, hence the same precautions as for wood must be taken."

In addition to what has been said as to the use of peat in producing heat for various manufacturing operations, we find in Bulletin 253 the statement that "Under a certain set of conditions peat can be used satisfactorily and economically as an industrial fuel." "It must be recognized that pound for pound, peat fuel is not practically equivalent to coal." "Peat may be and has been used to generate power; first, by burning it under boilers with specially designed furnaces and combustion chambers; second, by burning it in producer gas generators, with or without the recovery of by-products." Of course this all depends upon relative cost of different fuels.

On page 65 of Bulletin 253 there is given a table showing the comparative advantages and disadvantages of nine kinds of fuel. This table seems to the writer sufficiently interesting to deserve a place here and is accordingly quoted.

"ADVANTAGES AND DISADVANTAGES OF VARIOUS FUELS AND OF ELECTRICITY

Fuel	Advantages	Disadvantages
Wood	(*a*) Cleanliness, (*b*) cheerful fire, (*c*) quick increase of heat, (*d*) cheapness in some localities.	(*a*) Low fuel value, (*b*) large storage space necessary, (*c*) labor in preparation, (*d*) scarcity, (*e*) does not hold fire long, (*f*) unsteady heat.
Anthracite ...	(*a*) Cleanliness, (*b*) easy control of fire, (*c*) easier to realize heat in coal than is the case with other coals, (*d*) steady heat.	(*a*) High price, (*b*) difficulty of obtaining, (*c*) slower response to change of drafts.
Bituminous coal	(*a*) Low price, (*b*) availability, (*c*) high heat value (in the best grades), (*d*) low percentage of inert matter (in the best grades).	(*a*) Dirty, (*b*) smoke produced, (*c*) more attention to fire and furnace necessary than with anthracite.
Subbituminous coal and lignite	(*a*) relatively low price, (*b*) availability (in some regions), (*c*) responds quickly to opening of drafts.	(*a*) Slacks and deteriorates on exposure to air, (*b*) takes fire spontaneously in piles, (*c*) heat value generally low, (*d*) heat in fuel difficult to realize, (*e*) fires do not keep well, (*f*) gases generated over fire pot sometimes burn in smoke pipe, causing excessive heating.
Peat	(*a*) In general, the same as for wood.	(*a*) Low heat value, (*b*) bulkiness.
Coke	(*a*) Cleanliness, (*b*) responds quickly to opening of drafts, (*c*) fairly high heat value.	(*a*) Bulkiness, (*b*) liability of fire going out if not properly handled, (*c*) fire requires rather frequent attention unless fire pot is deep.
Oil	(*a*) High heat value, (*b*) immediate increase of heat, (*c*) cleanliness, (*d*) small storage space necessary.	(*a*) High price, (*b*) difficulty of safe storage.
Gas	(*a*) Ease of control, (*b*) cleanliness, (*c*) convenience, (*d*) immediate increase of heat.	(*a*) High price in many places.
Electricity ...	(*a*) Every advantage.	(*a*) High price.

"Peat would probably be a satisfactory fuel for many of the purposes for which wood is used; the cost will determine whether wood or peat will be used in such circumstances."

According to some authors, peat has been found useful as fuel when mixed with some kinds of coal. As to this, Odell and Hood say, "When combined with certain kinds of coal it (peat) prevents the formation of troublesome clinkers in the grate. The longer flame produced by burning mixed peat and coal is better distributed over the boiler tubes than the short and hotter flame from burning coal alone, therefore, the mixture may be used with less damage to the boiler. Two parts coal and one part peat are reported to have given excellent results."[1]

AGRICULTURAL VALUE OF PEAT.

While peat has from no one knows how early been used as fuel and will always be so used mainly, yet it is in many regions used to some extent as dressing for the ground as fertilizer, or at least as a useful addition to other materials.

Dean Hills in the Vermont Bulletin remarks as to the use of peat for this purpose, "As a fertilizer and soil amendment in some sections peat, or muck, is drawn directly from the bog and spread as a top dressing. Good results are usually obtained though they may not be at once apparent. The benefit seems to be a lasting one. Theoretically this is not an ideal practice. Peat nitrogen is but slowly available. Other methods which render this element more quickly available are to be preferred as a preface to soil application. Furthermore, the organic acids which are formed as a result of fermentation tend to inhibit or unfavorably to alter crop growth. However, this very acidity serves some good purposes. The basic elements of plant food, such as calcium, potassium, magnesium and others, normally exist in insoluble silicate combinations which the organic acids thus developed tend to dissolve, forming relatively soluble and available humates. Piling peat on dry ground for a year or more before using is a practicable way of utilizing it. Its nitrogen becomes more available, its organic matter decomposes."[2]

In Bulletin 728, U. S. Geological Survey, page 3, we find: "Peat has been used commercially in the United States since 1908. It has been mixed with potash or phosphate, limed, treated with nitrifying bacteria, and applied directly to the soil as a fertilizer, or it has been dried, screened and used as a nitrogenous ingredient of commercial fertilizers. The use of peat in agriculture probably offers greater opportunities in this country than in any other."

Bureau of Mines Bulletin 753, which is the latest Government publication on this subject, takes up this phase of the use of peat in another way. "A large percentage of this country's peat

[1] Bulletin 253, U. S. Mines Bureau.
[2] Vt. Bulletin, page 169.

lands can probably be prepared for crop production without much difficulty and without prior removal of large quantities of peat. In many instances, therefore, it is a matter of judgment whether a particular peat bog should be used for crop producing or should first be stripped of the peat for fuel or other purposes with subsequent development of the land for agricultural use. The problem is not the same in any two regions, hence the correct conclusion can only be reached by careful consideration of all the factors pertaining to a particular case."

In Bulletin 16, Bureau of Mines, Mr. Davis writes, *"Peat soil*—In its natural condition, peat soil is too wet to be worked, and before any plant crop can be made to grow upon it the surface must be cleared and the water level lowered by effective draining and ditching. In general, after this has been accomplished, the surface layers of the peat are coarse in texture and often full of decayed stumps, roots and other woody débris which must be removed. Extensive observation in various parts of the country seems to indicate that after one or two crops have been taken from newly cleared peat land of the common kind, grass is most likely to yield good crops for a number of years until the surface layers are blackened and disintegrated into a fine grained, homogeneous mass. Peat soils generally need mineral fertilizers, especially potash, because they contain little available mineral matter and barnyard manure is often very effective in adding to their productiveness, both because it adds to the peat material which it lacks and because it seemingly promotes the decomposition of the peat by introducing the fungi and bacteria which cause decay and hasten the humus formation. In some parts of the country peat soils are the most productive of any, yielding large crops year after year with no more care than is required to obtain inferior crops from other kinds of soil." l. c. 178.

All writers on peat agree that, properly prepared, peat soil is very productive. Some of our Vermont farmers have discovered all this and need no advice, but there are many peat bogs in the State which could be advantageously utilized. In Bulletin 728, U. S. Geological Survey, page 59, this subject is discussed, but only a few extracts can be given. "Peat soils are well adapted to certain crops. * * * * * The average nitrogen content of air-dried peat is 2 percent, although many peats contain more than this quantity. This nitrogen may be recovered in the form of ammonium sulphate * * * * * or may be made available for plant food without extracting it from the peat.

"Arguments are often advanced against the direct use of peat as a source of nitrogen in soil fertilization, because not all the nitrogen it contains, as shown by chemical analysis, is readily available for plant food, but this criticism seems to be based on a misconception of the nature of peat. It is true that only a part of the nitrogen shown by analysis can be immediately used as food by plants, but it is equally true that a chemical analysis of peat is not a fair test of its value as a fertilizer and that the total quantity of potential soluble nitrogen formed and released by bacterial action from time to time after the peat has been applied to the soil is in the aggregate, often greater than the percentage found in some commercial fertilizers. Fortunately all the nitrogen in peat is not soluble at one time. Bacterialized peat as a direct fertilizer is said to be even a more prolific source of soluble nitrogen than the crude material."

The writers of Bulletin 728, Soper and Osbon, go on to say (page 61), "Whether used as a direct fertilizer or as an ingredient of commercial fertilizers, peat when properly treated is valuable, both chemically and physically. Its content of soluble nitrogen is immediately available for plant food and it is potentially rich in this element which gradually forms soluble compounds and is released; it supplies humus, a valuable requirement for plant life under natural conditions; on account of its black color it absorbs heat; soils to which it is applied are made friable and can be readily worked; and its water-holding properties are proverbial."

One more quotation may be of use to some farmers, though the method recommended is not new to many of our farmers. "Peat fertilizer may be cheaply prepared by farmers owning small bogs by composting the raw peat with manure and, after the bacteria have saturated the mixture, it may be applied to the soil in the same way as manure. Land that is deficient in humus and nitrogen may thus be materially benefited." l. c., page 62.

It must never be forgotten that a most essential condition in the use of peat soil is thorough drainage and unless this can be compassed there is no chance of success. Most peat soil to be entirely satisfactory, usually must be treated for acidity and in other ways and before the owner puts much work or money into preparation for crops he will do well to seek advice from the Experiment Station of the State or some other competent authority. As has been already indicated, when properly treated, a peat bog, or even swamp, becomes most valuable for agricultural purposes. In U. S. Geological Survey Bulletin 728, page 64, is an excellent summary of the proper treatment of such bogs.

MUCK AS RELATED TO PEAT.

In many peat bogs there is in places muck instead of peat. When peat is fully decomposed it may become muck. As muck, peat loses its value as fuel entirely, but the agricultural value is usually much greater, as muck is, as has been stated, the result of the more complete decomposition of the materials found in peat.

As peat thus grades, under certain conditions into muck, a hard and fast line between them cannot be made, but in general most farmers readily distinguish one from the other.

"Drained bogs on which the surface moss has ceased to grow, are said to be 'dead.' The peat therein undergoes a sort of ripening, a more complete decay, darkens in hue, becomes more compressed, and its ash percentage increases; all this because of organic matter oxidation. It now resembles a black loam or mud and constitutes a true muck. Peat naturally tends thus to oxidize as is shown by the rapidity with which it blackens when loosely packed and exposed to the air. * * * * * Muck is of higher value agriculturally than peat, provided it is not too greatly reduced by soil admixture."[1]

OTHER USES OF PEAT.

During the years many attempts have been made to use peat in many ways. Some of these have been in some measure successes, more have failed. As most of these processes need special machinery, and thus a more or less expensive plant, they are not likely to be undertaken by Vermont farmers and, therefore, are not within the intended scope of this paper. Yet it may not be without interest to mention the most important briefly. Perhaps the most promising of the uses to which peat has been put is the making of gas, particularly that variety known as producer gas.

It may be well to define the term producer gas, as its meaning is not always understood. In Bulletin 16, U. S. Bureau of Mines, Davis defines it as follows: "Producer gas, therefore, is obtained by gradually converting solid fuel to the gaseous state by the heat given off by the complete combustion of a part of the fuel. The character and composition of the resulting gas is quite variable, according to the kind of fuel and the type of gas producer used. In the gas producer only sufficient oxygen is supplied completely to satisfy enough of the carbon and hydrogen units of the fuel to convert the rest of it into permanent gases." l. c., page 144. Of course to accomplish the above, special apparatus is necessary and skilled workmen.

Davis goes on to give an extended account of needed machinery and processes. In conclusion, he remarks, "All or nearly all of the uses suggested as possible for producer gas as fuel have been tried on a commercial scale, and are now embodied in plants in operation in the United States and Europe. There seems to be no doubt, also, in view of the facts already stated, that a good quality of producer gas can be cheaply made from peat * * * * * if properly designed and well constructed gas producers are used

[1] Bulletin 165, Vermont Experiment Station. p. 146

at a place where a supply of peat is available." l. c., page 161. This is in 1911. In the latest Bulletin issued by the Bureau of Mines, 1926, we find in regard to producer gas the following: "From peat fuel can be made a good quality of producer gas which will generate power, if a mixture of this gas and air is exploded in the cylinder of a gas engine; it can also be used as fuel in gas furnaces. In addition more ammonia or ammonium salts can be recovered as a by-product per ton of dry fuel than by any other method of treating fuels."

The reason why peat has not been more extensively used in producer gas machines up to the present seems to be about the same as is given to explain why peat is not generally used as ordinary fuel, *viz.:* That cost of production is greater than the value of the product.

In Bulletin 253, U. S. Department of Mines, the manufacture of producer, and other kinds of gas, is quite fully discussed with numerous calculations as to result and the reader who may be interested in this matter is referred to pages 90 to 122 of this Bulletin.

There are so many promising results which have been attained in numerous experiments in using peat for fuel and in gas making that it seems not improbable that under somewhat different conditions and by somewhat different methods, peat may in the future be profitably substituted for some of the fuels with which it cannot as yet satisfactorily compete. While peat has always been most extensively used for fuel, and also very largely in agriculture, there are many other uses to which it has been more or less successfully applied. Also, there are several valuable by-products which can be obtained during the processes adopted for other purposes. Nearly all of these have been undertaken by European manufacturers, very few in the United States, and they are not likely to be of much practical interest to Vermont farmers. Hence no more than brief mention is in place here.

Ground peat, or at least well screened, is used as an absorbent, mixed with the uncrystallized residue of beet or cane sugar refineries as food for stock, but the value of peat for this purpose is greatly doubted by many. Because of the scarcity of raw materials in some European countries, fibrous peat has been used for filling, in coarse paper, cardboard, cloth and artificial wood. Since 1914 Sphagnum moss has been extensively used for surgical dressings as a substitute for absorbent cotton. To some small extent, peat has also been used in dyeing, tanning, etc.

In concluding it may be said in the language of the writers of Bulletin 728, U. S. Geological Survey, "Although the prospects for a commercially successful peat-fuel industry in the United States are now limited to regions remote from the coal fields, it seems that ultimately when our reserve of high-grade coal is consumed, there will be a general demand for other fuel, and unless heat and power are obtained from other sources, a large peat-fuel industry will be created in this country."

Since the foregoing pages were written, a Bulletin of the Canada Mines Branch, 641, has appeared (July, 1926). This Bulletin of 298 pages, LVIII plates, 46 figures, XXVIII tables, is given as a "Final Report of the Peat Committee appointed jointly by the Governments of the Dominion of Canada and the Province of Ontario." The volume contains a résumé in the form of a "Report" of the results which the Committee have obtained in course of a very thorough and expensive investigation of peat which has been carried on during the last eight years in various parts of Europe and Canada. A large and costly experimental plant was built at Alfred, Ontario, where the most promising machines for collecting and manufacturing peat for use as fuel and other purposes, were installed and their value ascertained. Numerous references to the work of this Committee have been made in foregoing pages and, though involving some repetition, yet because we have in this Report the final conclusions of the Committee and because their work has been more extensive and complete than any other reported, further extract from its pages will be given. It may be said that this Report and that of Messrs. Odel and Hood, noticed above, are not only the latest works published on this subject, but they are of greater importance to Vermont readers than any other discussions of the subject. In fact, in these two Reports (see bibliography) we have a summary of what is at present known about peat, its varied uses and the numerous machines which have been contrived by which the raw material may be prepared for use. As the last-named volume is designed to be a summary of what is known about peat, it contains much that may be found in earlier writings, but brought up-to-date. Most of the topics treated in the several partial reports made from time to time by the Committee are more fully considered in the last, as new facts have been discovered in course of the investigation.

As will be seen, the results of later study largely confirm the conclusions given in earlier reports of both the Canadian and United States investigators. For hand cutting of peat a drained bog is required. A suitable space adjacent to the excavation must be prepared for spreading the sods or turfs to be air dried. Then follow detailed directions for carrying on the digging and drying the peat, which are similar to those given on earlier pages of this paper. There are also remarks upon machine-cut peat.

Of some practical value are "Defects of Cut Peat." (Haanel, l. c., page 24.)

"1—Subject to deterioration by bad weather during manufacture * * * * *.
2—Reabsorbs water during every shower and must lie for months in the open before it can be brought into sheds.
3—A great loss of material and labor due to the upper layers of the bog not being suitable to produce cut peat, owing to its fibrous nature and to destruction of its cohesive properties by the action of heat and cold. Eighteen inches or more of the surface material must be removed and thrown aside as useless.
4—Sods which break up while being cut are lost.
5—Owing to the bulkiness of the product its transportation is inconvenient and expensive and it requires more room for storage than denser fuels.
6—On account of its friability there is a great deal of breakage in handling, both during manufacture and in transportation.
7—Owing to its loose texture it burns rapidly, with only small heat production from a given quantity."

The Report continues, "In order to produce an economic fuel from peat its waste content must be further reduced from 25 to 30 percent. The only means by which this can be accomplished are:
"1—Air drying.
2—Evaporating the water by artificial heat.
3—Removing the water by mechanical means.
4—Electrical osmosis."

"No economic method of drying by artificially generated heat is yet available * * * * * *. In every case where peat fuel is produced commercially the product has been air dried and the only processes which have attained commercial success are those which are solely dependent upon air drying."

The following "Steps in the Process" of preparing peat for use are discussed:
1—Clearing and drainage of the bog.
2—Excavation of raw peat from the bog.
3—Pulping or maceration.
4—Transportation to drying field.
5—Spreading on drying area.
6—Cutting into blocks.
7—Turning partly dried blocks.
8—Collecting the finished fuel.
9—Transportation to railway cars or storage.

Each of the above topics are briefly discussed, but only the first will be quoted here.

As to the drainage of the bog, Mr. Haanel writes, "Not all bogs are capable of natural drainage. Those of the built-up type, the so-called high bogs, which show uniformity of structure, or the presence from bottom to top of the remains of such plants as always grow near or slightly above the ground-water level, can be drained as deep as such structure is found. Some deposits, however, lie chiefly below water level and can be drained only at great expense."

As to the drying ground, which is of course a necessary adjunct to any worked peat bog, Mr. Haanel says, "When the bog adjacent to the excavation is utilized as a drying area, the condition of the surface is of material importance. * * * * * * * * * A well humified bog which has no shrubby growth or moss covering the surface will have practically the same moisture content from floor to surface, and macerated peat which has 90 percent water content when spread on such a surface will always assume moisture content of the entire bog. * * * * * The nature of the vegetation growing on the surface of a bog is, therefore, of great importance. * * * * * * * * The Alfred bog, * * * * which is covered with a low shrubby growth, consisting mostly of heath plants, which when pressed down makes an ideal drying surface. * * * * * * * * A bog covered with moss provides a favorable drying surface for peat under Canadian climatic conditions, when the bog is properly drained." l. c., page 157.

LIST OF WORKS ON PEAT PUBLISHED IN THE UNITED STATES AND CANADA, 1910-1926.

For the convenience of any of the readers of the foregoing pages who may care to pursue the subject farther, the following list is given. This list is not intended to be a complete bibliography of works on peat, but only to include such papers as may be readily obtained by those wishing to read them.

It is hardly necessary to say that many books and pamphlets not mentioned here have been published in Europe, as well as on this side of the water. I think, however, that most of those of practical value to Vermont readers will be found in this list.

In Bulletin Number 614, Mines Branch of Canada, Mr. Haanel gives a much fuller list. Not all of the papers listed here can now be had from the Departments which issued them, but they should be found in any considerable library, and most can still be obtained.

1910—Anrep, A. Investigation of the Peat Bogs and Peat Industry of Canada. Bulletin Number 8, Mines Branch, Canada.
1911—Anrep, A. Investigation of the Peat Bogs and Peat Industry of Canada. Bulletin Number 9, Mines Branch, Canada.
1911—Davis, C. A. The Use of Peat for Fuel and Other Purposes. Bulletin Number 16, United States Mines Bureau.
1912—Anrep, A. Investigation of the Peat Bogs and Peat Industry of Canada. Bulletin Number 9, Mines Branch, Canada.

1912—Hills, J. L. and Hollister, F. M. The Peat and Muck Deposits of Vermont. Bulletin Number 165, Vermont Experiment Station.
1913—Adams, J. G. Canada Peat Industry. Journal of the Canadian Peat Society.
1914—Haanel, B. F. Peat, Lignite and Coal. Bulletin 299, Mines Branch, Canada. (Mainly on Producer Gas.)
1915—Huels, F. W. The Peat Resources of Wisconsin. Bulletin Number 43, Wisconsin Geological and Natural History Survey.
1915—Shear, C. L. Utilization of Peat Land for Cranberry Culture. United States Department of Agriculture, Report, 1915.
1916—Coville, F. V. Blueberries on Peat Soil. Bullein 334, United States Department of Agriculture.
1917—Blizard, John. Value of Peat Fuel for Generation of Steam. Bulletin Number 17, Department of Mines, Canada.
1918—Anrep, A. Summary Report. (In Geological Report.)
1919—Anrep, A. Investigation of Certain Peat Bogs in Ontario. Geological Survey Report, Part E.
1920—Alway, F. Agricultural Reclamation of Peat Soils. Minnesota Experiment Station Bulletin Number 188.
1922—First, Second, Third, Fourth Peat Reports, 1919-1922, Joint Committee, Ontario. Report, Department of Mines, Canada.
1922—Osbon, C. C. and Soper, E. K. The Occurrence and Uses of Peat in the United States. Bulletin 728, United States Geological Survey.
1926—Odell, W. W. and Hood, O. P. Possibilities for the Commercial Utilization of Peat. Bulletin 253, United States Department of Mines.
1926—Haanel, B. F. Final Report of the Peat Committee, Canada, Department of Mines Bulletin, Mines Branch 641.

A CONTRIBUTION TO THE STRUCTURAL RELATIONS OF THE GRANITIC INTRUSIONS OF BETHEL, BARRE, AND WOODBURY, VERMONT.

ROBERT BALK.

CONTENTS.

INTRODUCTION.[1]

During the past seven years new methods of geological research work have been introduced by Professor Hans Cloos of the University of Bonn, Germany. These methods deal especially with igneous rocks and have afforded many interesting results regarding the history and manner of intrusion of deep-seated masses. A list of publications upon this subject will be found in the Bibliography at the end of this paper. The writer has been studying for many years with Professor Cloos and has given a brief report on these methods in the first reference in the Bibliography. A short résumé of the new methods is here given in order to a better understanding of what follows.

Igneous masses while intruding into the earth's crust, are usually subjected to tectonic stresses because of the general coincidence in time of orogenic processes and magmatic activities. A fluid and highly mobile magma, therefore, moving between solid country rocks has the tendency to give way to such exterior stresses and to yield in the direction of least pressure. The result is frequently concordant tracts of igneous rocks between sedimentary wall rocks. The minerals which ultimately crystallize within the magma may be also affected by the *directed* (*not hydrostatic*) *pressure* under which the whole system stands while moving. Thus the single mineral grains, inasmuch as they grow

[1] The writer wishes to express his sincerest thanks to Professor G. H. Perkins, Mr. Rudolf Erbsloh and Miss Irma E. Sapper who rendered valuable assistance in the technical preparation of this paper.

into elongated prisms or squares, will tend to orientate themselves with the longest faces approximately at right angles to the pressure. And as most of the minerals (feldspar, mica, quartz) grow that way, the igneous rock takes on a primary parallelism which may be either linear ("linear stretching": the single prisms coincide with the orientation of their longest *axes only,* comparable to a pencil of parallel rays) or platy ("gneissic foliation" in part: minerals arranged in parallel layers, the layers nearly at right angles to the pressure). Or a linear parallelism may be superimposed on foliation planes. The reason for the different development cannot be explained in this brief summary. Thus the direction of the minerals and certain finer details in their arrangement which date back to their original settling during the closing stage of the magmatic activity, enable us to calculate both tectonic pressures and partial yielding movements of the crystallizing magma. Independent magmatic movements can be distinguished also. Attention should be called especially to the linear parallelism or stretching (German "Streckung"). It occurs in many igneous rocks which at first sight seem to be wholly massive and compact, without any parallelism, and whose solidification consequently simulates a ruling hydrostatic pressure. In order to explain such hydrostatic relations, far-reaching theories have been advanced which embrace the entire conceptions about the rôle of igneous masses in the earth's crust.

In the present paper the primary movements of three granitic intrusions in Vermont will be demonstrated on the basis of detailed measurements and observations in the field. Certain dependable relations between primary flow-movements and ruptural reactions, such as joints, slickensides, overthrusts, etc., enable us to use and to incorporate the latter group of structural features in the reconstruction of the conditions under which the intrusion took place.

For data regarding strike, dip, pitch, etc., an abbreviated system had to be chosen.

On Maps.—Figures refer almost always to the dip (or pitch) only, not to the strike. The latter may be found by a compass. The figures for dip-angles are placed on the side of the dip-arrow; vertical dip is indicated by dip-symbols in both directions. Symbols for pitching linear elements are represented by an arrow, the figure next to the head means the pitch-angle. The horizontal projection (strike) of linear elements (striæ, stretching, etc.) is indicated by the orientation of the arrow, and the exact value may be also found out by the reader. Where linear stretching is superimposed to platy foliation, as in the country rock of the granites, both are given with their respective symbols, the dip arrow and the stretching arrow starting from the same point in true directions.

In the Text.—Strike and dip measurements are given as follows: The horizon is divided into 360°, the numbers beginning with 0° in the N., thence proceeding to the N. E., E., S. E., S., etc. Strike 0° means, therefore, due N. S., strike 45° means due N. E.-S. W., strike 90° due E. W., strike 135° due S. E.-N. W., strike 180° is the same as 0°, due N. S. The figures from 180° to 360° (western semi-circle) are not used for the sake of convenience, since any direction of strike is identified by figures between 0° and 180°. 225° would be the same direction as 45°, 270° the same as 90°, etc. The dip angle is given after the strike, separated by a comma. Thus strike 45°, 70° N. W. means strike due N. E.-S. W., dip 70° to the N. W.; strike 90°, 57° S. means strike due E. W., dip 57° to the S.; strike 160°, 15° N. E. means strike about S. S. E.-N. N. W., dip 15° to the N. E. Data for linear elements give the horizontal projection (strike), and the pitch angle after the comma, *e. g.,* stretching 0°, 10° N. means linear parallelism runs due N. S., the pitch is 10° to the N. Striæ 75°, 0° means horizontal projection of the streaks runs about E. N. E.-W. S. W., lies horizontal.

The average declination is 13° W. This has been respected in plotting the strike symbols on the maps. But in the text, the true measured figures for strike are given, including the declination.

The writer spent four weeks in the Barre region, eleven days in Bethel, three weeks and a half in Woodbury. The outline maps, which were obtained by counting paces and a network of compass measurements do not claim absolute precision (about 94 percent).

Location of the Granite.—The granites of Bethel, Barre and Woodbury are located in a north and south line—Bethel to the south, Woodbury to the north—which runs approximately parallel with Lake Champlain in a distance of forty miles. The average distance between the granite areas themselves is about twenty-two miles. As to the general features of the involved granite areas, the reader is referred to No. 11 of the Bibliography.

THE COUNTRY ROCK.

Rock Types.—The wall rocks of the granites are dark to black phyllites, often exceedingly thin-bedded and easily cleavable along the bedding planes. Garnets and phenocrysts of biotite and ottrelite are common (contact phenomena, see 11 and 21). Sometimes one finds amphibolites and garnetiferous amphibolites (N. E. of Cobble Hill, Barre), quartzites, and quartz-sericite schists (Buffalo Mountain—Woodbury).

East of East Barre there appears a characteristic phyllite having knobs of quartz (figure 1). There are also sandy limestones which weather out as boulders of rusty brown color. These generally form narrow tracts within the phyllites. In a

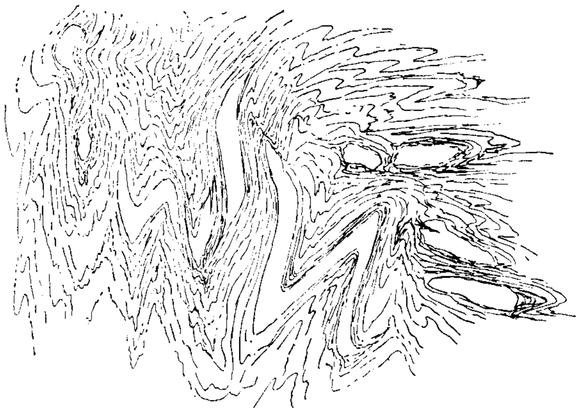


FIGURE 1.—Phyllite strongly folded, East Barre.

few limited areas—N. N. E. of Washington, N. N. W. of Cobble Hill, Barre—injections may be seen of a gneissoid granitic rock which in the second locality are older than the normal granite.

Structure.—The general strike is N. N. E.-S. S. W. At Bethel the phyllite strikes N. S.; at Barre, N. E.-S. W. At Woodbury the normal strike varies, due to local zones of disturbance. The rocks are mostly steeply tilted. Eastward dip prevails near Bethel, westward dip at Barre (60°-90°). The sediments are everywhere *highly folded*. The uniform parallelism of the Barre schists reveals itself repeatedly as pseudoparallelism due to iso-

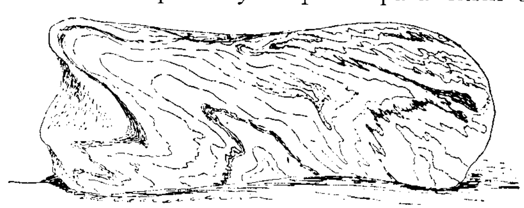


FIGURE 2.—Marble and phyllite, isoclinally folded. Boulder, west of Washington, Vt.

clinal folding. Favorable exposures show the calcareous rocks intricately folded with the phyllites (figure 2). Closely connected with the folds is a conspicuous *linear stretching*. Regarding the origin and importance of this feature, see Bibliography 1, 18. On the bedding planes one sees micaceous minerals, horn-

blende or garnets, arranged in *linear* tracts. The schist then shows a significant striated surface.

It is of special interest that these lines of stretching coincide everywhere in strike and dip with the axes of the folds of the phyllite. (Compare the maps.) A hundred and forty measurements show that *both linear elements pitch to the north* (N. N. W.-N.-N. N. E.), at 5°-40°. At right angles to this linear stretching are *cross joints*. For instance, if the stretching strikes N.-S., pitching 20° N., the associated cross joints will strike E.-W. and dip 70° S., making thus a right angle with the stretching. (One may compare this mutual relationship with a mooring mast on the ground. The mast represents the linear stretching, the surface the cross joints. The mast, however, in our case may be inclined anyhow, while the planes of the cross joints depends as to their orientation on the former).

The *cleavage* of the Vermont phyllites has been investigated and described long ago (Bibliography 8, 9, 11, 20). It is younger than the folding. In zones where the strike and the dip of the schist varies, the cleavage is to be found with a constant orienta-

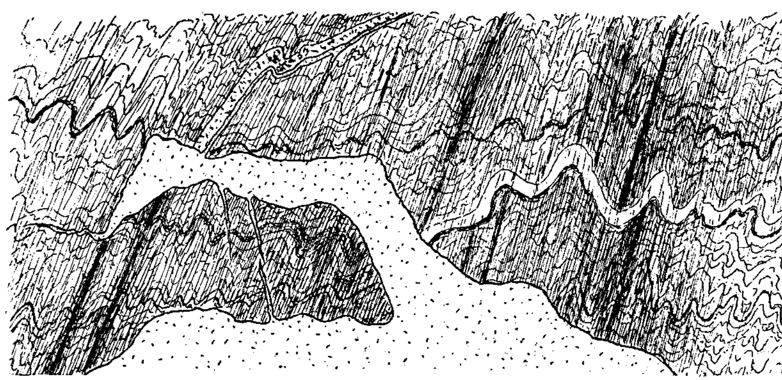


FIGURE 3.—Western contact of Robeson Mountain granite, Woodbury. Older folds of the granite are cut off by granite, which also follows cleavage planes.

tion superimposed upon the folds. The cleavage is also of pregranitic age (figure 3).

The stratification planes, the stretching and the cleavage are arranged in a fixed and constant relationship. *The linear stretching lies everywhere in the intersection of the stratification planes and the cleavage.* As the former two elements are older than the cleavage, and as the axial pitch is always toward the north, the cleavage was formed as a dependent plane, regarding its orientation, and both structural elements are apparently due to one and the same diastrophic movement, marking but subsequent reactions.

Sometimes the cleavage reveals itself as a result of very minute wrinkling and folding of the rock (figure 4). One hundred and thirteen measurements from Woodbury and Bethel show a slight maximum of the strike of the cleavage in N. W.-S. E. (110°-160°). In the present region, therefore, the relations do not seem to be so regular as in the area of Rutland (see Bibliography 8, 10, 20). In the limestones all the structures mentioned are more elusive. Cleavage never was found, the stretching is very indistinct, but the vigorous isoclinal folding may weather out very well (figure 2).

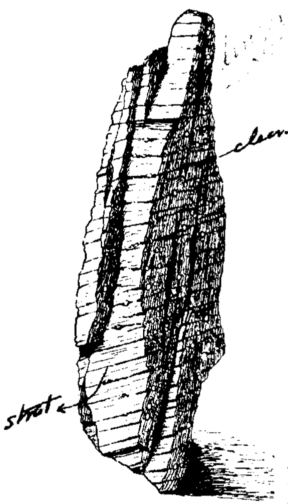


FIGURE 4.—Relations between bedding, cleavage and linear stretching. Phyllite, Bethel. Hand specimen one-half natural size. Vertical bright faces: stratification planes, cleavage dips slightly to the left. Linear stretching lies in the intersection of the bedding and cleavage. Note garnets in the centers of the minute wrinkles

Second in importance to the cross joints are longitudinal joints, parallel to the strike of the rock, and flat-lying fissures, which occasionally tend to embrace the stretching (see Barre, page 56) or they may join the strike of the rock, but vary in dip (Robeson Mountain).

It should be borne in mind that in strongly tilted rocks, steep joints, especially longitudinal crevices, will weather out much more conspicuously than horizontal ones and that the latter may be often overlooked and underestimated. This is of importance if we consider the rôle which these joints are to play during the following granite intrusion.

The phyllites thus previous to the arrival of the igneous rocks, are seen as a complex of highly folded schistose rocks with a uniform axial pitch toward the north and resting on a gneissic basement. (Bibliography 9.) Within the series there are no far-reaching rock boundaries or unconformities, but the rock in detail is characterized by long, straight bedding planes and systems of steep and flat joints. The granites of Bethel, Barre and Woodbury which have been intruded into the phyllitic series, exhibit close relations to the older structure of the wall rock. The different character, for instance, on the map of the Woodbury granite, is to be explained, as we shall see, by the different structures of the phyllites.

BETHEL.

CONTENTS.

The Rocks.—The medium grained rock of this intrusive is extremely light and acid (77.5 percent SiO_2), rich in plagioclase and light mica (comp. 11). There appear equigranular, somewhat fine grained types as flow bands. Well known is the orbicular granite, nodules of mica of the size of a hazel nut or a watch, often with feldspathic core, lying without any transitional formation in normal granite, but at a certain place they are concentrated in a dark syenitic band. This rock consists largely of an accumulation of nodules of black mica and feldspar and some quartz. The "schliere" grades northward into isolated nodules of mica. Quartz veins and pegmatites are frequent.

Shape of the Intrusive Body.—The Bethel granite has a narrow lenticular ground plan (see map, Plate I) which is about 4,800 feet, north to south, and 600 feet, east-west. It constitutes the crest of Christian Hill, on the slopes of which is the surrounding phyllite. Exposures of the contact show that the granite is intruded as a steep conformable body into the N.-S. striking wall rock. However, in the northeast, where the contact is well exposed, the immediate boundary is less regular. It follows the bedding planes of the phyllite, but makes sudden salients along cleavage planes and cross joints into the schist; the contact warps in places even into a flat plane, the granite overlying the wall rock. Fine grained, conformable dikes are occasionally seen accompanying the main body.

The Downward Continuation.—If it is supposed that the granite follows a bedding plane downward, the shape of the intrusive would suggest a steep plate. But the owner of the Maplewood farm, next the quarry district, informed the writer that some years ago a test boring struck phyllite at a depth of four hundred to six hundred feet and that no granite was found below this. This being correct, one must assume a thinning out of the granite. Observations at Barre seem to corroborate this.

PLATE I.

The Granite of Christian Hill, Bethel, Vt. The dotted line shows the contact. Exposures are shown by the usual strike and dip signs. Broken lines within the intrusion refer to the parallelism. In this map figures for the strike of the phyllite are given. The thick, black line is a lamprophyre.

[CORRECTION.—Below the numerals 28, an oblique bar should appear, and the oblique bar at the left of the numerals 80 should show a right-angle spur to the right. Corrections received too late to remake the plate. EDITOR.]

THE INTERNAL STRUCTURE.

Foliation.—A platy parallelism (foliation), very conspicuous due to the tendency of the mica to form little aggregates, strikes N.-S. (5°-20°), and dips, parallel to the contact plane, steeply toward the east. Flow bands and the mica nodules mentioned follow this plane.

Stretching.—Besides this, and superimposed upon the foliation planes, there is a linear stretching conspicuous particularly on steep artificial north to south planes ("grain" of the workmen). The longest axes of most of the little muscovite aggregates and the larger biotite nodules pitch to the north at 5°-35°. In the above mentioned flow band the biotite flakes are stretched and even slightly wrinkled in the same direction.

Joints.—A very well developed system of joints runs at right angles to the linear stretching (strike 90°-105°; 90°-65° S.): *Cross Joints.*—They are especially numerous in an old quarry on top of the hill.[1]

Longitudinal joints are much more rare, they dip 80°-90° W. or E., additional joints are even more rare.

The *"bedding"* harmonizes everywhere with the present casual surface. The whole rock is divided into thin plates and sheets, which follow the strike and dip of the surface (dip angles 0°-40°). The vertical spacing of the bedding joints increases with the depth of the exposures and does not show any phenomena of primary development. It is doubtful whether there are any structures indicating primary bedding, *i. e.*, either flat lying dikes, veins, flat primary joints, flow bands, or other features.

Cleavability ("Rift").—The cleavability of the granite corresponds with European relations; the best cleavage plane runs approximately horizontal.[2] The strike of the longitudinal plane ("grain") follows the parallel structure, but it stands vertical, dipping only rarely east like the foliation. The cross planes ("hardway") feel rough and are the most difficult to obtain, as the name indicates.

Dikes.—Aplites, pegmatites, quartz veins, and a lamprophyre (two yards wide, exposed between the two largest quarries) *follow in strike and dip the east-west cross joints.*

In the abandoned quarry on top of Christian Hill almost every second joint is coated with an acid dike. In the southern part

[1] A sketch of this quarry may be found in fig. 4, p. 684, of bibliogr. 1.

[2] The quarrymen in the quarries visited use the following nomenclature for artificial parting. The plane that splits most easily is habitually called the "rift," no matter whether it lies horizontally, obliquely or vertically. The roughest plane and the most difficult to get is the "hardway." Wherever the granite splits most readily with the horizontal bedding this is called the "rift." In such a case, the longitudinal steep (primary) planes of the granite generally exhibit intermediate ease of splitting, and this is called "grain," but where the longitudinal plane splits most easily, as at Barre, this is the "rift." Occasionally, different workers in the same quarry use different terms.

of the quarry district where cross joints are less abundant, acid dikes are also rare, but follow these joints just the same, thus proving the early age of the joints.

Partial Movements in the Granite.—Several exposures enable us to study some early partial displacements and movements of the granite. One finds slickensides on the cross joints which pitch toward the east-southeast, 45°-60°. Measurable displacements of the walls show that in general the northern block has been pushed and at the same time lifted westward. These movements took place at a very early stage, as seen from the following observation.

In the large quarry of the Woodbury Granite Co. there is a long acid dike on a cross joint, composed of a quartz vein and a coarse grained aplitic pegmatite. Not only do the quartz grains appear as little stems and prisms parallel with the striæ of the wall, but feldspar crystals of the pegmatite up to half an inch in length, and the surrounding quartz crystals with a few little mica flakes, arrange themselves parallel with the striæ, as to their longest axes. Dike and granite wall are still strongly welded together so that the striæ and parallelism of the crystals belong to the same movement. Such a relationship between the orientation of the striæ and the largest stereometric axes of the crystals was observed at three additional points at Bethel, also at Barre and Woodbury.

Effective movements took place along the edge of the syenitic band above mentioned in the southern end of the granite body. This peculiar rock stands isolated as a high, steep wall in the midst of the quarry, the surrounding granite being removed from its eastern flank. The steep rock face is extensively waved and wrinkled, due to long and broad gliding tracks which pitch north, 20°-25°. The slickensides actually represent most vigorous displacements in a solid stage of the rock, but they coincide in strike and pitch exactly with the orientation of the stretching!

Another very early stage of movement is preserved in the northeast corner of the largest quarry. In a vertical quarry face, running east to west, a set of dark flow bands is seen, starting from the eastern contact and extending about a hundred and twenty feet into the granite body. These schlieren dip conformably with the vertical contact in the east. Farther away, however, the dip angle is constantly more to the west; finally they rise on the exposed plane, dipping west about 25°. However, as we approach the contact these flat-lying bands dip more steeply, too. There are, of course, several interpretations possible. But, if we remember that at the time of the acid dikes there was a tendency to raise the middle parts of the granite and to push them westward, one would get a uniform process, assuming that the upward flow of the magma has been greater in the core of the body than near the contact. In such a case, early formed biotite bands would have moved farther up in the middle, while they might have remained in a steep orientation near the contact.

Mechanics of the Intrusion.—These observations lead to the following conception of the mechanics of the intrusion. The granite of Bethel was intruded into the north-south striking, isoclinally folded, steeply tilted, stretched and readily cleavable phyllites. The plane of entrance is apparently a bedding plane of the schist, which is followed, in general, by the magma. Additional planes of weakness, such as cross joints and cleavage planes, have also been utilized by the granite. The acid magma is charged with basic flow bands and schlieren rich in mica, which were scattered through the intrusive. The stoping power of the magma seems to be directed obliquely upward to the west. Central parts of the intrusive have been pushed upward perhaps more actively than the outer rim of the magma.

The decision of this question depends upon the northern exposures of the granite. If the above assumption, as supported by displacements along cross joints, is correct, the same displacement should raise, in the north, the *southern* block to the west. Unfortunately, the northern end of the granite is very poorly exposed and no decision could be reached. The assumption is, however, supported by corresponding and well-exposed relationships in the granite in the Barclay-Jones quarry in Barre (see Barre, p. 70).

The east-west pressure which has folded, metamorphosed and stretched the phyllites was still active during the time of the granitic intrusion, so that the magma yields to a north-south direction. Even the axial pitch of the older deformation lines of the phyllite was fully respected by the intrusive, and aggregates of mica were elongated and stretched into small lenticular nodules and ellipsoids whose longest axes pitch north.

In the consolidating rock, cross joints were developed as genuine tension joints, running east-west and depending closely on the orientation of the older flow lines (stretching), being a brittle reaction to the same lateral pressure. In accordance with the similar deformation of the country rock, these joints in turn coincide with the older cross joints of the phyllites in strike and dip. Acid dikes, which appear next, depend almost entirely upon the gaping tension joints.

During a later stage of the consolidation, movements started along the cross joints because of which the central parts of the igneous body, at least in the southern part, were pushed and raised upward to the west.

Nothing has been found indicating a farther extensive deformation of the granite by tectonic forces. Neither the crystalline structure nor the rock boundary have been notably altered. The latter, on the contrary, shows resemblance to the contact lines of unconformable (discordant) granites, favoring generally the longest, straightest, and mechanically most favorable planes, *i. e.*, the bedding planes, but also repeatedly additional structural planes of the wall rock (steep and flat joints, cleavage planes, etc.). Marginal melting or "soaking" or "lit-par-lit"—injections were sought in vain. The contact planes are straight and distinct, the rocks on either side unmixed.

At the close of the magmatic activity a basic dike is inserted into the intrusive; like the older acid dikes, this follows the cross joints.

The present weathering produces bedding planes parallel with the present surface which are subject to temporary changes.

BARRE.

CONTENTS.

Location.—About two and a half miles southeast of the city of Barre the country rises in two hills about a mile and a half distant from each other—Cobble Hill (N. E.) and Millstone Hill (S. W.). A broad valley between them is filled with a vast accumulation of glacial gravels dissected into three terraces and cut by Jail Brook which flows westward toward Barre. Both heights are made of granite and especially Millstone Hill and the rock of some additional rises, which lie to the southeast yield the raw material of the well-known granite industry of Barre.

The Rocks.—The average rock is a light gray, fine to medium grained, pure biotite granite. Irregularities, or impure pegmatitic stages are found sporadically. Porphyritic or fine-grained varieties are also rare. (Limited occurrences in the quarries of Boutwell-Milne-Varnum, E. L. Smith & Co., Barclay Bros., Jones Bros. Co., a few small dikes, etc.).[1]

At a few localities the granite is more acidic and coarser. (Old quarry N. N. W. of Millstone Hill, N. N. E. of Boutwell Quarries, etc.) A basic, darker granite, "Dark Barre," quarried in some of the southern openings, is of technical and scientific interest (see below). It is everywhere older than the normal granite.

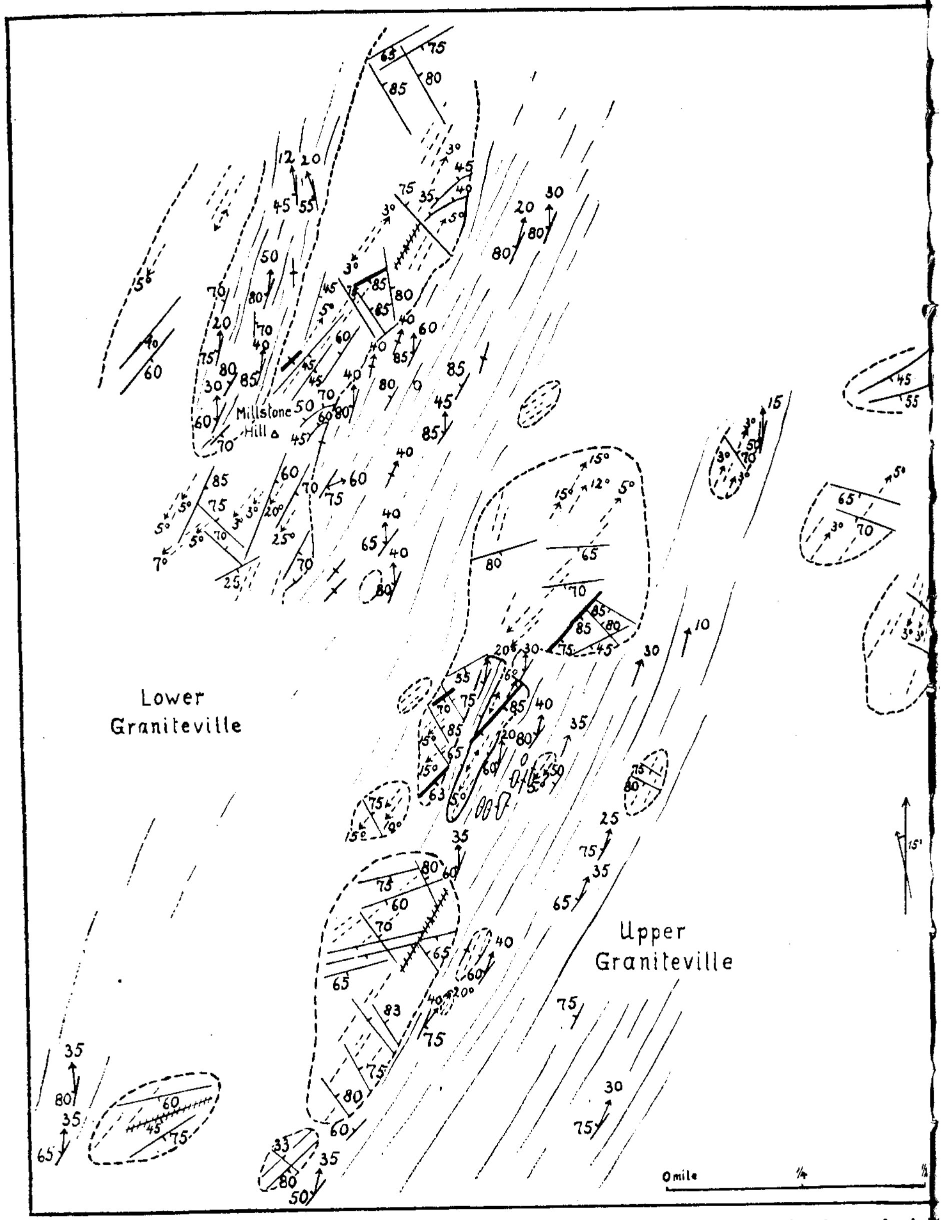
A local lithologic observation may be mentioned. In the Barclay, also Jones Bros. quarries, the margins of large inclusions of phyllite are seen to be fringed by pegmatitic formations. Feldspar crystals the size of a hazel nut or larger, are "hanging" on the schist growing in part as uniform crystals through the surrounding granite, and push aside the ground mass so that there appear narrow foliated zones in the granite between the crystals. Almost imperceptibly the pegmatitic zones grade into normal granite; their width varies from nine inches to eighteen inches. It seems as if the presence of the inclusions had stimulated and caused the formation and growth of the crystals. A corresponding observation was made at the contact of the light and dark granite in the Boutwell quarry; also at a quarry in Woodbury.

Size and Dimensions of the Intrusions.—The granite appears in several intrusive bodies separated from each other by undisturbed belts of phyllite (Plate II). As a whole there are ten or twelve ellipsoidal, or oval, bodies elongated in a northeastern direction parallel to the strike of the country rock. Most of them dip steeply northwestward and reach maximum dimensions of about seventeen hundred yards in length by fourteen hundred in width, decreasing in size to small lenses and dikes. Outside the bodies plotted on the map, granite may occur in dozens of small lenses, plates or dike-like bodies in the vicinity. Far to the east, within the so-called Orange High Mountains, there seems to be a large granitic mass which has not been investigated.

Small Conformable and Unconformable Dikes and Lenses.—The great majority of the smallest granite masses traverse the

[1] For location of quarries, see Bibliography 11, map p. 109.

PLATE II.



A simplified map of the Barre Granite Area. The contact of the intrusives is shown by bro[ken] lines, if mapped, and by unbroken lines if the contact is exposed. Numerals indicate dip. In the granite, broken lines refer to parallelism. Horizontal pitch of stretching shown by arrows in both directions, without numerals. Straight lines crossed by ... lines indicate faults.

phyllites without special relations to the structures and in any direction. Frequently, however, the boundaries coincide with older structural planes of the schist.

More than forty-two observed and measured contact planes are conformable or unconformable to the sedimentaries, and the small intrusives lie flat as well as tilted and vertical. We shall return to this point later on.

Relations Between Large and Small Bodies.—Of what kind is the relationship between the smallest offshoots and the larger bodies? Are the latter, as might be expected from the narrow, lenticular ground plan (see Plate II), merely conformable bodies, *i. e.,* to some extent different from the foregoing group, or do they, too, sometimes exhibit unconformable contacts? It turned out that *there are significant similarities between both groups and that either one shows corresponding relations to the country rock. It is the older structural planes of favorable mechanical properties in the sediments which are preferred as contact planes by the larger bodies also.* The bedding planes, as characterized above are by far the most important ones. Next, the shorter joint planes, longitudinal and cross joints, as well as flat fissures. *As a consequence, the bulk of the larger intrusions form oblong steep bodies, elongated in a N. E.-S. W. direction parallel to the regional strike. However, the depth of every single body and the internal structure show individual features which are different from place to place and are to be determined for each body.*

R.Balk

LARGE INTRUSIVES

Contact Relations.—Some especially interesting observations may be described first. An outline of the general contact relations is given later.

Examples—*East of the large Boutwell quarry* there is a small abandoned opening where a conformable granite body, about sixty feet thick, is exposed. Both the granite and the country rock dip steeply to the northwest. Parallel to the schist an apophysis branches off from the northwestern contact dipping also northwest at 85°. A few yards from the starting point, however, the steep dike is seen warped into gentle position and lies unconformably upon the schist. (The under surface strikes first 50°, dips 30° northwest, then 105°, 25° N., whereas the phyllite retains its steep dip, 35°-40°, 90°-82° N. W.) The reason for this abrupt change from the original steep position of the dike is a flat joint of the phyllite, and several "barren" joints of the same system appear in the wall rock farther away from the intrusive. At the same locality a thin dike starts from the main body, following for a considerable distance a cross joint of the schist (strike 140°, 45° S. W.).

Perhaps the most interesting relations are represented in the *Barclay-Jones quarry southeast of Millstone Hill.* The exposed intrusive is about fifteen hundred feet long and a hundred and ten feet wide. It strikes north-northeast and dips 50°-75° northwest conformably to the wall rock. Along the longitudinal walls of the working the phyllites are continually exposed. The strike and dip of the contact and of the planes of stratification vary but little (northwestern contact, strike 40°, dips 70° N. W.; 40°, 55° N. W.; 35°-40°, 60° N. W.; 35°, 65° N. W.). Southeastern contact strike 40°, 60° N. W.; 45°, 75° N. W.; 40°, 73° N. W.

In the northeastern corner, the granite seems to project somewhat into the wall rock, but here, unfortunately, the exposures are rather incomplete and do not afford any clear conception of the actual conditions. As a whole, however, the granite lies quite conformably between the phyllite beds. Despite this general conformity, *the intrusive* does not continue downward as a steep, broad plate, but *is found in three places resting on the phyllite and having a flat, unconformable under-surface which overrides the steeply tilted sediments.*

The deciding exposure is in the northern corner of the quarry. Normal phyllite emerges here to a considerable extent under the granite (strike 45°, 70° N. W.; 48°, 85° N. W.; 45°, 75° N. W.). It forms repeatedly the floor of the steep granitic quarry walls. The contact plane dips southward at 25°, 35°, 0° (strike 85°-95°). About two hundred and thirty feet south the phyllite emerges again from the bottom of the quarry in a long front. The contact plane here is rather uneven and lies horizontally; the schist strikes 45°, 75° N. W.

The third place lies in the most southern exposure. The granite here overlaps slightly-folded phyllite along a saucer-shaped undersurface. The axes of the folds strike N. N. W. (180°), and pitch 35° north. The undersurface dips about 30°-32° north, thus truncating one layer after the other at a very acute angle.

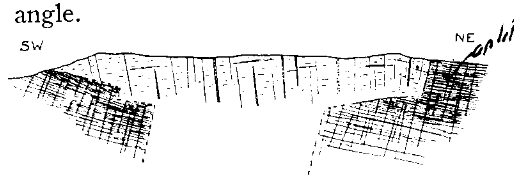


FIGURE 5.—Granite body in the Barclay-Jones quarries, Barre. Longitudinal section showing the northeastern corner and the dependent arrangement of the cross joints and aplites (double lines). One looks upon the bedding planes of the phyllite where stretching pitches 20°-35° N. E., while the pre-granitic cross joints of the country rock dip steeply S. W., serving as local contact planes. The unbroken parts of the contact line are seen. The broken lines are conjectural.

The northnortheastern front of the intrusive cuts the phyllite unconformably, too. To some extent the contact follows a cross joint (strike 135°, 75° S. W.). The original height of the body, of course, is unknown. In one place, however, the granite is seen discontinuing its steep contact plane, bending flatly backward and, therefore, underlying the phyllite of the cover unconformably (figures 5 and 6).

As the country rock outcrops below the narrow edges of the intrusive and as the magma very likely rose along a steep bedding-plane, *the downward continuation may be sought below the present core of the body, but not at the edges.* This would suggest that *the intrusive as a whole has the shape of something like a hatchet, or a hammer,* whose broad handle is tilted toward the west-northwest at an angle of 60°-70°, the iron pointing with the longest axis toward the N. N. E.

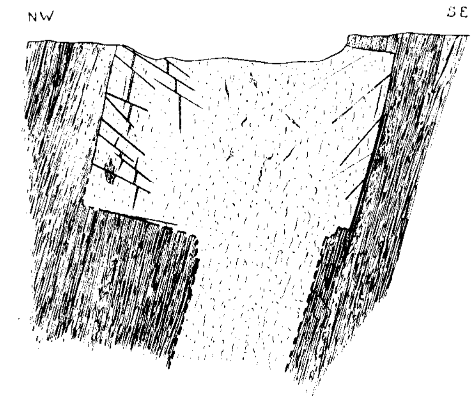


FIGURE 6.—Cross section at right angles to figure 5, showing displacements along glide joints, overthrusts to the N. W. The latter are more numerous along the northwest side and are coated with acid dikes. Note the acute angle at which the granite in the northwest overtakes the phyllite beds. Width and depth of the conduit conjectural, except for the under surface in the N. W.

To the west, northwest and north the described granite is accompanied by *another longer and broader intrusive.* To the west they run parallel to each other with conformable contacts, separated by a belt of schist, 150-300 feet wide which, as seen in exposures, dips under the western body.

As soon as the granite in the Barclay and also the Jones quarry reaches its northern end, the western neighbor advances toward the northeast. The schist of the southeastern contact is seen (in the Jones light quarry) dipping gently, 30°-35°, to the northeast and in the southern corner of the quarry the granite works its way upward across the phyllite. (Contact strikes 10°-15°, 50° W., the phyllite strikes 55°, 80° N. W.) Thence northward the granite increases considerably in breadth and seems to end as a round body more than nine hundred feet in diameter. The material of both granite bodies seems to have communicated through a narrow channel connecting the end of the Barclay quarry with Jones light quarry.

The contact relations of the large granite body which constitutes *Millstone Hill* are frequently exposed along the southeastern side. In the Smith quarries the boundary line strikes conformably for a short distance. 75°, 83° N. W. East of the hill top (Consolidated quarry) it appears again parallel to the schist running 30°-35°, 80° E. On the northeastern slope of Millstone Hill the contact is to be seen in an abandoned quarry; strike about 70°, vertical; phyllite strikes 40°, 80°-90° S. E. Finally, in the Wells and Lamson quarry, on the road from Barre to East Barre, the granite seems to underlie the phyllite to some extent, both the country rock and the boundary line are almost vertical, the latter, however, seems to dip somewhat under the sedimentary series. The northwestern border of the intrusive is concealed.

The great complex of the granite of *Cobble Hill,* unfortunately, is but once exposed in connection with the country rock. At the very top of the hill the boundary runs conformable, 30°, 70° N. W., dipping under the granite.

The contact phenomena of the *Boutwell granite* were not exposed at the time of the investigation. There is, however, some likelihood that the contact may be struck by further work (see below).

A few *additional observations* may be given, *showing special relations to inclusions.* At the Smith quarry, Millstone Hill, are large inclusions near the eastern contact bounded by a joint-plane of the phyllite (strike 80°, 60° S.). At the Boutwell quarry, western part, center, large inclusion, nineteen by twenty-two feet, phyllite strike 95°, 60° N., stretching 130°, 30°-40° N. W. The undersurface of the inclusion (strike 55°, 20° N. W.; striæ 145°, 20° N. W.) is a plane which embraces the linear stretching. East-northeast of the Barclay and Jones quarries, small granite body with long contact parallel with a joint system of the slate (strike 40°, 80° S. E.) McIver and Mattheson quarry, north of Barclay. Large inclusion in the northern quarry-face is terminated by bedding planes, unconformable contact planes and, to some extent, by joints of the phyllite.

Examples of Unconformable Contact Lines.—In a quarry south of East Barre granite overlies the phyllite for about sixty feet along a flat unconformable boundary. (Phyllite strikes 25°, 50° W.) In a quarry east of Barclay Brothers, the granite underlies the schist for something like forty-five feet along a flat surface, dipping 10° N. N. W., when it warps downward conformably (40°, 75° N. W.). An almost completely exhausted granite body southeast of the Boutwell quarry has been intruded at several places into the phyllite unconformably. (The latter strikes 45°, 85° N. W. Contact strikes 100°, 60° N.; 105°, 60° N.; 150°, 68° N. E. Stretching of the granite in an apophysis 50°, 20° N. E., across the contact.)

We have repeatedly met with *contact lines which cut the wall rock at an acute angle.* In this respect they seem to reconcile the conformable with unconformable planes. In the Barclay, and also in the Jones, quarry were found loose blocks in which

the granite almost imperceptibly slightly overtakes the single layers of the phyllite. One can hardly resist the conclusion that next to the magma, gliding movements have taken place along the bedding planes due to which the single layers were thinned out so much that they at last lost their consistence and were then overtaken by the magma. That gliding movements may actually have occurred during the intrusion is perhaps shown by an observation in the Jones light quarry (figure 7). A small spindle-

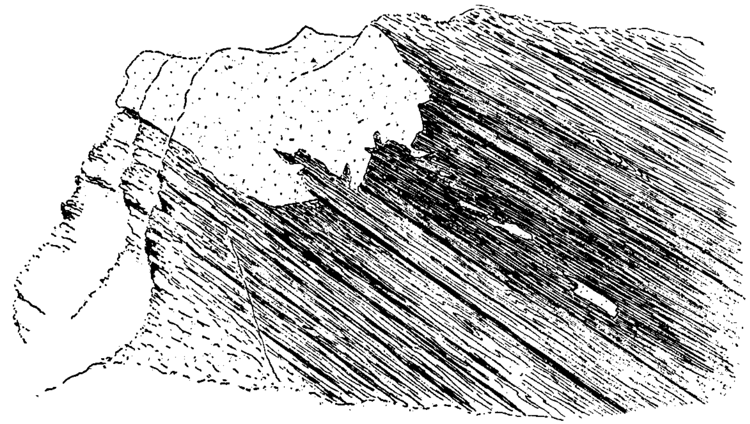


FIGURE 7.—Small spindle-shaped granite with obliterated downward continuation. Quarry north of Barclay-Jones openings. Exposed plane 15x7 feet.

shaped granite body is to be seen there underlain by phyllite. The *downward continuation* of the body, however, in the exposed wall face *is reduced to a few square- or lens-shaped patches of granite lying isolated within the schist.* They seem to suggest the remainders of the former conduit whose fluid filling seems to have been squeezed out.

The Distribution of the Dark Granite.—The distribution of the dark granite ("Dark Barre") may be mentioned in connection with the shape of the intrusives. The large Piree quarry situated in the southern part of the area, is made up entirely of basic granite; no contact exposures are found. Hence the dark granite extends northeastward, decreasing in mass (quarry east of Barclay and Jones). The relationships to the main granite are always very significant (see figures 8-10). They suggest everywhere a co-magmatic, but slightly older rock. In a small opening south of the Boutwell quarry, the dark granite may be seen forming numerous flow-bands in the light rock. The outer zones of the flow-bands are often richer in mica than the cores; occasionally the same rock is seen forming large bale-shaped bodies surrounded everywhere by the light granite. Both rocks meet along a slight gentle boundary. At the Boutwell quarry a large phyllitic inclusion is surrounded almost entirely by basic granite, the latter intruding the schist. Toward the outer part the whole complex is

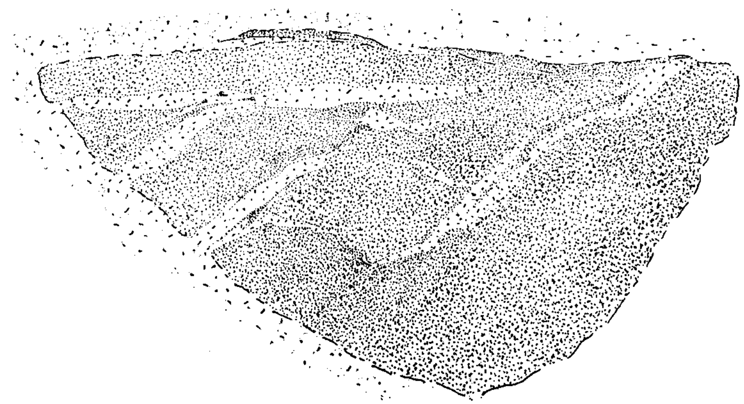
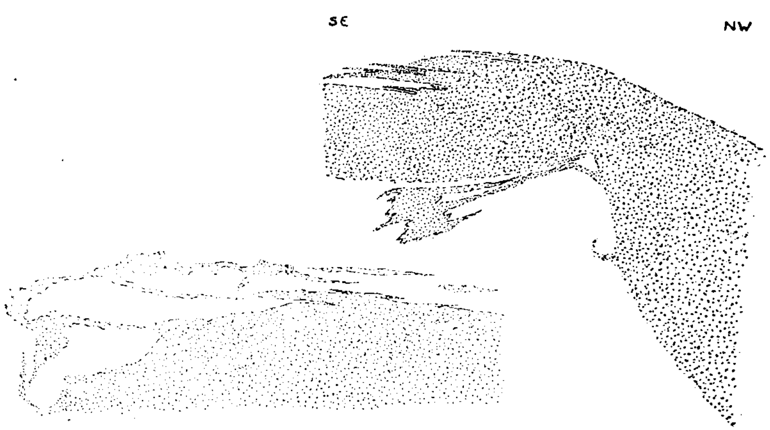


FIGURE 8.—Inclusion of dark granite in light granite. East of Barclay-Jones quarries.

dissected into large egg-shaped masses which float in the light granite. The latter intrudes here and there far into the basic rock and splits and cuts, so to speak, its predecessor into picturesque fragments. In a quarry east of Barclay Brothers, the



FIGURES 9 and 10.—Contact relations between dark and light granite.

boundary line is sharper. Aplites starting along indistinct boundaries from the main granite, cut the dark rock in a sharp, straight line (figure 8).

CONCLUSIONS AS TO THE SHAPE OF THE INTRUSIVES.

1. The majority of the large granite bodies have an oval ground plan, the long axis of which runs northeastward. These longitudinal boundaries in general are conformable to the phyllite and dip conformably to the northwest. The proportion of length to breadth does not exceed a mile to 1,200 feet, usually far below this.

2. There are gradations between large and small granite bodies.

3. Unconformable contact-planes are established joining the conformable ones and affording thus a great variety of structural forms in the intrusions. In case of spindle- or lens-shaped bodies the narrow borders are sometimes unconformable planes.

4. Pre-granitic structural planes of the country rock are responsible for most of the contact relations. The bedding planes are followed by the magma in particular; besides joints and planes connected with the linear stretching of the country rock. In accordance with this, most of the contact planes are straight.

5. Contact lines which cut the bedding planes at a very acute angle, are not rare. They may have originated from slight gliding movements within the layers next to the granite.

6. The dark granite, which is somewhat older than the main rock, appears in numerous inclusions in the latter. It is not known whether or not it forms independent bodies in the phyllite.

It is still an open question whether or not the described intrusive bodies at a greater depth join each other, forming a uniform massif. Some of them are certainly connected with each other.

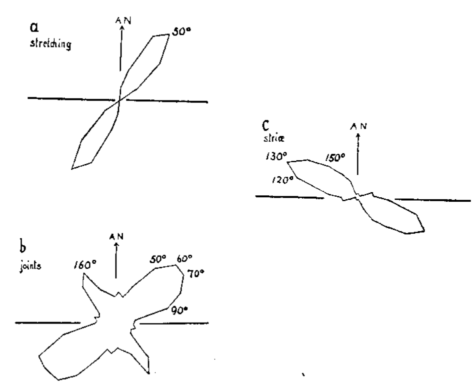


FIGURE 11.—Diagram showing the orientation of stretching (11a), joints (11b), striæ (11c), Barre. The maximum of 108 measurements of the stretching is 50°. Eight hundred measured joints show two maxima. One in N. W.-S. E. (cross joints); another in N. E.-S. W. (longitudinal and glide joints). Four hundred and sixty measured striæ run N. W.-S. E., regardless of the orientation of the joints upon which they occur.

The decision of this question was reached by the evidence of

THE INTERNAL STRUCTURE.

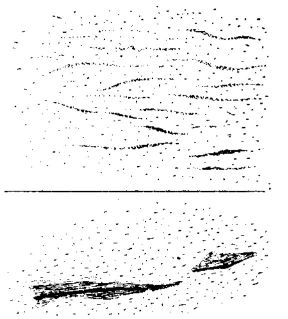


FIGURE 12.—Primary flow bands and the largest axes of inclusions run parallel to the parallelism of the granitic minerals.

Primary Parallel Structure.—A conspicuous linear or platy parallel structure strikes northeast-southwest (74 percent of 140 measurements lie between 40° and 60° (see figure 11). The primary origin of this structure is proved by frequent parallel inclusions and light and dark flow bands (figure 12).

Stretching and Foliation.—The impression of stretching is caused by a linear parallel arrangement of the minerals in so far as they have a *linear* elongation (feldspar, quartz, mica in part). Because the rock tends to develop a platy foliation parallel to the contacts, the strike of the stretching, which is superimposed upon the foliation plane, is generally more easily measured than the pitch. Occasionally, however, minute cracks follow the mineral boundaries, making the pitch very clear.

While the dip of the foliation planes is governed more or less by the dip of the contact, the inclination, or pitch, of the linear stretching shows independent changes. *The lines of stretching in many of the narrow, elongated intrusives rise from the northeast and southwest toward the centers. They form thus several independent, symmetrical arches which pitch down toward the narrow borders of the bodies. The tops of these arches, or domes, coincide with the cores of the now visible granite bodies* (see Plate II). These domes should not be confused with usually concentric domes with a circular ground plan (exfoliation domes), which in general represent only the shape of the rock body, not of the structure.

Examples: 1. *Millstone Hill dome.* The stretching is found in the southwestern part, pitching to the southwest: Smith quarries, stretching strike 45°, pitch 25° S. W.; 53°, 5° S. W. Wetmore and Morse quarry, strike 40°, 10° S. W. Western slope of the hill, strike 50°, 15° S. W. Stretching with a northeastern pitch in the northeastern part of the hill: Wells and Lamson quarry, stretching strike 45°, 10° N. E.; 50°, 10° N. E. Large abandoned quarry, northern slope, strike 55°, 0°-5° N. E. Idle quarry south of Websterville-Barre road, strike 35°-40°, 3° N. E.

2. *Barclay-Jones dome.* Above the floor of the phyllite, in the northeastern end, the stretching runs 53°, 6° N. E. Middle

part of the intrusive, strike 50°, 0°; 50°, 0-3° S. W. Southeastern half, strike 50°-55°, 0-5° S. W.

3. *Dome west of Barclay-Jones quarry.* In three quarries north of the Upper-Lower Graniteville road, stretching pitches southwest, strike 50°, 20° S. W.; 65°-70°, 15° S. W.; 60°, 0-3° S. W.; 60°, 8° S. W. The stretching pitches northeast in the quarries east of Websterville. Strike 55°, 5° N. E.; 45°, 15° N. E.

South of East Barre and *southeast of the Boutwell quarry* several additional *domes* seem to appear, but are poorly exposed.

From the study of the dome structure, it is believed that the Barclay-Jones granite is independent and does not join the structure of its western neighbor. While the stretching in the northeastern end of the Barclay-Jones quarries pitches 6° northeast, one measures a hundred and fifty feet to the northwest in the light Jones quarry, southwest pitch up to 20°. Such abrupt changes of the pitch have never been found in a single body.

Flow Bands.—It has been pointed out that flow bands, schlieren, are rare. It is only next to the contact plane that they appear, arranging themselves roughly parallel to the rock boundary.

Joints.—There are three systems of primary joints, which exhibit clear relations to the parallelism and the mechanics of the intrusion of the granite. They originated during a very early stage and are of much importance for the arrangement and direction of dikes, for intensive movements within the rock during early stages of the solidification and for the present cleavability.

Eight hundred measurements show two distinct maxima of the strike. First: *45 percent,* or 364 joints, *strike N. E.-S. W.* (50°-80°) (figure 11b). Second: *10 percent strike N. W.-S. E.* (156°-165°). The first group of northeastern strike must be subdivided as follows:

1. Joints, steeply tilted, coinciding, as to strike, with the parallel structure (maximum 50°), almost devoid of acid dikes, and younger than any other primary joints: *Longitudinal joints.*

2. Joints dipping at a moderate angle southeast (exceptions see below), striking more eastnortheast, 70°-80°, coated with acidic dikes: *Glide joints.*

The N. W.-S. E. system is oldest; the joints strike at right angles to the parallelism and are followed by acid dikes, as the glide joints: *Cross joints.*

In the relation of the cross joints to the stretching some independence is shown, since they dip everywhere to the northeast and do not conform to the domestructure of the stretching except in one interesting instance. As mentioned above, in the Barclay-Jones quarry, the stretching forms an eccentric arch with its apex far in the northeastern end of the intrusive. In the very northeastern corner the associated cross joints dip 80°-85° to the southwest. Soon after they stand vertically and in the main mass of the granite they dip at 75°-85° N. E. (figure 5).

Movements Along Joint Planes.—Cross joints and glide joints afford evidence of partial movements within the granite bodies during early stages of the consolidation. The joint faces, as such, resemble each other closely. They generally appear greenish because of chlorite veneers. Aplites, quartz veins and pegmatites are frequently fou.d on them. *These dikes and sometimes the granite of the joint walls are widely mashed and disintegrated on account of vigorous movements.* The affected rock is often changed into a plate of dense mylonite, streaked through and through by slickensides and coated on the surface with chloritic striæ. In the sunlight the faces shine like bright mirrors! The glide joints exhibit these features at its best. *Despite the different strike of the glide and cross joints, all slickensides measured in the area strike W. N. W.-E. S. E.* Sixty-one percent of four hundred and sixty measurements were between 120° and 140° (figure 11c).

The earliest displacements took place along the cross joints. The striæ on them generally pitch gently 0-30° in either direction. Usually the northeastern block has been pushed to the northwest, the movements thus being faults as well as overthrusts. Wherever cross joints and glide joints come across each other, the former are in general displaced, showing that the movements along the glide joints are younger. More than fifty measurable displacements, and the one-sided smoothness of the planes prove that most of *the movements have been overthrusts to the northwest.*

The glide joints are especially characterized by the intensity of the movements. As a whole they resemble very much the *streckflächen* described by H. Cloos (see Bibliography 6), although their relations to the parallel structure are different.

The glide joints make their *most impressive appearance* in a *large abandoned quarry, on the north-northeastern slope of Millstone Hill.* The whole rock mass of this quarry is dissected into slanting plates, three to twelve feet thick, by about one hundred long, straight glide joints which dip gently southeast. Looking down from the southeastern wall of the quarry the exposures appear dark green from the chloritic surfaces of the joints.

Fortunately, the rock is rich in cross joints with dikes, so that the displacements here can be measured. Over thirty overthrusts were measured, some of which exceed three yards. Even much larger displacements are probable, as it is sometimes impossible to find the continuation of large truncated quartz veins. *All the displacements are directed toward the northwest,* as indicated by the abundant striæ.

The glide joints are perhaps the most abundant in the whole area; they are scarcely missing in any of the granite bodies. They traverse the large Boutwell quarries as huge walls hundreds of yards long and sometimes more than a hundred feet high. They are fewer in the Pirie quarry, but they are well developed in the Barclay-Jones quarry (figure 6), also in the quarries farther northwest; in the large quarry south of East Barre, Wells and Lamson quarry, etc. It has been mentioned that many acid dikes follow these joints, and also that they sometimes govern the direction of the artificial cleavability. The latter and the dikes may be described next.

Cleavability.—The direction of the easiest cleavage, or rift, runs northeast, stands vertical, follows the linear stretching and is technically facilitated by the ever present, though occasionally latent, steeply tilted platy foliation. The horizontal parting-plane ("grain") is said to be obtained with more difficulty and the steep northwest-southeast planes ("hardway") are not easily cut and feel rough and uneven. The dip of the hardway planes is repeatedly governed by the pitch of the stretching (see Introduction, page 43), arranging itself at right angles to the latter as the cross joints generally do.

Examples: Small abandoned quarry north of the Boutwell quarry. Stretching pitches 20° S. W., hardway dips 65° N. E.; Smith quarry, Millstone Hill, stretching 25° S. W., hardway dips 70°-80° N. E.; Wells and Lamson quarry, northwest of Websterville, stretching pitches 10° N. E., hardway dips 78° S. W. The present artificial hardway planes, therefore, depend more on the pitch of the stretching than the cross joints did.

When the granite is crossed by many glide joints the cleavage may run parallel to them. This may be seen, for instance, in the northeastern corner of Wells and Lamson quarry, both planes run 90°, 45°-50° N. The same in many parts of the large quarry at Millstone Hill which shows the long glide joints mentioned above, also in the Boutwell quarry and in several small quarries west of Barclay-Jones quarry. The reason for this dependence seems to be the gradual decrease of strain toward the surface and the writer was convinced in the Wells and Lamson quarry that there actually exists considerable tension in the rock at the bottom of the quarries.

The *bedding,* wherever typically developed, coincides with the present surface and is found to be quite independent of the primary structures. A primary bedding seems to be missing. Concentric dip of the bedding, for instance, prevails at Millstone Hill, despite the constant northeastern stretching and foliation. The bedding is also well developed at Cobble Hill, northern and northwestern slopes in particular, in several idle quarries east of Websterville, north-northwest of Barclay-Jones quarry, etc.

Dikes.—Dikes of appreciable thickness outside the joints are rare; by far the greater part are short, thin, and strike and dip without any noticeable order. In the Pirie quarry, however, a long pegmatite dike is seen five feet wide, also two similar ones south of East Barre.

Four basic dikes have been seen. They strike northeast-southwest, always parallel to the longitudinal joints and cut any other dikes and joints. This proves the comparatively young age of those joints and the lamprophyres.

It is interesting that the long vertical dike that traverses the Barclay-Jones quarry dips in its southeastern continuation 63° S. E., at the same time changing the strike somewhat. (Compare the study of H. Cloos on the lamprophyres of the Riesengebirge, Bibliography 7.)

Relation of the Joints to the Wall Rock.—The features imposed by the fluid stage (flow bands, stretching, parallel structure, etc.) do not show surprising phenomena. The structure of the contact lines, mostly pre-granitic structural planes, is also clear. *But the joints and associated dikes exhibit exceedingly interesting relations to the contact.*

Arrangement of Joints and Dikes Due to the Influence of the Contact.—Joints next to inclusions, or to the contact, sometimes tend to arrange themselves at right angles to the rock boundary.

Examples: Jones light quarry, northwest of Barclay-Jones quarry. Surface of large xenolith strikes 55°, 45° N. W. Joints coated with quartz strike 25°, 50° S. E. In Anderson's quarry the quartz veins and joints in the large granite dike strike nearly parallel, but dip at right angles to the contact plane; the latter strikes 45°, 60° N. W.; joints 30°, 60° S. E. Smith quarry, Millstone Hill, a large pegmatite runs at right angles to the contact, this strikes 75°, steep, the pegmatite 165°, 70° N. E.

Relations of the Glide Joints to the Contact.—During the investigation it appeared that the *orientation of the largest glide joints is notably influenced by the orientation of the contact planes.* The great system of long, chloritized glide joints was described above, in the abandoned quarry northwest of Millstone Hill. The exposure lies next to the northwestern contact of the granite body so that the southeasterly dipping joints are all tilted *into the intrusive, away from the contact.*

Going thence eastward one approaches the southeastern contact, exposed in three quarries. Here, too, in the Consolidated and Wells and Lamson quarries, glide joints are seen (see Plate II). Starting from the wall rock they traverse the quarries as huge, even planes and cease at a distance of about two hundred feet from the contact. In these quarries they are tilted to the *northwest* and *north-northwest*, dipping thus off the contact, *into* the granite. The same orientation of the glide joints is found in the Barclay-Jones quarry. Long planes start from the northwestern contact, dip gently into the intrusive, stop after a while, and do not reach the interior. But next to the northeastern contact there appear a few glide joints dipping northwest (see figure 6).

It is a very interesting fact that the contact plane has never been displaced by the joints. The intensity of the striæ, on the contrary, decreases and finally ceases near the contact. In general, the dip of the glide joints is southeast, and in the northern part of the Jones light quarry, a set of long glide joints dipping south-southeast cross the whole body from one contact to the other.

Changes of the Orientation of the Glide Joints Next to the Wall Rock.—How closely the glide joints depend upon the contact is evident from the fact that they sometimes change their strike and dip as they approach the rock boundary.

Examples: Consolidated quarry. Eastern contact 25°-35°, 80° S. E., glide joints 75°, 40° N. W.; next to the contact 110°, 50° N.; 50°, 40° N. W. to 70°, 45° N. W.; 58°, 45° N. W. to 70°, 70° N. W. to 100°, 60° N.; 48°, 47° N. W. to 58°, 38° N. W. Wells and Lamson quarry. Eastern contact 30°-40°, vertical. Glide joints 70°, 30° N. W. to 90°, 35° N.; 85°, 42° N. N. W. to 90°, 52° N.

Continuation in Depth.—It is still an open question how the granite continues downward. Observations on the glide joints seem to enable us to answer this question with certainty.

Are the wall rocks parts of large inclusions or pendants of the roof? Several granites communicate with each other through visible channels and vents. They also repeatedly send out offshoots. Therefore, considering all visible bodies as parts of one larger intrusive, the phyllitic rocks within and between the magmatic bodies are necessarily to be considered as inclusions or remnants of the roof. In this case, it is probable that the granite will display the same behavior along these supposed inclusions as along the frequent additional inclusions which are exposed in the quarries, whose nature is beyond question. But this is not so. In general the granite does not react at all upon inclusions, even the largest ones. Or, as we have seen, joints without slickensides occasionally tend to arrange themselves at right angles to the surface of the fragments.

Among all the inclusions studied, not more than two were found that were surrounded by numerous slickensides. Aplites and pegmatites, however, were never found on them, nor have typical glide joints ever been observed which showed any relation to inclusions. Widely different is the manner in which these joints are arranged along the supposed true contact planes. As has been pointed out, they present a symmetric system, or fan, of two sets of glide planes whose frame is evidently represented by the contact against the phyllite. Thence they start, dip ***into*** the intrusives on either longitudinal side and cease toward the center. If the conception that the association of the contact and glide joints as an expression of mutual dependence is correct, it should be possible to calculate the location of the contact from the appearance of the glide joints, with the restriction, however, that the northwestern contact might be determined less exactly because of the prevalence of southeastward dipping glide joints.

Two field experiments corroborated this view, one of which may be mentioned. The northwestern border of the granite body west of the Barclay-Jones quarry is concealed, but long glide joints with southeastern dip were found toward the western margin of several quarries. Thereupon the most promising places were carefully surveyed and after long search, loose slabs and two little ledges of phyllite in place were found in a thicket about a hundred and fifty to two hundred feet distant from the granite.

The mechanical importance and the nature of the glide joints near the contact is revealed by a quite different consideration according to a recent study of H. Cloos (see Bibliography 7).

Similarity of the Joint Systems in Glaciers and Granite.—So far as we consider the upward "stoping" as the active force for the movement of the magma, we may compare a vertical northwest-southeast section through any of the granite bodies with the horizontal ground plan of a glacier or a lava stream. In either case, a rather viscous mass is moving between more or less parallel, solid walls. For a detailed and comprehensive study on this problem, the reader is referred to Cloos (Bibliography 7, page 54).

It is well known that there are in glaciers several systems of joints whose direction is governed essentially by normal and shearing forces. In this connection the so-called marginal fissures are of particular interest (crevasses marginales; see A. Heim, 15, page 194, etc.). Cross sections through several of the Barre granite bodies represent precisely the same general arrangement (figure 6): Systems of marginal fissures, which end toward the center with symmetrical dip toward the core.

The nature of the glide joints as tension joints is almost proved by the many acid dikes which evidently favor them.[1] It is hardly possible to find any explanation for this lawful arrangement other than that the glide joints are merely an expression of the pressure of the magma against the wall rock; that they strike parallel to the maximum stresses and gaped during the time of the aplites as do the cross joints elsewhere. The only irregularity is that the angle between the contact and the joints varies

[1] Fig. 6 is so much reduced that the double lines which represent aplites, are not visible any more on the glide joints.

more than in glaciers and that on the northwestern side there are more fissures developed than on the southeastern. Both facts are certainly due to contemporaneous dynamic, non-magmatic lateral pressure, which easily disarranges the ideal relations. This latter point will be mentioned later.

From this lawful, and fan-like symmetrical arrangement of the glide joints towards the wall rock, *it necessarily follows that there was a solid resistant wall, against which the intrusive has been pushed. Such resistant bodies, however, cannot be xenoliths which float within the magma, but they must be the very contact, a part of the undisturbed, stationary country rock.*

It may be also mentioned that the strike of the phyllite in all of the presumed contact exposures is normal and not turned. This would be very striking if the rocks represent loose fragments. Even the supposition that the phyllite exposures are pendants of the undisturbed roof of a large body is not supported by the observations.[1]

In spite of special attention, no place has been found where the intrusions cut and widely underlie the country rock along a flat surface. The only body where such a horizontal surface is exposed is at the Barclay-Jones quarry, where it forms a lenticular intrusive which has an almost horizontal axis (figures 5, 6). The majority of the exposures do not indicate relations as required by a body with a large uniform surface. We see steeply tilted bodies, narrow and short dikes and offshoots which branch off from spindle-shaped bodies, which in turn are underlain by sediments. Even in the large intrusive of the Boutwell quarry there appears a large mass of phyllite in the bottom on which the joints react very conspicuously in a manner which makes it probable that the undersurface of this body may not be far away. Moreover, observations made in Woodbury show that true unconformable surfaces do not justify the assumption of an indefinite downward continuation (figure 13).

Evidence of the Structural Domes.—It was also demonstrated that the granitic bodies form several individual structural domes independent of each other. Each represents a separate dynamic realm whose reach coincides fairly well with the visible parts of the intrusives. ***The granites appear, therefore, as independent dynamic individuals*** and not as casual rises of one large uniform mass. At any rate, there is no evidence which may compel the supposition of a batholithic mass. All observations are decidedly against this supposition.

Uniform Source of the Magma.—The remarkably similar character of the rock makes it plain that there must have been a uniform common source. But the coherence of the phyllitic country rock has not been destroyed by the intrusion of the

[1] Compare also T. Nelson Dale, Bibliography 11, p. 122.

granite. This is best shown by the different pitch of the stretching in the Barclay-Jones intrusive and the one in the Jones light quarry next to it (see above). A thin septum of phyllite separates two bodies with remarkable dynamic independence.

MECHANICS OF THE INTRUSION.

Pre-granitic State of the Rocks.—The observations enable us to picture the subsequent stages of the intrusion about as follows: Previous to the introduction of the granites, the sedimentary rocks have been converted into a series of isoclinally folded phyllite (strike northeast, dip steeply northwest). Steep cross joints and gently dipping additional fissures join the stratification planes constituting a system of natural crevices which traverse the whole rock mass. The southeast-northwest pressure which has folded the rocks still continues to act, causing a few displacements along cross joints (observed southeast of the Boutwell quarry).

The Introduction of the Magma.—The earliest forerunners of the commencing intrusion are fine-grained granitic dikes. They are intricately involved in, and folded into, the sediments and finally they solidify as small bodies of gneissoid character (north of Cobble Hill; northeast of Washington). After the cooling of these first shoots, the introduction of the magma begins on a larger scale.

Numerous fine-grained dikes are formed which grow porphyritic in part (east of Cobble Hill; northeast of upper Graniteville), in part basic (Pirie, east of Barclay-Jones, Boutwell quarries). It seems that they are concentrated within the zone of the subsequent main intrusion; the resulting rocks are not foliated. As soon as these fine-grained predecessors have invaded the sediments—their consolidation is not yet completed—the bulk of the granite appears.

The magma splits the steep stratification planes of the schists, pushes the walls slightly aside, advances along preëxistent older joints and fissures into the country rock (east of the Boutwell quarry), loosens part of the walls from the main mass (Smith largest quarry, north of Barclay-Jones) and, while the main channels are filled by long intrusive bodies, secondary dikes and apophyses branch off in every direction (Anderson, southeast of Boutwell, east of Websterville, etc.). They, too, move upward along the stratification planes (Anderson, east of Barclay Bros. & Jones, east of Boutwell), thence they shatter the severe system of their walls to some extent, proceed along flat planes across the "grate" of schists, until a new stratification plane may intercept the liquid.

Again the magma may follow new cracks and fissures, is scattered into more and finer veins, and will finally cease, or may meet another body with which it may unite (Barclay-Jones with granitic dikes to the east and southeast; old quarry east of Websterville, south of Pirie and many additional exposures). It is not unlikely that sometimes the open planes may have closed again after a part of the magma had passed (figure 7, Jones light quarry).

The larger intrusions have often followed the courses which their forerunners used. However, the younger masses advance farther, overtake the former, and may surround them together with fragments of the country rock (Boutwell quarry). Both igneous rocks penetrate each other while still plastic. Significant "tender" and indistinct contact phenomena result, where the older and basic granite plays always a passive rôle, being torn into picturesque marginal bands and dissolved gradually by the lighter magma (Boutwell quarry; east of Barclay-Jones). Because of the great increase of heat along the contacts, the country rock at the very boundary seems to have participated slightly in the general movement. Light gliding movements commenced which probably overwhelmed the original mechanical contrasts of the single layers, so that the granite is able to cut or "overtake" the strata at an exceedingly acute angle. These movements are wanting, however, along joint planes and unconformable fracture-contacts. As final products of the intrusion, long conformable bodies come into being. Their regular shape is frequently interrupted by schists and undisplaced parts of the country rock (Barclay-Jones, Boutwell, Millstone Hill). A few bodies overlie to some extent the sediments and are likely to maintain their downward continuation merely through a narrow and short zone. Thus the shape of some of them suggests rather spindle- or hammer-shaped bodies, while the majority may be considered as steep plates or square-shaped intrusions.

INFLUENCE OF THE DYNAMIC STRESS.

In the Plastic Stage.—The magmatic bodies adjust their shape to the contours of the walls by yielding movements. As shown by the direction of light and dark bands, and the axes of many inclusions, the general movement was in a southwest and northeast direction. Whether or not the pressure which was exercised by the longitudinal contacts was the true regional pressure or only a component, cannot be decided, still no evidence was found which might indicate another main direction (compare Woodbury, page 90). While the fluid magma cools gradually, those crystals which form longest axes, as feldspar, mica, etc., are also subject to the directing power of the tectonic pressure.

The rocks, both light and dark granite, are subjected to linear stretching and, next to the contact, to platyfoliation, in a northeast-southwest direction. Yet the upward pressure seems to have been still active in the core of the larger bodies; the middle parts rise most and draw the linear stretching upward toward the centers so that symmetric structural domes ensue (Millstone Hill, Barclay-Jones, south of East Barre, etc.).

In the Solid Stage.—As a further reaction on the regional northwest-southeast pressure, cross joints appear almost everywhere with northwestern strike. Aplites, pegmatites, quartz veins, find these tension joints gaping and precipitate their material along the walls. Very remarkable are the exhibitions of tension between the granite and the wall rock. Systems of tension joints come into being just as in glaciers. They are especially frequent next to the contact, dip as systems of slanting planes into the granite, but do not reach the center of the bodies. Joints dipping southeast prevail over joints dipping northwest.

These glide joints are followed by acidic dikes, just as are the cross joints. One might ask why is the interior of the granite destitute of these joints? From direct observation no answer can be given as yet; however, it may be said that acidic dikes which follow these fissures so frequently are reduced in the interior to small, irregular formations. This favors the supposition that joints existed already in the outer parts of the intrusives before the cores were wholly solidified.

We also referred to the surprising fact that the uniformity of the contact line has never been interrupted by the movements and displacements along the glide joints. Both observations favor the view that some mobility of the magma has continued somewhat later in the interior parts than in the marginal zones of the intrusives.

The movements which took place along the joints are interesting in two ways: First, because they are confined to the granite bodies, then because there are evidently both magmatic and tectonic forces which cooperate. As previously mentioned, it is in general the northeastern block which has been pushed forward to the northwest along the oldest (cross) joints. These movements, too, are to some extent connected with the doming and rising of the magma: In the northwestern corner of the described structural dome in the Barclay-Jones quarry, the southwestern block has always been moved to the northwest. In the middle and at the other end, however, slight movements took place in the other direction (compare the similar relations at Bethel, Vt.). *This seems to indicate that the interior central parts of the intrusives have been moving most strongly to the northwest, whereas the parts next to the contacts were left behind, comparatively.* In good correspondence is the fact that at the

Barclay-Jones quarry those slower marginal zones rest upon phyllite, while the downward continuation is to be sought in the center.

The movements took place without disintegrating the contact, nor did they leave any other traces in the phyllites. The displacements cease toward the boundaries of, and are restricted to the material of, the intrusives, although the joints themselves reach the wall rock. Almost at the same time tension joints appear in a few places surrounding the inclusions and tend to arrange themselves at right angles to the rock boundaries. They are of quite local development, just as the cracks which form in very fragile and thin parts of the bodies (east of the Boutwell quarries, joints between an inclusion and the contact). While *steep* plates or square blocks of granite are moving northwest along the *cross joints,* the bulk of the *glide joints* dissect the bodies into plates and sheets, which are *obliquely tilted to the southeast.*

We have considered tensions of the intrusives against the country rock as the ruling factor for the direction and orientation of those joints, while the striæ point constantly west-northwest or northwest. This can hardly be interpreted otherwise than by supposing a uniform cause for uniform movements along cross and glide joints. From the fact that almost all of these glide movements are overthrusts to the northwest, by which the intrusives increase in height, it follows that *this kind of movement would correspond both with a tangential southeast to northwest pressure and an upward rising magmatic force. They can, therefore, be considered a resultant of two active forces, a regional tectonic pressure, acting apparently toward the northwest, and of a vertical magmatic force.* The same joints which were originally formed as pure tension joints, serve afterwards quite different purposes.

The movements have settled and all primary manifestations of the magma ceased when the longitudinal joints were formed. Unfortunately, their origin is wholly obscure. They are everywhere the youngest fissures and almost always devoid of movements (exceptions seen in the Smith quarry, Millstone Hill), and also of dikes. But in accordance with their youth these longitudinal joints play an important rôle for the lamprophyres. With the appearance of the basic dikes the magmatic activity stops.

SUMMARY.

First.—In the Barre region there are several granite bodies.

Second.—Their shape and general configuration is essentially governed by the older structure of the wall rock. As the magma has followed the most favorable planes of weakness of the bed rocks, and as these are steeply tilted northeastward, striking stratification planes, elongated, oval intrusive bodies resulted which strike northeast and form rather steeply tilted lateral contacts. Next in importance to the bedding planes are steep cross joints as well as gently dipping fissures. As the granites have utilized these planes, too, unconformable contacts result and they are found terminating some intrusives as gentle undersurfaces, or as steep cross cutting boundaries along the narrow sides of the single bodies. The "typical" intrusive, therefore, may be represented by a steeply tilted, square block, trending northeast, with steep lateral, but sometimes rather gently tilted upper and undersurfaces. The conduit is to be sought for beneath the center and is most likely a bedding plane of the wall rock.

Third.—The granitic magma has adjusted itself to the available space by differential movements. Their direction is fixed by the orientation of flow bands as well as by the stretching. The latter indicates the existence of a number of structural domes, each being due to magmatic forces which raised the cores of the originating intrusive bodies higher up than the narrow marginal flanks.

Fourth.—In a later stage, the brittle solid rock reacts interestingly to both the diminishing magmatic and the lateral tectonic pressure. Overthrusts to the northwest result which can well be considered as the physical resultant of a lateral force active to the northwest and an upward, igneous force due to which the intrusives increase in height.

Fifth—During the granitic intrusion the country rock continued to resist the magma. The latter has never overcome the consistence of the phyllites. The granites worked their way upward as several dynamically independent bodies along separated planes of weakness, pushing aside the country rock to a limited extent only. The single intrusives originated, however, from a uniform magmatic source and may communicate now through narrow, irregular dikelets and offshoots within the now exposed level.

Sixth.—No marginal fusion or assimilation ("soaking") occurs. The magma has found a static, stationary wall rock which does not admit any "lit-par-lit" injections. The contacts are everywhere distinct, clear-cut planes.

WOODBURY.

CONTENTS.

GENERAL SUMMARY.

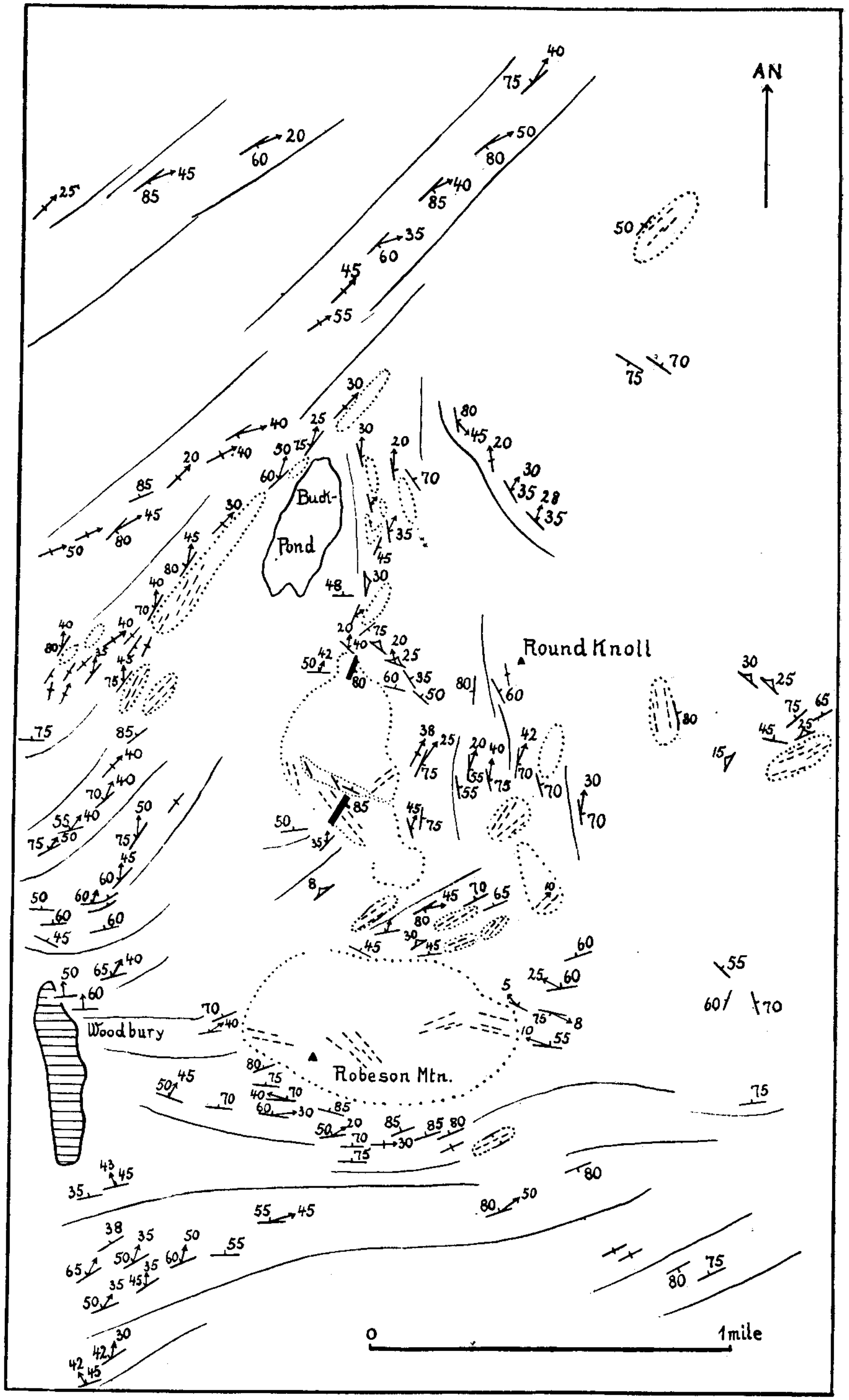
The vicinity of Woodbury is forested and mountainous. Only near the village and along the valley which leads to Hardwick agricultural and pasture land may be seen.

General Character of the Rocks.—Except for some glacial gravels and sands, the country rock consists of the same phyllites as those of Barre and Bethel and of granitic rocks.

Sequence of Intrusions.—So far as the Woodbury area is concerned, one can recognize within the granitic rocks the following sequence of intrusion:

1. Dioritic or syenitic rocks, hornblende-bearing, fine to medium grained, older than 3, relation to 2 unknown. Found in place only at Nichols Ledge, southern slope. As large boulders also along the shore of East Long Pond.
2. Basic granite, "Dark Woodbury," in many localities seen as "schlieren" and inclusions in 3, also as sporadic independent intrusives in the phyllites.
3. Main granite, medium grained, normal, exceeding in quantity all other intrusive rocks.

PLATE III.



The Granite Area of Woodbury. The intrusives appear within an area where the regional N. E.-S. W. strike of the country rock is greatly disturbed. The disturbances are of pregranitic age and have probably facilitated the expansion of the granite. Symbols as usual.

4. Fine grained granite of normal color, seen in one locality only.
5. Basic dikes.

The relationship between 2 and 3 corresponds exactly to the conditions found in Barre.

In the northwestern and southeastern part of the area the phyllites *strike northeasterly and dip northwest or southeast.* Very near Woodbury the strike is predominantly east and west, but north of the village it swings to the northeast. The flexure zone itself is repeatedly and very well exposed. Within limited distances, the strike bends sharply, *e. g.,* just north-northeast of Woodbury, as seen on the map (Plate III). Here one can measure on funnel-like curved ledges changes of strike up to 35° within a distance of twenty-five yards. Northeast of Woodbury the strike of the schist is irregular and disturbed. The structure of the rocks so uniform elsewhere, is here shattered into small fragments which confront each other abruptly in many places. This is largely due to disturbances and intensive folds of frequently complicated orientation and very limited reach. *The Woodbury granite appears within this disturbed area.* Between Hardwick and Nichols Ledge much normal and basic granite may be seen. But, as the area there is very poorly exposed, no special investigation has been attempted.

Whereas, in the uniformly striking sediments at Bethel and Barre, large ellipsoidal intrusives have been formed, in the present disturbed area, within the shattered phyllites, numbers of small granite bodies of different shape and position appear. Only in two places are there somewhat larger bodies.

It should be noticed in advance that the *disturbances of the phyllites are of pre-granitic age, almost without exception. Disturbances of strike in the phyllite are not subsequent to the intrusion, but the latter and the shape and boundaries of the granites in particular are a consequence and a reproduction of the older disturbed conditions of the country rock.*

This statement must, however, be restricted inasmuch as larger bodies next to the contact planes may affect and bend the strike of the sedimentaries. The rather diversified interrelations between the country rock and the granite may be studied to good advantage if we start from simple conditions which resemble those at Barre. First the numerous small bodies may be described, then the larger intrusives of Robeson Mountain and of the southwestern slope of Round Knoll Mountain (the local name of this mountain).

The Small Intrusives.—Concordant intrusives. In phyllites of uniform strike and dip concordant intrusives are common. The longitudinal concordant contact planes follow the bedding planes.

Within the schists west and southwest of Buck Pond, which strike straight northeast and dip steeply towards the northwest, there appear many conformable granites. Their longitudinal dimensions vary from a few yards to several hundreds.

Examples: Small lenses about two hundred yards east of the wagon road Woodbury-Hardwick, 2.4 by 9 yards. East of this a second one, 3 by 12 yards. Along the scarp west of Buck Pond there are seven intrusives: 50 by 120 yards; 15 by about 70 yards; 20 by about 80 yards. Here is found the largest body of this type, 10-80 by approximately 300 yards. North of the pond there is another narrow intrusive, about 30 by 150 yards. The thickness of these narrow bodies varies somewhat, and the fine-grained granite (2) joins the main granite (3) in constituting the rock material. In the last mentioned examples the basic granite is found to be restricted to the contact zones and appears also as a few elongated inclusions in the main granite. While the latter is only stretched linearly, or very gently foliated, the basic rock is conspicuously foliated.—In an old quarry south of Robeson Mountain, a small conformable lense of granite is especially well exposed within vertically dipping slates which strike east-northeast. Size: 8, 4 by about 30 yards.

Smallest Dike-like Bodies.—The numerous small and generally short bodies which are scattered throughout the phyllitic rocks, usually as conformable shoots (exceptions see below), may well be termed genuine dikes. Differing from the two narrow bodies at Buck Pond (see above), they do not display any structural complexity. They surely are primitive stages of the intrusion from which the larger intrusives may have originated sometimes (see below). A few such dikes were found which consist of basic granite exclusively; *e. g.*, dike on the south-southwestern slope of Round Knoll, 25 inches thick, strikes 110°, 70° north. Such could not be found in Barre.

Tilted Bodies, in Part Very Gently Dipping.—Where the phyllites dip gently and uniformly, the conformable intrusives may also be seen as gently dipping lenses; steeper dip of the country rock of course causes corresponding inclination of the lenticular bodies. Good instances of this group of intrusives may be studied along the western, northern, and eastern slope of Round Knoll Mountain, east of Buck Pond, between Round Knoll and Robeson Mountain.

As seen in continuous exposures along the northern slope of Round Knoll Mountain, the gentle dip of the sediments is merely a consequence of the intercalation of flat limbs with the elsewhere steeply tilted limbs of the folds for appreciable distances. Naturally this does not interfere at all with the orientation of the fold axes which pitch 10°-30° north. On the *southwestern slope of Round Knoll,* the exposures are exceptionally complete. Descending west from the top of the mountain one meets some twenty tilted or flat single granites of lenticular shape. They weather out as hard, resistant edges over the softer schists and strew the slope with large boulders. This suggests at first sight that the whole slope consists of granite, while the latter, as found frequently, constitutes only a very limited part of the surface. All of these lenticular intrusives strike northwest, or north and south and dip conformably with the surrounding phyllite 10°-45° northeast. A few measurements may be given: 3 yards by 10 yards, dip 25° N., 13 yards by 62 yards, 10°-20° N. E., composed only of basic, fine grained granite; 7 yards by 50 yards, 30° E.; 6 yards by 37.5 yards, 35° N. E., 10 yards by 50 yards, 30° E.; 6 yards by 37 yards, 10 yards by 62 yards, 20° N. E.

Small Phacolithic Intrusives.—East-northeast of Robeson Mountain there is another flexure zone of the phyllites, so that the east-west strike of the beds swings once more to the northeast. Within fifty yards one can measure in outcropping ledges; strike 120°, 80° S., immediately after, due to a large fold, strike 100°, 10° N., to 60°, 45° N. W.; 55°, 40° N. W. Then strike 90°, 50° N., to 80°, 60° N. W., to 45°, 60° N. W. to 50°, 90°-85° N. W. In three places amidst these cliffs small, conformable curved granitic masses occur, a few yards thick, which are strictly conformable with the saucer-shaped structure of the sediments and dip likewise northwest.

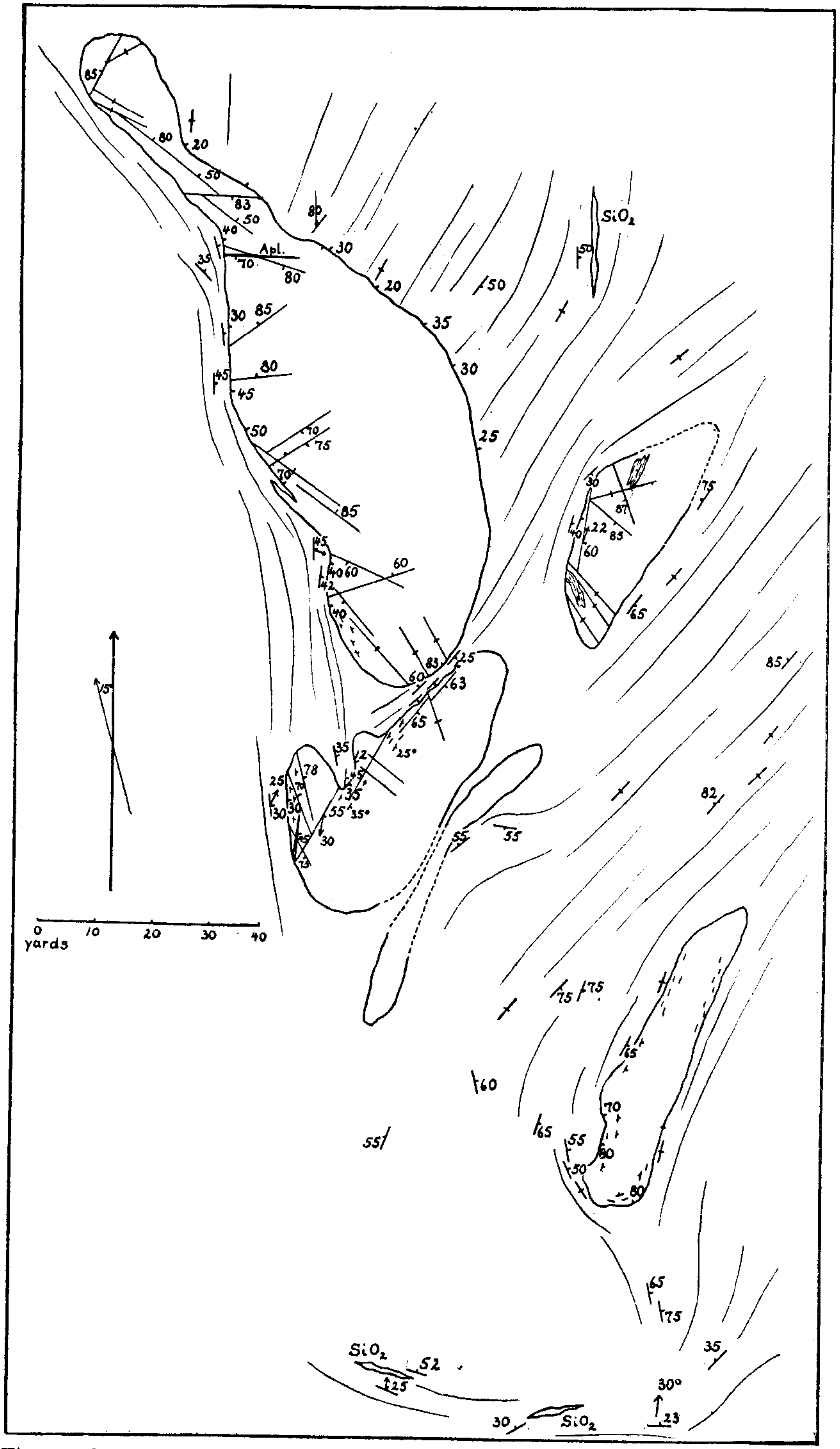
Intrusives of Uncertain Character.—North of Robeson Mountain numerous small granite bodies are exposed in several abandoned quarries. They seem to represent conformable bodies within east-northeastward striking phyllites. At any rate, their longest axes coincide with the strike of the schists.

A few exposures were found where, for some distance, *unconformable contact planes* take on in relay for conformable boundaries (see also below).

Examples: The undersurface of one of the flat lenticular bodies on the western slope of Round Knoll dips conformably at 25° northeast (strike 130°). While it retains this orientation, the underlying phyllite farther southeast strikes 48°, 80° S. E. In the southeastern corner the undersurface plunges down more steeply, but remains unconformable throughout. The contact plane of one of the above mentioned intrusives north of Robeson Mountain (strike 95°, 75° S.) cuts in one place the northwest striking phyllite unconformably (140°, 90°).

A few hundred yards west is another granite, trending north-south which ends toward the east along a contact plane, 25°, 75° E. The bordering phyllite is strongly folded and is cut by the boundary line unconformably at an acute angle.

Dikes on Joints of Phyllite.—Cross joints and common joints of the phyllite may substitute in this area the exceedingly favorable bedding planes, and are frequently followed by intrusives, smaller and larger. Other planes may be cleavage planes and, as a new element, disturbances.



Five small granite bodies east of Buck Pond, Woodbury. They follow in the south the bedding planes of the phyllites, while the northwestern intrusion lies upon an older disturbance.

Examples: On the west-southwestern contact of the Robeson Mountain granite body, a dike runs for several yards along a cleavage plane (strike 150°, 80° N. E.). Figure 3 shows another apophysis on such a plane (strike 145°, vertical).—On the south-southwestern slope of Round Knoll is a joint of the schist (strike 123°, 75° S. W.), which is followed by a narrow and inconspicuous vein of granite. This, however, gradually forms a dike three feet thick.—Among the exposures of phyllite along the railroad track south of Hardwick, one can frequently study granitic dikes on cross joints of the country rock which strike 120°-145°, 45° S. W.

Granites on Fault Zones of the Country Rock.—A particularly interesting group of smaller granite bodies may be studied along the scarp east of Buck Pond (see Plate IV). The plane figured dips west. It is particularly the western margin of the granite that forms the scarp at the base of which the underlying phyllites emerge everywhere. Five granites appear in a limited area, each completely surrounded by phyllites. The three southeastern granites lie conformably within slates which strike northeast and participate in every slight wrinkling or curving of the beds. The larger of the two northern bodies, however, trends

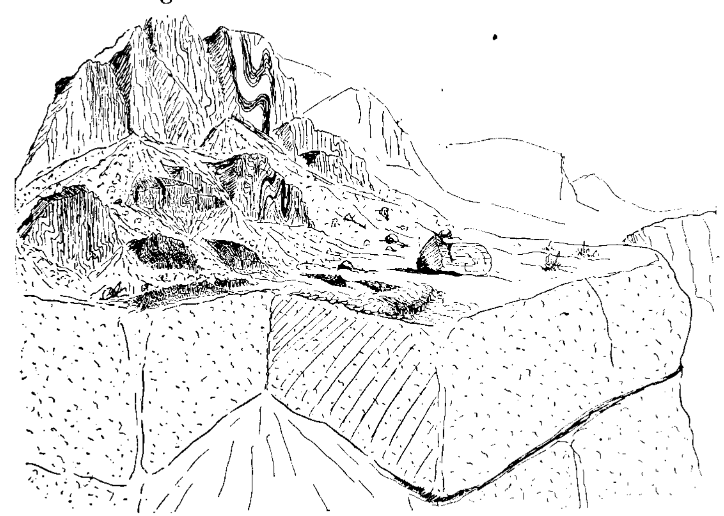
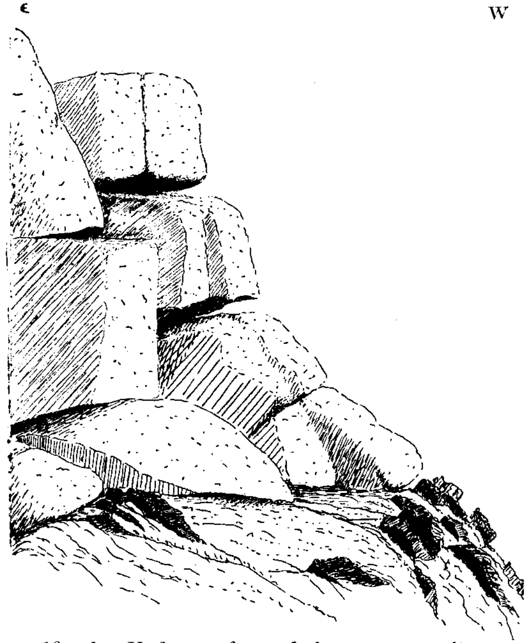


FIGURE 13.—*a*. Upper surface of the northwestern granite of Plate IV. The intrusive cuts unconformably the strongly folded phyllite in the N. E. and rests conformably upon unfolded schists. Buck Pond, Woodbury.

north-northwest, its longitudinal flanks dipping northeast at a low, or average angle, but while the undersurface rests conformably on southeastward dipping phyllite, the upper surface cuts sharply and unconformably a series of steeply dipping and intensely folded schists (see figures 13). Farther south the two directions of the strike of the bed rock converge and it is just there that a second intrusive appears. It expands with one salient into either tract of the phyllite, but in the center it projects unconformably northward over the divergent beds. These intrusives are separated by a two-yards wide, intact, anticline of the phyllite; both contacts cling closely to the limbs of the fold.

Now is the position of these plugs of granite in the wall rock casual or is it influenced or determined by older structures? The



13.—*b.* Under surface of the same granite.

two flanks of the large body are essentially different (see figures 13a, 13b). A very regular, even-bedded phyllite underlies the intrusive over which is a mass of steep folds of confused general structure.

About fifty yards to the south, beyond the map, precisely the same relations occur *in a pre-granitic condition:* Highly folded phyllite, striking northeast (50°-55°, 80°-95°) is seen approaching to three yards northward trending beds (180°, 60° E.), which are practically not folded at all. A crushed zone separates both systems.

North beyond the margin of the map, strongly folded rocks confronting abruptly unfolded schists may be found. Corresponding relations caused by very irregular folding can be seen on the southern slope of Round Knoll Mountain. Also north-northeast of Woodbury along the railroad track, etc.

By measuring the stretching and strike it can be shown that these folds are pre-granitic, *i. e.,* that younger stretching is superimposed on older folds. The table below gives measurements of the strike and stretching east of Buck Pond:

Phyllite		Stretching	
Strike	Dip	Strike	Pitch
5°	70-75° E.	20-30°	30° N.
175°	80° E.	15-20°	55° N. N. E.
10°	80° E.	20°	·20° N.
3°	75° E.	25°	23° N.
10°	45° E.	40-45°	30° N. E.
120°	25° N.	27°	25° N.
100°	25° N.	20°	20-25° N.
45°	65° S. E.	70°	30° N. E.
65°	75° S. E.	65-75°	10-20° N. E.
130°	30° N. E.	20°	25° N.

Hence the variation of the horizontal projection of the stretching, no matter how the phyllite strikes, does not exceed 60° with an accentuated maximum in the middle. Obviously, the stretching varies somewhat in sediments with such extensive folding.

The crushed zones, which are of limited extent obviously represent the planes along which the two differently formed blocks have been shifted and displaced against one another.

Now, shear zones and minor disturbances of local importance are by no means restricted to the vicinity of the granites. They also occur, for instance, within the large flexure-zone of Woodbury. But, as they are not very well exposed, the writer could not obtain any measurements.

As to the described exposures, it seems certain that the granite has used an older shear-zone as its plane of movement and expansion. It strikes and dips with it. Where the disturbance is diminished because of the convergence of the strike (in the south) the magma (of the second body) at once follows the bedding planes, neglecting them only in the central zone of weakness and disintegration of the country rock.

How thoroughly the granite has conformed to the structure of the framework may be inferred from the fact that, between the two intrusives, the narrow fold of the schist mentioned above, runs through as a fragile and yet undestroyed septum! The contact plane of the body next to the northeast also follows the bends of a larger fold.

An *intrusive breccia* of a great scale seems to be the granite of Nichols Ledge. This is a high, narrow crest which falls vertically down to Nichols Pond, one of the most attractive places in the vicinity. The steep rock walls are dotted by large inclusions which closely resemble gneissic rocks. However, observations in this place were only preliminary.

The Large Intrusives.—The two larger intrusive bodies in which most of the quarries are located are closely related to the small neighboring bodies. The granite southwest of Round Knoll Mountain originated, as can be conclusively shown, from the coalescence of several smaller bodies. This also holds, perhaps, for the Robeson Mountain intrusive. At any rate, several stages in the gradual development of structure and contours are well exposed.

Robeson Mountain.—This whole mountain, except the southwestern slope, is made up of granite. In the eastern corner there appears a darker, fine grained granite included in the mass of normal medium grained granite. The contact is very well exposed on the western border. The folded phyllite extends upward nearly to the top of the hill. The single beds, so far as they strike nearly straight, are followed by the magma; their dip may be bent parallel with the contact, but if complexly folded they are mostly cut off unconformably by the intrusive. The contact as a whole, strikes nearly straight west-northwest.

While a few apophyses follow cleavage planes of the phyllite (see figure 3), the main contact does not follow this rather delicate structure of the wall rock.

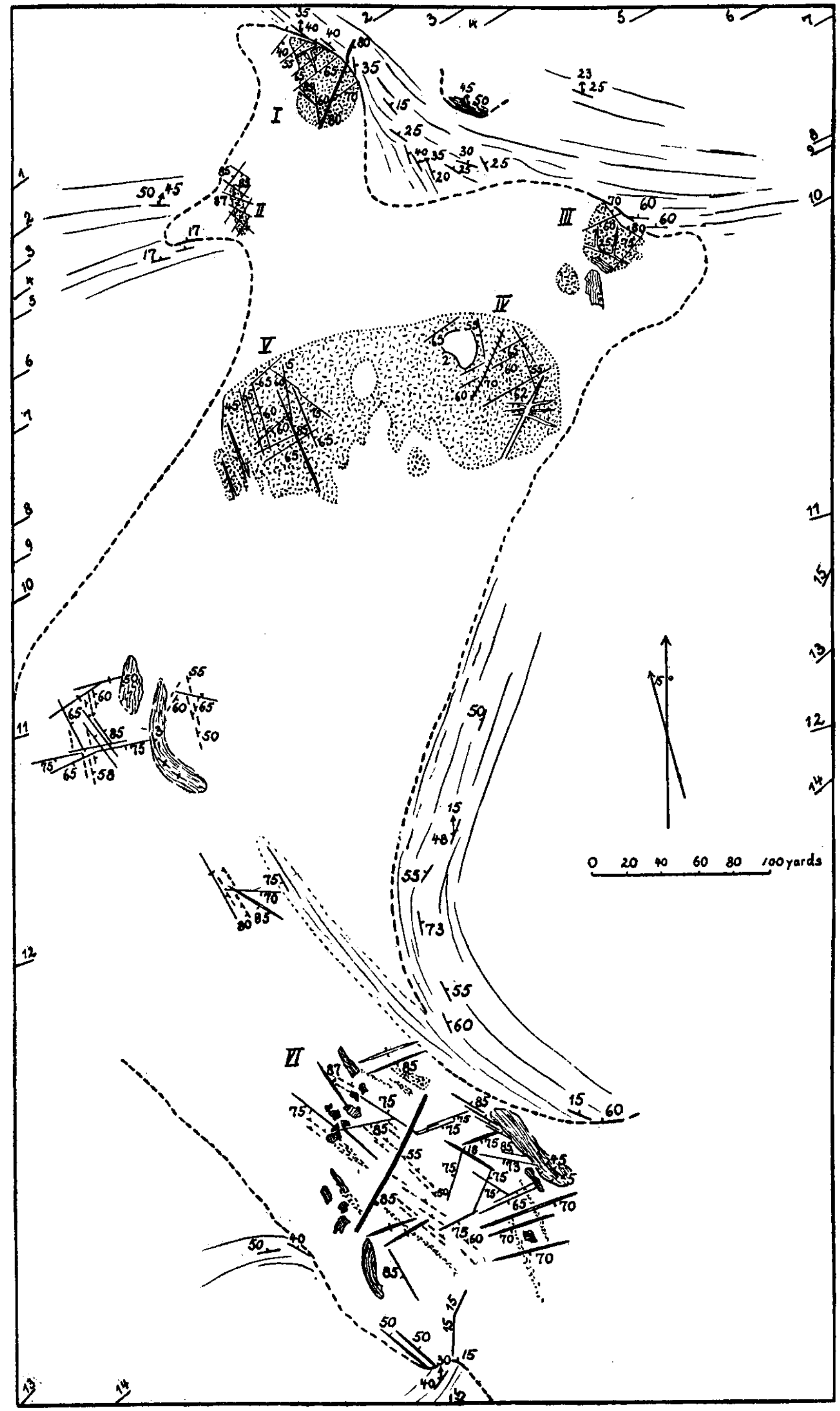
Toward the northwest and southeast the phyllite very soon descends along the slope until, in the east, the granite attains nearly the foot of the hill. Just there, however, the eastern contact is exposed again.

A highly contact-metamorphosed, black phyllite may be studied in a group of ledges in the forest along the eastern foot of Robeson Mountain (strike 115°-135°, 65° N. E. to 75° S. W.). Having disappeared for a short distance under the dumps from the quarries, it appears in fine exposures in the "Gray Granite" quarry of the Woodbury Granite Co. The granite overlies the country rock along a very flat-lying contact plane which runs slightly up and down and dips as a whole somewhat southwest. The dip of the phyllite remains unchanged; the granite is impure and pegmatitic, and has caught up a few inclusions.

Thence northwest, ledges of schist are frequently found, but the contact is not exposed until on the northern foot of the mountain below the dumps of the old Thomas quarry. The phyllite here is cut off unconformably along a line of approximately northwest trend (strike of phyllite 75°-90°; 63°-85° N.).

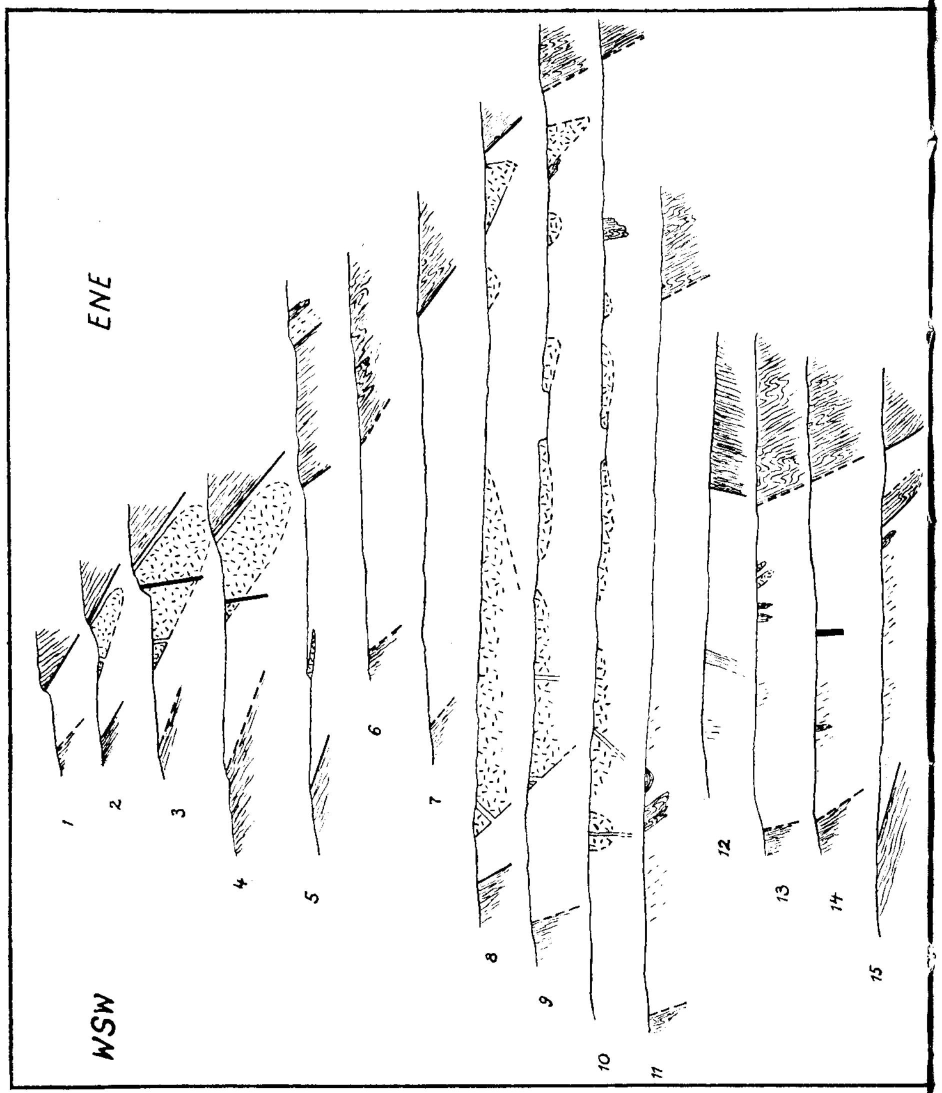
In general, the granite may be regarded as a steep block within steeply standing sediments. The flat-bottomed eastern contact seems to be only of local importance, or the granite may have slightly projected as a rather clumsy salient over the steep contact. Nothing indicates that the larger part of the intrusive

PLATE V.



Granite on the southwestern slope of Round Knoll, Woodbury. Dotted areas show basic granite, ruled areas phyllitic inclusions with the true orientation of the strike, dip, etc. In Quarry VI, double lines show quartz veins; narrow dotted zones are flow bands. The short lines on the margin, numbers 1-15 refer to the proper profile on Plate V-a.

PLATE V-a.



rests upon a flat sedimentary floor. However, the general uniform feature is interrupted by the appearance of numerous scattered schist exposures rather high up in the northern slope, unfortunately poorly exposed. As an alternative, it may be asked whether these may not represent merely inclusions of the common type, or last remnants of the country rock, which have been broken up, scattered and isolated by the merging of several granites of smaller size originally and independent origin. This latter possibility is supported by the rather irregular orientation of the parallelism in the granite and also by the field relations in the second intrusive where they are better exposed.

Round Knoll Granite.—The ground plan of this interesting granite, as a whole, has the form of a clumsy arch, open to the northeast (see Plates V, V-a).[1] Fine-grained, basic granite joins the light rock in constituting this intrusive, though the main granite prevails.

The Basic Granites.—Four or five single bodies appear, which probably have no direct connection with each other, but are surrounded by the main granite. They no longer are found at the site of their original intrusion, but in the same characteristic connection with the main granite, as described above from Barre.

The northernmost occurrence (lettered I on the map) is of oval or lenticular shape, 37 yards by 50 yards, the longitudinal contacts dip at 40° (in the northeast) or at 15° (in the west) to the east; compare the profile-series.

In the northeast the main granite invades between the dark granite and the phyllite as a narrow plate only a few feet thick cutting the sediments at an acute angle. To the north it pushes the older body away from the slate, underlies it in the west and cuts it in several long, straight dikes.

The second basic body (II on the map) is a flat lense of dark granite about fifty feet long and seven to ten feet thick, is overlain and underlain by the main granite along a flat contact plane. The same type of rock is represented in quarry III by several huge inclusions in the main granite.

The boundaries are straight and dip east. Here the main granite again separates the older predecessor from the contact plane and pushes the single parts farther aside.

The largest exposures are seen in IV. The dark, commercially valuable rock is traversed by a network of light granite. Evidence was found here that there are older aplites and pegmatites associated with the basic granite, which are cut by the younger granite.

[1] The outline map of Woodbury shows a slightly different general shape, since a few narrow phyllite zones could not be plotted. These are situated between several additional granite bodies farther northeast.

At the bottom of the northwestern part of this quarry the working has reached everywhere light granite.

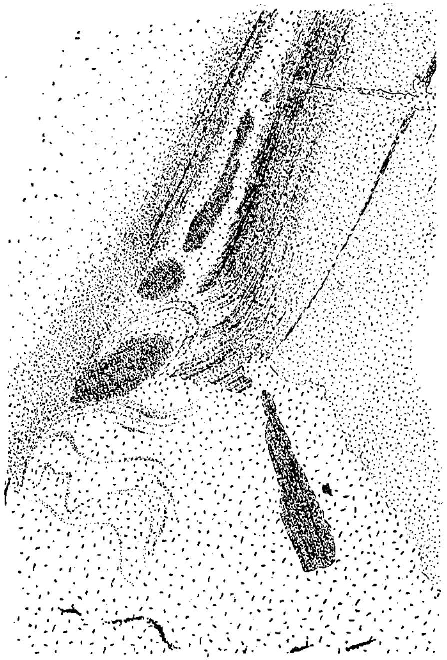


FIGURE 14.—Elusive undisturbed contact between dark and light granite, Woodbury. The micaceous minerals of the dark rock, which is slightly older, are frequently concentrated along the contact.

The flat boundary plane between both rocks zigzags along the quarry walls; it is partly a straight plane, but in places the main granite is seen penetrating the dark, overlying granite, displaying peculiar phenomena of mutual fusion and intermingling (see figure 14).

The main granite also appears *above* the dark rock so that the latter represents something like a flat or moderately inclined bale within the younger rock, increasing in thickness, apparently towards the northeast, since at the same depth, over there, the light granite has not appeared as yet.

A little farther east the fifth body is operated, which also is underlain by the main granite from the west. The contact dips 45°-60° east. A few large fragments and bale-like bodies dissected by light dikes terminate the exposure toward the west.

In the northwestern corner of the quarry VI, farther south, is found a significant exposure which displays very well the relationships of the two granites (see figure 15). The older basic granite appears as a large "schliere" trending northwest. The mica is noticeably concentrated along the edges where the rock ends in picturesquely shaped bands and thin, curved sheets. The rim of the basic granite is frequently surrounded by pegmatitic formations of the younger granite.

The older intrusive is repeatedly seen in original contact with phyllites and both appear as composite inclusions in the medium grained rock.

The basic granite appears for the last time far east, beyond

the limit of the map, seemingly as two very pure little bodies, the contact relations of which are concealed.

The Main Granite.—The medium grained and main granite, which surrounds and underlies its predecessors, has, as a whole, the form of a slanted plate or curved lense which dips northeast as shown by the contact and parallelism.

The *upper surface dips at average angles northeast* and repeatedly cuts off the phyllite. (Quarry I: northeast contact, strike 150°-175°, 30°-35° N. E.; phyllite strike 160°-10°, 40°-45° E. Unconformity at an acute angle. Quarry III: contact strike 130°, 40° N. E., schist 115°, 60° N. Quarry VI: contact strike

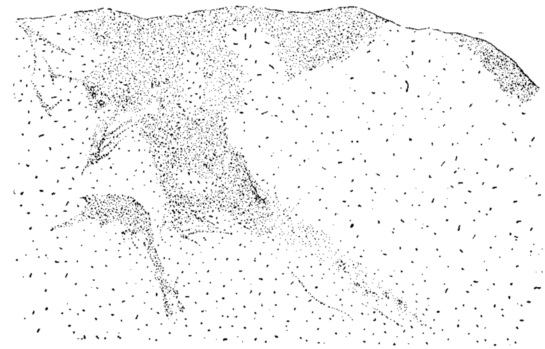


FIGURE 15.—Basic granite as irregular schliere in the main granite. Plane about 5x15 feet. Woodbury.

160°, 45° N. E.; phyllite strike 165°, 45° N. E. Unconformity at an acute angle along an oscillating plane. At the same place contact strike 105°, 60° N.; phyllite strike 130°, 15° N. E.)

The undersurface is exposed twice, dipping gently north and northwest, while the general inclination of the body is indicated by the foliation. (On the northwest end of the intrusive: Undersurface conformably on gently [17°] north-dipping phyllite [see figure 16]. At the southern edge of quarry VI, conformable, strike 50°-70°; 10°-30° N. W. This orientation [northwest dip] is a consequence of the peculiar folding which has caused warping of the beds not unlike corrugated iron. The axes of the folds dip gently north and the contact plane conforms to the surface of the beds.) Towards the western boundary of the intrusive, platyparallelism of eastern dip is repeatedly seen (strike 180°-20°, 55°-60° E.) and throughout the body numerous aplites and schlieren may be seen, which dip at different angles to the east (*e. g.,* strike 150°, 50° N. E.).

As regards shape and position, the main body imitates precisely its basic forerunners. In this respect this large, complex intrusive corresponds with those smaller formations which strew the flanks of the mountain, dipping northeast (see above). The curved bed of phyllite, southwest of quarry V, may be deemed, perhaps, a remainder of a schistose wall between two smaller

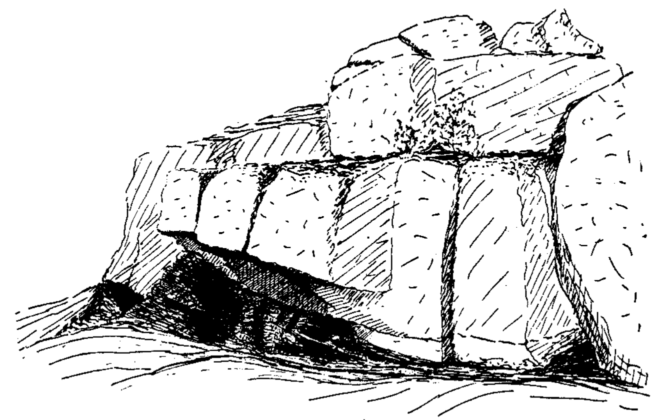


FIGURE 16.—Black phyllites underlying conformably the granite of Round Knoll intrusive.

granites which used to be independent. This explains the absence of basic bodies on the southeast (if one omits the small basic flow band in VI) and the different strike of the parallelism in each of the bordering bodies (see special map). The position of this phyllite belt accords perfectly with the general contour of the curved intrusive.

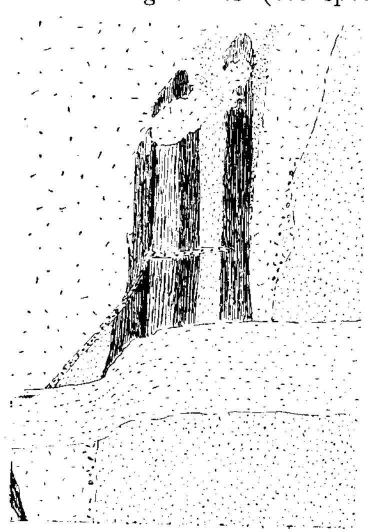


FIGURE 17.—Granite number four cutting the main granite (3) and injected inclusions. Quarry 1, Round Knoll, Woodbury.

The intrusive activity which introduced granite bodies (2 and 3 of the sequence of intrusion) displays as a whole a rather diversified picture. As compared with this the earlier and later activity shows very meager results. The dioritic rock (number 1), as mentioned above, has been found in place only at Nichols Ledge as a tiny, inconspicuous occurrence. Granite number 4 appears only in quarry I, Round Knoll, as a dike in the main granite (see figure 17). It is here that the only two *basic dikes* can be studied. They

strike northeast-southwest. Other dikes of the vicinity have been described by Richardson (Bibliography 21, page 329).

Summary.—As regards the main intrusives, the following data seem well established:

I.—In size the granitic bodies are decidedly inferior to those in Barre; in only two localities, larger intrusives are found. These may have been formed by the coalescence of smaller bodies.

II.—Owing to the complex structure, strike, dip and folding of the country rock, the majority of the conformable, lenticular intrusives strike and dip in every direction. Not infrequently, the granites gather in groups, or swarms, of intrusives (west of Buck Pond, Round Knoll, etc.).

III.—The bedding planes of the phyllites here also represent the favored planes of entrance and movement of the magma; it advances even into limbs of folds and flexures, as east of Buck Pond and east-northeast of Robeson Mountain.

IV.—Unconformable contacts result:

- *a*—If the magma enters and follows joints or fissures instead of bedding planes.
- *b*—If zones of older disturbances or weakness of the country rock are followed.
- *c*—If the phyllites are complexly folded whereby the direction and mechanical reach of the bedding planes diminishes or even vanishes.
- *d*—After increased magmatic activity along primarily conformable contacts and probably due to glide movements of the single sedimentary beds next the contact.

The Internal Structure.—While the contact relations of the granites are diversified and interesting, the internal structure does not present any important features. Regular relations between joints and parallelism in particular are sought in vain in the smaller bodies. In the large intrusives, while there are sometimes regular systems of joints, the relation to the parallel structure is hidden nevertheless, as this is almost indeterminable in the extremely massive rock.

On the following pages no strict order has been attempted, but certain additional observations are given.

Parallelism.—The parallelism which often appears to be a platy structure (foliation), next to the contact planes, follows in the smaller bodies, more or less, the longest axis, either linear or platy, as seen in the long, narrow mass next to Buck Pond, as mentioned above. In the mentioned basic lense southwest of Round Knoll Mountain, the foliation runs parallel with the contact in a northwest direction (dip 15° N. E.). Compare, also, details in the special map of the Round Knoll intrusive.

Relation to Tectonic Pressure.—The outline map, consequently, shows almost any direction of the parallel structure and so the question arises whether or not the parallelism in this area is of any value for the determination of the tectonic stress. The northeast areal strike of the phyllite shows evidently an older folding pressure at right angles, N. W.-S. E. The northeastern direction of the two basic dikes is of little significance, since H. Cloos (Bibliography 7) has shown that their direction may be governed by tension joints in arches. Besides, the direction of an underlying conduit plane of the phyllite might be responsible. Under these circumstances a few observations in the Round Knoll intrusive seem to be important.

In quarry I of the special map the plane of the rift strikes northeast, 60°, at right angles to the contact. No parallelism is visible, but the differences of the planes are plainly felt. Corresponding relations are exhibited in quarry IV and, finally, the rock of an old quarry just east of VI is characterized by a conspicuous and extensive "rissigkeit" (*i. e.*, intensive penetration by minute cracks), which strikes northeast (55°-65°). Light and acidic flow bands run at right angles (140°, 75° N. E.), and the nearby contact strikes west to east (95°, 45° N.). As it is very difficult to explain the northeastward "rissigkeit" by magmatic forces, one might perhaps think of tectonic forces of a northwestern direction (compare the description of glide joints).

The imperfect development of the internal elements of the small intrusions is not surprising if we keep in mind the fact that the size and shape of everyone of them depends only on the casual structure of the surrounding phyllite. Since this is exceedingly confused, no uniform structures of wide extent can be expected. A few instances, however, should be given to show that the usual structural features tend to develop wherever the respective intrusive bodies are sufficiently large and uniform.

Examples: In the long granite body east of Buck Pond, parallelism strikes 45°-50°, cross joints run 130°, 75° N. E. Longitudinal and cross joints are very prominent at Nichols Ledge (see above). The porphyritic granite exhibits a conspicuous parallelism, W.-E. because the square feldspar crystals arrange themselves parallel to one another with the longest edge, while rhombic forms lie with the diagonal in the same direction. Inclusions, flow bands, and most of the minerals of the ground mass have this parallel structure (see figure 18). The rock is traversed by long joints which strike north (180°-25°, 85°-95°). These are frequently coated by acid dikes.

The *joint systems of Round Knoll intrusives* are unusual. Along the southwestern and western flanks joints appear, the strike of which accompanies the bending of the parallelism (N. W. to N. S. to N. N. E.). For instance, joints in the south strike 140°-150°; in the southwest, strike 160°; farther northwest,

the strike is 165° to 170° to 180° to 20°. It might be possible that in quarry I the longitudinal joints swing as far as 65° and then would be at right angles to the contact. On the other

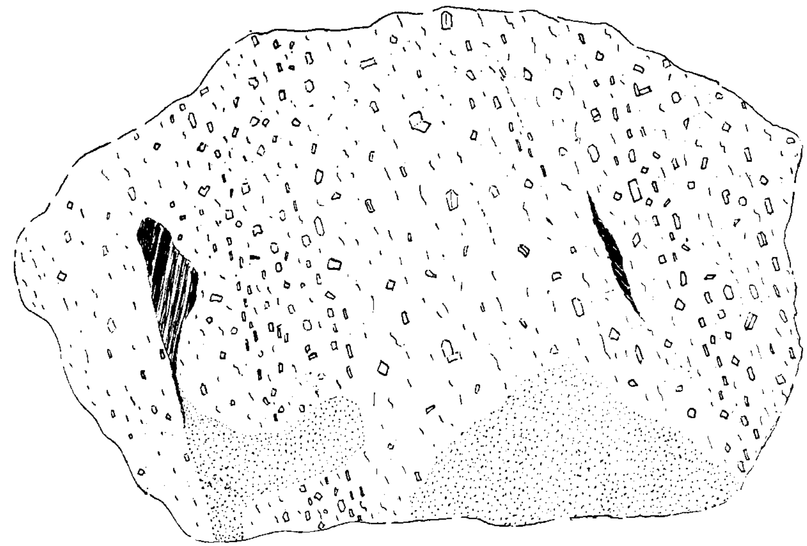


FIGURE 18.—Primary arrangement of the minerals and inclusives in the porphyritic granite of Nichols Ledge, Woodbury. Note the angle between the bedding and the longest axes of the inclusions.

hand, the prominent cross joints in quarry VI, in the south, strike 75°-90°, followed by long quartz veins; farther northwest the strike is 95°, 100°, 130°, 145°, 132°, 130°, 135°.

The relation between the strike and the parallelism is certain only in the south, while one can judge in the north and northwest only from the rift of the massive rock. If we consider the rift a reliable guide, then the longitudinal joints would run parallel with the contact in the south and in the north at right angles to it; the cross joints would arrange just opposite; in the north parallel, in the south at right angles, to the rock boundary, their strike at the same time, would suggest a fan spread to the west-southwest, the curving strike of the longitudinal joints would form something like an arc with the convex side towards the southwest or west.

MOVEMENTS ALONG JOINTS.

Glide Joints.—It is interesting that the same joints which were described as "Glide Joints" at Barre should appear in quarry IV at Round Knoll. They strike east-northeast, dip at average angles south-southeast and exhibit the same typical striæ of northwest strike, also overthrusts to the northwest were repeatedly measured. The quartz veins of quarry VI may be referred to the same system, though the striæ here are less uniform.

The particular combination of dynamic stresses which has led to the typical orientation and condition of the glide joints seems to have been present at Woodbury as well as at Barre, but their actual development may have been restricted to such intrusions as grew larger and were less hampered by the country rock.

It seems also that the striking similarity of these joints was caused in part by tectonic forces and *in both localities,* the overthrusts to the northwest favor *the assumption of an orogenic pressure which was directed actively to the northwest.*

Age of the Movements.—The movements along joints seem to be very old. The slickensides are cut by basic dikes.

Examples: The lamprophyre of quarry I, Round Knoll, traverses a long slickenside, strike 123°, 47° S.; striæ 180°, 40° S. The striæ continue on either side, but the dike is not affected. A few crush zones of northeastern direction, which is also preferred at Barre, are younger than the glide joints.

Acid Dikes.—A study of all other structural elements, such as dikes, schlieren, inclusions, planes of movement, etc., did not furnish any satisfactory results. There seems to have been but one intrusion, in two phases, which was followed by a few acid offshoots. These latter *increase with the size of the intrusive,* so that aplites are frequent in the long granite west of Buck Pond; in the granite of Robeson Mountain, Round Knoll and at Nichols Ledge. It seems not unlikely that the conduits to the larger bodies were more readily passable than those to the smaller intrusives. The bedding only follows the present surfaces, as it usually does, being merely a secondary phenomenon. It is particularly prominent on Robeson Mountain, where it forms a circular dome according to the circular contour of the hill.

Comparison of Woodbury, Barre and Bethel.—Having characterized the significant elements of the Woodbury area, we may proceed to a comparison of this district with Barre and Bethel.

The general appearance in the field and on the map of the Woodbury granite, differs from the intrusives at Barre and Bethel and seems to be accounted for by the country rock rather than by the intrusion of the granite. In each area, the magma follows essentially the same planes of movement and expansion, *i. e.,* bedding planes, joints, cleavage planes and at Woodbury older disturbances and flexures. At Barre and Bethel the balance of the counteracting magmatic and orogenic forces is represented by large intrusives which are separated by intact and regular, though bent and contorted, belts of country rock. At Woodbury, however, the granite appears to be much more dependent on the wall rock. Where the latter lies regular for long distances, the intrusives are uniform, parallel, conformable. But when the slates have been compressed into short, irregular blocks and complex folds, the granite has apparently lost its long, straight conduit planes, so that the magma is forced to follow the remaining plane fragments, short and unfavorable though they are, as the only alternative. It was evidently unable to destroy the weakened structure of the country rock.

Any evidence which may point conclusively to the presence of a large subjacent mass has not been found. Only the Round Knoll granites seem to have had a common root-zone in the northeast. A subjacent reservoir which furnished the uniform rock material is by no means improbable. But how deep it lies, how large it may be, what are its relations to the country rock, all these questions are unsolved and cannot be answered by field observations in this area. They are, therefore, a matter of theoretical consideration.

As another consequence of the scattering of the magma in many small intrusives, *the formation of structural arches is wanting,* which is found in the Barre granite.

As we have endeavored to show, the principles of the mechanics of intrusion are the same in both areas. This seems strong evidence that in either case, the magma has played merely a passive rôle. On the other hand, this is an example of how many forms may be produced by the same structural principles.

GENERAL CONCLUSIONS.

A few questions of more general character remain to be considered briefly.

Relations of the Three Granites to the Folding.—The descriptions of the Bethel, Barre and Woodbury granite areas have shown that the different intrusives were not affected to an appreciable amount by subsequent folding. The evidence of this is as follows:

1. The primary mineral structure is undisturbed.
2. The contact planes are distinct and sharp.
3. The inclusions exhibit angular, clear contours.
4. The typical internal structure of the granite.

On the other hand, the present intrusives recall gneissoid granites, *i. e.,* such as were affected by primary folding simultaneously with the intrusion (Bibliography 4; 13, p. 253) in having conformable, oblong ground plans and being prone to concordant platy schistosity. The decisive reason for separating the granites from the latter group is the *entire absence of "lit-par-lit" injections of the magma into the phyllite.* If there is any rock inclined to favor this kind of injection, it is the slates of widely straight and uniform orientation, splitting readily into thin layers.

The numerous pegmatites, on the other hand, indicate clearly *that we have to deal with a magma of at least normal gaseous composition.* Attention should be called also to the numerous exposures where phyllitic beds are cut by the contact plane at a very acute angle; they suggest strongly a purely mechanical "wearing off" of the sediments by the magma. The country rock appears as a solid, resistant block, whose single layers are drawn out and worn off rather than followed by the granite. The latter was evidently unable to penetrate the country rock in such an intimate way as the gneissoid granites do.

This coincidence of various characteristic features seems obscure unless we accept the interpretation that in the case of the lit-par-lit injections *the single beds of the country rock acted as planes of gliding, shearing, and differential movements during contemporaneous folding* (Bibliography 4, p. 58, 116). In the present case, however, we are concerned with magmatic bodies which were inserted into a static, brittle system where no contemporaneous or subsequent folding occurred. Hence the characteristically different features. As to static and kinetic metamorphism compare V. M. Goldschmidt (Bibliography 14), O. H. Erdmannsdörffer (13), P. Niggli (18).

Another question may be asked: What is the meaning of the present characteristic appearance of the Vermont granites? Are the long, straight contact planes of the single bodies also planes of movement along which larger blocks of the country rock have been moving against each other? Unfortunately, the uniform condition of the phyllites did not admit a decision of this question, though nothing has been found against this assumption. Should it be found that the granites lie in zones and planes of weakness and movement, it would not only unite the preceding folding with the igneous intrusion, but would better explain the structural position of many intrusives which, as such, manifest so surprising a dependency and passivity.

The internal structure of the granites corresponds very closely with European instances. This was not expected. For instance, the granite of Bethel is only thirty miles distant from Ascutney Mountain, the intrusives of which, according to R. A. Daly (Bibliography 12) worked their way upward as batholiths. The only varying element is "streckflächen" (Bibliography 6). As seen in figure 11c, and as found at Woodbury and Bethel, even the earliest movements and displacements ran at right angles to the parallelism, N. W.-S. E. The purely magmatic doming and rising of the intrusives is represented only by the dome-shaped streching at Barre and was not found at Bethel or Woodbury. It seems to have been dominant in large bodies only. The stage of the formation of the "streckflächen" is represented in these areas by glide joints.

The northwest overthrusts are considered to be resultants

of a magmatic upward doming and a tectonic tangential force acting from the southeast. Combinations of this kind have not yet been found in Europe, but the small size of the Vermont intrusives, their narrowness at right angles to the mountain-making movement may account for stronger influence of the tectonic pressure in the present areas. And, finally, an earlier introduction of the intrusives after the main folding may be considered.

The Downward Continuation.—As the direction and dip of the single intrusives, as they disappear downward, depends upon local structures of the wall rock, the exposures do not afford any evidence of the true character of the downward continuation, nor is it likely to be found among the phyllites. The complex of the underlying pre-Cambrian gneisses would probably show this. Many of the New England granites appear within gneisses and are probably of the same age as the described intrusives. The massif of Ascutney Mountain, for instance, appears along the boundary of gneisses and phyllites. No attempt has been made by the writer to follow the Vermont granites into gneissic areas.

Relations of the Granite to the Regional Rock Structure.—The bulk of the Vermont granites lies in a north-south zone which can be traced from the Canadian boundary south to Brattleboro. The three areas investigated in this paper are links in this series of intrusions. It is interesting that in every district unmistakable evidence was found of a tectonic pressure that was directed towards the west or northwest, and that the magma itself has been notably affected by it. Movements in this direction are most significant features of the Appalachian Mountains (Bibliography 2, 3, 16, 19, 20, 22, 24).

A little to the west from the described areas runs the great St. Lawrence and Champlain disturbance, which in an approximately southern direction, can be traced from Canada through Vermont, New York, far into New Jersey, and has been repeatedly described as an overthrust to the west.[1]

The three granite intrusives appear, therefore, to have originated under a westward directed regional tectonic stress, after the main folding, and seem to represent the final stage of the general diastrophism. The location of these granite masses shows relations to important zones of disturbance of the country rock. It seems not improbable that the Champlain overthrust is accompanied eastwards by a parallel zone which gave rise to most of the Vermont granites.

BIBLIOGRAPHY.

1. Balk, R. 1925. Primary Structure of Granite Massives. Bull. Geol. Soc. Am., Vol. 36, pp. 679-696.

[1] Bibliography, Perkins, 19, p. 68; Berkey, 2. Compare also Cushing and Ruedemann, N. Y. Museum Bull. 169, p. 107-115.

2. Berkey, C. P. 1919. Geology of the West Point Quadrangle. N. Y. State Museum Bulletin, 225-226.
3. Chamberlain, R. T. 1910. The Appalachian Folds of Central Pennsylvania. Journal of Geology, Vol. 18.
4. Cloos, H. 1920. Geologie der Schollen in schlesischen Tiefengesteinen. Abh. d. Preuss. Geol. La.—Anstalt, N. F. Heft 81, Berlin.
5. Cloos, H. 1921. Der Mechanismus tiefvulkanischer Vorgänge. Sammlung Vieweg, Heft 57, Braunschweig.
6. Cloos, H. 1922. Der Gebirgsbau Schlesiens und die Stellung seiner Bodenschätze. Berlin, Bornträger.
7. Cloos, H. 1925. Finführung in die tektonische Behandlung magmatischer Erscheinungen (Granittektonik). Berlin, Bornträger. Part I, Das Riesengebirge in Schlesien.
8. Dale, T. N. 1894. On the Structure of the Ridge Between the Taconic and Green Mountains in Vermont. 14th Ann. Report, U. S. G. S.
9. Dale, T. N. 1902. Structural Details in the Green Mountain Region and in Eastern New York. Bulletin 195, U. S. Geol. Survey.
10. Dale, T. N. 1914. The Commercial Marbles of Western Vermont. 9th Report, Vermont State Geologist, Burlington, Vt.
11. Dale, T. N. 1923. The Commercial Granites of New England. Bulletin 738, U. S. Geol. Survey.
12. Daly, R. A. 1903. The Geology of Ascutney Mountain. Vt. Bulletin 209, U. S. Geol. Survey.
13. Erdmannsdörffer, O. H. 1924. Grundlagen der Petrographie. Stuttgart.
14. Goldschmidt, V. M. 1912. Ein Kambrisches Konglomerat von Finse und dessen Umwandlung. Vidensk. Skrifter I, Math.-nat. Klasse, Nr. 18, Kristiania.
15. Heim, Alb. 1885. Handbuch der Gletscherkunde. Stuttgart.
16. Keith, Arthur. 1923. Outlines of Appalachian Structure. Symposium on the Structure and History of Mountains. Bull. G. S. A., Vol. 34, Part 2.
17. Leith, C. K. 1923. Structural Geology. New York.
18. Niggli, P.–Grubenmann, U. 1924. Die Gesteinsmetamorphose. Berlin, Borntraeger.
19. Perkins, G. H. 1912. A General Account of the Geology of the Green Mountain Region. 8th Report, Vermont State Geologist, Burlington, Vt.
20. Pumpelly, R., Wolff, J. E., and Dale, T. N. 1894. Geology of the Green Mountains in Massachusetts. Monograph XXIII, U. S. Geol. Survey.
21. Richardson, C. M., Brainerd, A. E., Jones, D. J. 1914. The Geology and Mineralogy of Hardwick and Woodbury. 9th Report, Vermont State Geologist.
22. Van Hise, C. R. 1896. Principles of North American pre-Cambrian Geology. 16th Ann. Report, U. S. Geol. Survey, Part I.
23. Whittle, C. M. 1894. The General Structure of the Axis of the Green Mountains. Am. Journal of Science, Vol. 47.

THE SURFACE CHARACTERISTICS OF ASTROCYSTITES (STEGANOBLASTUS) OTTAWAENSIS.

GEORGE H. HUDSON.

ABSTRACT.

All thecal plates of the two best preserved cotypes of *Astrocystites (Steganoblastus) ottawaensis. Whiteaves*, save those of the tegmen, are illustrated in such a manner as to present not only the first analysis of the species, but also the varied ornamentation of its plates. The origin of this ornamentation is suggested, the presence of papule-pores and spiracles demonstrated, and the species shown to be an interesting example of a transition stage between a primitive form of papular respiration and the highly specialized respiratory mode of the Eublastoidea.

This unique species, from the Trenton (Curdsville) of Ottawa, Canada, is known only through three specimens. In this respect its rarity of preservation, in a more or less complete form, is closely paralleled by *Blastoidocrinus carchariaedens* of the Chazy formation, of which but one nearly perfect and three partially complete thecae are known. These two species are of exceptional interest because of neither has there been found any ancestral forms in earlier formations, descendants in later formations or near relations in any formation. Each species is the sole representative of its genus, of its family, and possibly also of its sub-order. Such examples of "Splendid isolation" are almost without parallel and deserve more than usual attention.

B. carchariaedens was a lover of comparatively clear and shallow waters. Living or dead, it furnished food for other denizens of Chazyan times and thecae not separated by digestive processes became the playthings of breaking seas and were thus disintegrated before the accumulation of sufficient sediments to secure their complete preservation through burial. Concerning the separated ossicles of this species Billings has said (2, p. 19),[1] "In many localities they constitute almost the whole of the ingredients of beds of solid rock, of from six inches to three feet in thickness." Its vertical range, on Valcour Island was through some 500 feet or more of sediments and its geographical range extended over large portions of both northern hemispheres. The species is, therefore, represented in the fossil state by count-

[1] The introductory number—in this case "2"—in the parenthetical references refers to the corresponding number in the bibliography at the close of the article.

less millions of individuals whose separated deltoids and star-like tegmenals are, thanks to Billing's figures, easily recognized, and though but a single nearly complete specimen (3, Plates 1-3) has as yet been recovered, its separated ossicles have become horizon markers of great economic value.

A. ottawaensis probably lived under somewhat similar conditions in Curdsville times and no doubt flourished over an extended territory. No analysis of the species has been illustrated, yet separate deltoids, radials, basals, tegmenals and even cover plates should be easily recognized (after proper illustration and description) and the species thus possibly become a concise and valuable marker for a Trenton horizon. This should be a sufficient reason for presenting its thecal characteristics in detail. The species, however, is one of unusual morphologic importance and the search for its separated ossicles would no doubt result in a clearer insight into its ancestral forms and, unless it was a very ancient example of a paleozoic "Persistent type," might result also in the finding of some of its nearer relatives.

ANALYSIS.

Plates VI and VII contain, save for the tegmenal region a complete analysis of the cotypes of *A. ottawaensis* which Bather designated as specimens "A" and "B" (1, p. 194). These plates are reproduced from photomicrographs, each of which were taken through gum-mountings (7). Because of reduction from the original ten diameter enlargements some of the sutural details are lost (8, plates 1-4), but these are restored by inked lines. The intensified plate boundaries will obviate the need for any formal textual description of plate outlines. As a scale accompanies these plates, measurements of ossicles will not be given. For details of the tegmen see Bather's four and eight diameter drawings (1, p. 200-201).

The surface ornamentation of the plates of *Astrocystites* is unique and when once seen in detail is not likely to be forgotten. It consists largely of peculiar dendritic groovings, and of innumerable spine-pits which occupied all the more exposed surfaces, save alone the immediate borders of the ambulacral areas, or along that narrow fringe which supported the brachioles.

SPINE-PITS.

The spine-pits, accepting Bather's interpretation of these features (1, p. 197), are shallow circular depressions attaining a diameter of .3 mm. on older portions of plates and decreasing to a diameter of .05 mm. on younger portions. The older spines were placed about .4 mm. apart and the smallest about .015 mm. apart. With very few exceptions the diameter and closeness of the pits

may be used to study the relative rate of extension of plate borders and to obtain a record of change in plate form with age. The older cover plates are unusually long and heavy. Some of these ossicles, Plate VIII, figure 1, have preserved 20 or more spine-pits. The largest of these occur midway of the length of the plate and close to the sutures which separate the members of a series (8, Plate III). They gradually grow smaller both toward the deltoid edge and toward the medial zig-zag suture of a covered ray. The spine-pits on one edge seem to be arranged opposite those across the common suture. Between these marginal rows a few additional pits occur. Thus an old cover plate may have carried as many as 25 spines on its surface. Their story of cover plate growth proclaims marked lengthening at both ends and but little widening in a radial direction. From counting of fairly well preserved areas we may find that the distribution of spines on a single individual was somewhat as follows:

On orotegmenals	500
On cover-plates	3,000
On deltoids	3,000
On radials	1,500
On basals	600
Total	8,800

As many spine-pits have been lost, we may call 10,000 a fair estimate of the number of spines carried. *A. ottawaensis* was thus a veritable burr in Curdsville seas. That the number of spines has not been over-estimated may be easily shown by computing the surface area of an 18 mm. diameter specimen and giving it a fair average of 12 spines per sq. mm.

Aside from plate form and the characteristics of spine arrangement, the balance of the ornamentation of *A. ottawaensis* was due to the kinds and number of pores which penetrated to the interior of the theca. For specimens "A" and "B" we may tabulate these as follows:

Hydropore	1
Anal-pore	1
Brachiole-pores—about	300
Spiracles, reduced during individual development from about 150 to	25
Papule-pores, similarly reduced to about	75

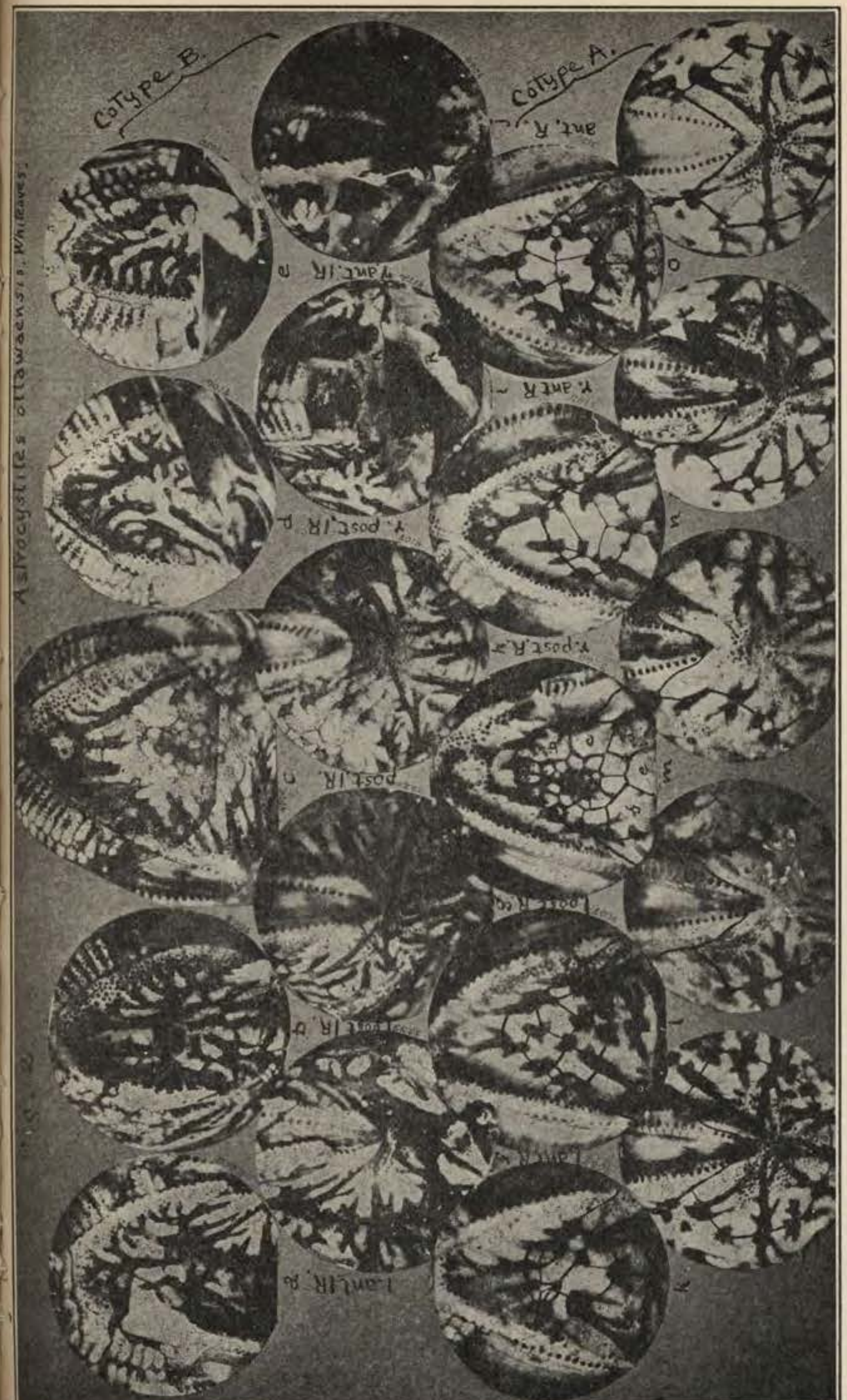
HYDROPORE-MOUNDS.

The hydropore of specimen A is shown in Plate VIII, figure 3. There it appears as a very distinct, meridionally placed line about 1 cm. long. In specimen B, Plate VIII, figure 1, the line is quite different (8, Plate III) in form and about twice as long. In the reproduction this line has lost some of the clearness of the photomicrograph, but through the use of a stereoscope (5) it may still be followed. Its aborad third forms a well shaped "S," connecting above with a right-angled middle portion, which opens toward the left as if influenced by the large spine-pit, and is then continued orad as a sinuous line twice gently concave toward the right. This line differs widely from Bather's drawing, both in form and position (1, p. 200, and 8, Plate III, inset). The very definite mound surrounding a hydropore will distinguish a posterior deltoid from the others.

ANAL AREAS.

In Plate VIII we show the posterior interradial group of ossicles of specimen B. It will be of interest here to note that even the periproctals bore spines. This plate also demonstrates the great advantage of mounting under gum and cover glass if minute detail is required. In this area Bather (1, p. 196) found "Seven plates converging to a point, where doubtless was the vent." The ossicles bearing numbers 1, 5, 9, and 10 are not themselves pointed and neither do the circumanal plates converge to a point, but they surround a crescentic depression still filled with matrix. The ossicles 1, 2, 3, 4 border the outer, orad limb of this crescent. Ossicle 12 thrusts an angle between 3 and 4. It is possible that ossicles 1 and 2 are parts of a fractured plate, but the line of matrix from the hollow would indicate that they were separate plates. The circumanal plates seem, therefore, to have been ten instead of seven. Bather (1, p. 196) surrounds his "seven" with "about fifteen other periproctal plates" making twenty-two plates in all. In our plate, however, there are 31 numbered periproctals. Number 9 is plainly fractured and the two parts have been counted as one. Surrounding the small periproctals is a circlet of 9 larger plates marked with letters.

In cotype A, Plate VI, m. it may be seen that the plates of Post. IR differ rather markedly from the arrangement just studied. On the left-hand side of the outer circlet they are smaller and the number is twelve instead of nine. On examining figures m, q, and r of Plate VI and l, m, and r of Plate VII it will be seen that the interradial area has apparently crowded two of its plates into the suture separating l, post R., and r. post R. This indicates an original 14 plates for the outer circlet unless we choose to consider the extra plates as remnants of an earlier thecal condition. No attempt has been made to clean the deeply sunken central area. In both cotypes may be noted the tendency to produce fewer and smaller plates orad of the anal pore. This seems to indicate a tendency toward achieving a more orad position for the latter.



Astrocystites ottawaensis Whit.

BRACHIOLE-PORES AND SPIRACLES.

Brachiole-pores may be clearly seen in Plates VI, VII, and X (and in 8, Plates I-IV). That they pass to the interior of the theca will be demonstrated in a future paper on ray-structure. The finding of separated deltoids would yield valuable evidence as to whether the deltoid was really fused to the floor plates and whether or not it extended under them to meet a neighboring deltoid along the clearly shown median suture of a ray floor. Ray sections indicate such fusion and indicate also that the deltoid was either fused to a lancet plate, involving paired or double lancets for each ray (bilancets), which supported the floor plates on their upper lateral margins; or else fused to greatly thickened floor plates which were extended medially during growth and also fused with each other along the common sutures of a series. In addition to a determination of these points, a separated deltoid would show the sinuses caused by the spiracles and possibly also the traces of earlier hydrospires on the under side of their more orad portions (kataspires), and possibly of anaspires (6, p. 165) on the inner surface of their younger, wing-like extensions. The finding of a single well-preserved deltoid would throw much light on important morphologic details of structure. The recognition of these plates by collectors holds promise, therefore, of a marked advance in our knowledge of pelmatozoan morphology and phylogeny.

The external appearance of a spiracle which has been nearly cleaned of its matrix is shown in Plate X, figure 1. It lies between two interradials, see Plate VI, m., and the deltoid wing. The sinus left on a deltoid by such a spiracle would be an unmistakable characteristic and besides its opposite on the other wing there would also be three or four sinuses lying between them (8, Plates I-IV). This arrangement is absolutely unique and represents a midway stage between *Blastoidocrinus* with its 75 or more spiracles on its aborad margin (5, Plate III) and the single pair which have pushed orad on the lateral margins of the deltoid in *Pentremites*.

PAPULE-PORES AND DENDRITIC GROOVES.

The dendritic figures deepen, at first very gradually and then rather abruptly, as they approach the sutures, and on the suture itself they penetrate to the interior of the theca through pores which we shall consider as papule-pores.

In substantiation of the above statement we first call attention to Plate IX, figure 2. On the right-hand edge of the hiatus caused by splitting of the calcite, the extreme shallowness of the groovings is in remarkable contrast with the great thickness of the basal and the figure negatives the idea of any primitive folding of the

PLATE VII.

Astrocystites ottawaensis.

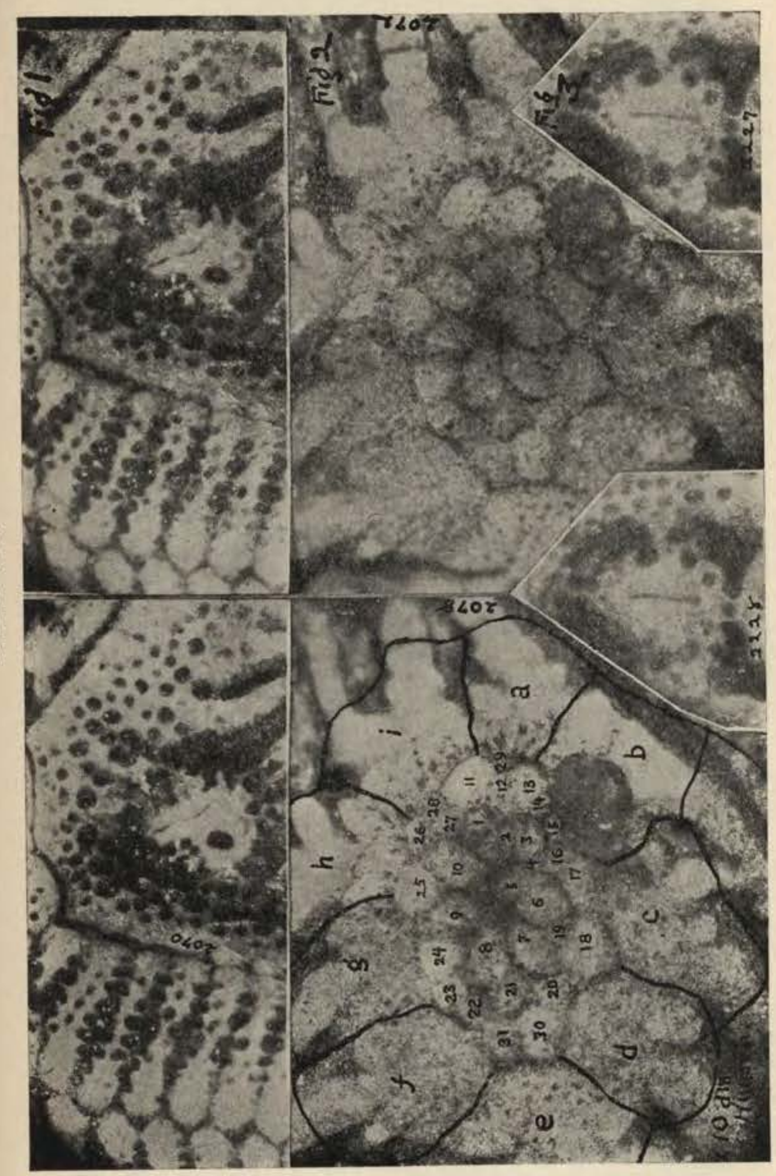
plate stereom as a cause for these features. On the opposite edge, or nearer the sutures, the groovings are seen to be deeper. For a true conception of the conditions here revealed the use of a stereoscope is a necessity.

Secondly, we may notice the left edge of l, post. R as shown in Plate IX, figure 1. The crushing in of l, ant. R., as revealed in Plates VI and VII, left this edge of l, post. R clearly exposed for study and a careful examination of it will further prove our statement. It was probably this plate that was the cause of the not very erroneous representation of a radial with a waved edge which was used by Whiteaves in illustration of his species. As, however, the dendritic figures, usually approximating a bilateral symmetry have their two halves exactly opposite each other, the waved edge of one plate would so meet its neighbor as to leave pores between their margins. In our Plate E the 10 diameter enlargement of a portion of the radial referred to is viewed somewhat edgewise and, therefore, the extensions of the plate between the entering pores of the dendritic figures is not so apparent as it would be in a more nearly vertical view. On the other hand, the angle of view does not show fully the sutural faces of the plate, but it shows enough to demonstrate the fact that the matrix of the filled pores, opposite the arrow points, did cross the edge of the plate and connect with the interior. The true condition of this edge will be better appreciated if a Holmes' stereoscope, with carrier removed, be used in its study.

To make the evidence for papule-pores still more convincing we show, in Plate X, figure 2, a stage in the sectioning of the ray of r. ant. R. of cotype B. where three pores are shown in section. The arrows of the figure all rest on internal portions of the theca. The cut through the two lower pores gives diagonal sections, the left-hand portions of which are still over the thinned inner edge of a radial. The cut through the upper pore is nearly vertical. Note that the dark lining, on the underside of the radial, connects with this pore. Note also the evidence for an internal plexus of tubes just back of the arrows. The projecting portions of the lower pores, on reaching the interior, suggest connections with the plexus. A stereoscope, to add an apparent third dimension, should be used with the plate.

Note also in this figure that we have a section through the inwardly thrust ant. R. The inner surface of both radials is remarkably uniform and smooth. The grooving of the exterior is seen to have nothing to do with any "Deep folding of the plates." The details of a series of sections of this ray will be given in a future paper.

PLATE VIII.



Astrocystites ottawaensis.

ORIGIN OF THE DENDRITIC FIGURES.

A comparison of these figures with each other yields interesting results. On the five basals of the lower row of figures of Plate VII we can find no duplicate patterns and the same is true of the lower row of radials shown in Plate VI. In variety these figures run from simple pores as in Plate VII, "r." (upper left), to the complex patterns of "k"—but over the whole theca there is not a single duplicate.

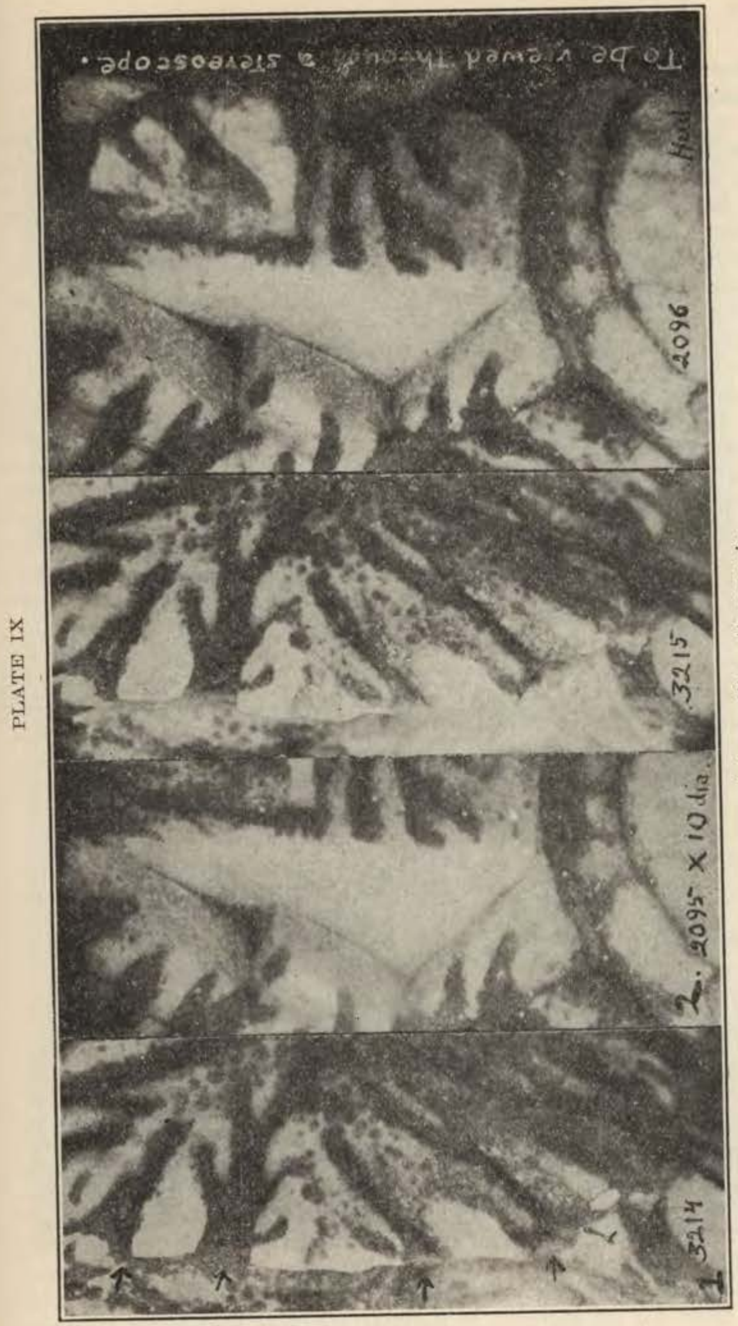
Compare next the similarly situated areas of different specimens as, for instance, the right-hand sides of the posterior basals in "h" and "r" of Plate VII. The difference is astounding. Take again the orad apices of the r. post. BB of same plate—one has no pore in this position, while the other has a pore with compound branches. Why should two specimens of the same species be so unlike in external ornamentation? Bather designated "specimen A" as the holotype—in specimen B do we have a different species?

With this great diversity of individual variation compare the tendency to symmetry of the parts of each figure which are separated by sutures. Why should the ossicles of *A. ottawaensis* seem to lack a fundamental or inherited plan of symmetry in ornament and, on the other hand, appear to be so susceptible to the influence of neighbors where side meets side. We have already seen the idea of stereom foldings negatived several times and here again this apparent freedom from any ancestral control also negatives Bather's idea that "In some cases it may be that the arrangement of the folds indicated rather the original constitution of the young individual (or of its ancestor) than any actual separation of plates in the adult" (1, p. 195).

Compare next the left orad shoulders of the r. post. BB of Plate VII. One is in contact with but three pores, the other with four. Cotype B has the longer sutures, is the older specimen, and presents the most complex figures. These figures increase in number and complexity with age. The older plates have not only added to the complexity of their earlier figures, but they have also started new ones, at the plate angles, of which *there could be no trace* in earlier stages of growth.

We have barely touched upon the testimony which these lately developed dendritic figures have to offer, but we have presented enough to show that, with the idea of ancestral stereom foldings out of the way, there are two other modes of formation which we may consider. Either the papules of *A. ottawaensis* forked on reaching the outer surface of the theca and these arms then branched to fill the new spaces produced by plate extension and thus formed an epithecal respiratory system protected by a forest of spines—or else as new papules made their exit at extending plate angles the older papules tended to approach each

PLATE IX



Astrocystites ottawaensis.

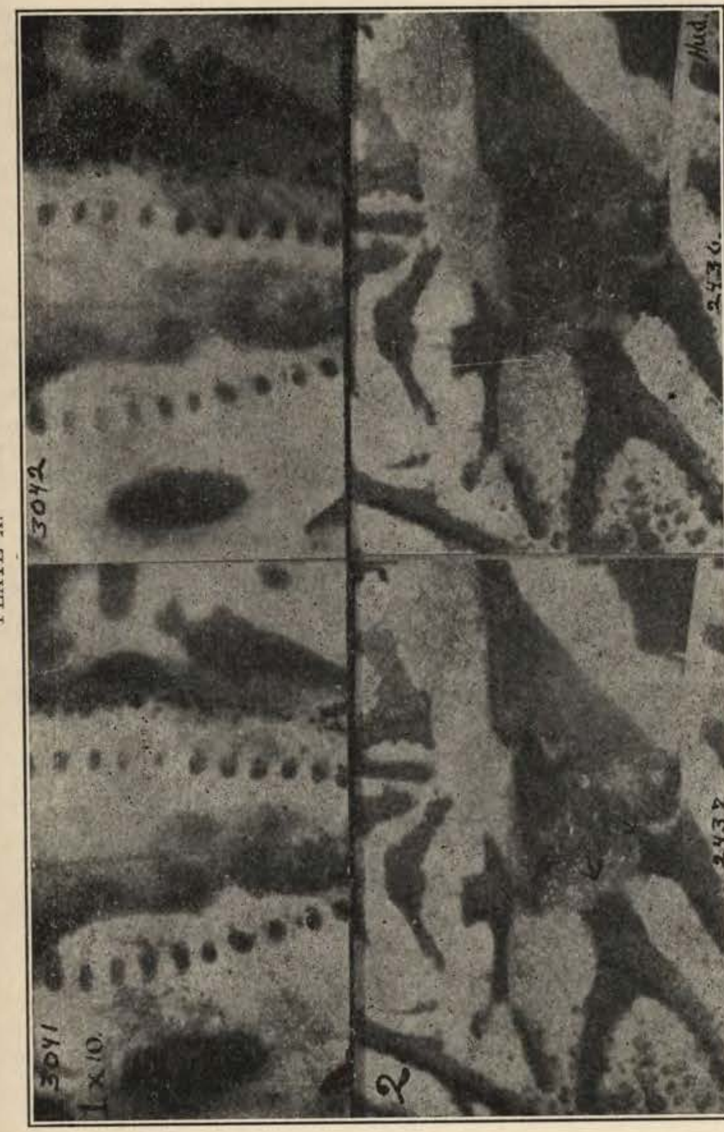
other and, grouped or fused, thus reduced the number of their exits.

Both hypotheses contain more less strange conceptions, but we are in a very strange field and the conditions are somewhat as they would be were we trying to explain two fossilized birds with a knowledge only of mammals, reptiles and amphibians. The second hypothesis seems to be the more simple and is in marked harmony with the evidence. The first papules to appear were at plate angles. As sutures lengthened, the plates met again beyond the papules and as the latter remained on the sutures there was a constant filling in of stereom back of them, though this was not built up flush with the plates' outer surface. The grooves so left became superficial features because of constant inner thickening of the plates. As new papules were added they moved toward more medial positions on the suture, but instead of maintaining a nearly uniform distance from the older papules as in *Palaeocystites, Palaeocrinus,* etc., they continued to approach them and their trails thus came to meet the older trails at acute angles directed toward the sutures. Here we have the commencement of a dendritic figure and a necessitated bilateral symmetry across the suture. The figures developing next to these would have a similar origin, after a pair of figures were thus started a continuation of each would require the projection of new sutured papules between the two. We have to account also for a few right-angled branches as in Plate VII at "t." The symmetry across the suture is presented in a remarkable manner, but in cleaning the specimen from matrix many of the dark fillings of shallower portions of the figures has been removed and much evidence lost.

Under the first hypothesis this primary bilateral symmetry would not be a necessity; there would be no necessity for the secondary symmetry of the halves of figures; no particular need for the acute angles directed toward sutures, and no need for appearance of new papules between older ones. For a study of the epithecal respiratory system of *Palaeocrinus,* see (4, pp. 218-237) and for a brief classification of respiratory systems in general, see (6).

In *Astrocystites* the papule-pores are from 1 to 2 mm. apart, while in *Palaeocystites* and *Palaeocrinus* they are but about half that distance and in *Cliocrinus perforatus* (4, p. 213, figure 2) they are frequently but 0.2 mm. apart. Reduction in number of plates and increase in their size means also increase of papule area if this type of respiration is to meet the demands of the species. We have seen, however, that *Astrocystites* was developing a very efficient system of respiration of a new type or that of passing the waters of brachiolar flow through hydrospires making exit through spiracles. There would then be less and less need for an increase in papular surfaces and a good reason

PLATE X.



Astrocystites.

for reduction of such area. Indications of such a tendency may be found—for instance there was a failure to form new pores next the columnals in figures "k" and "l" of Plate VII. It would seem that in *Astrocystites* we have an interesting stage in a phylogeny reaching out toward a respiration of the eublastoid type where papules were wholly dispensed with. We, therefore, account for the dendritic figures of the basals and radials in a manner very similar to that used (8, p. 652) in accounting for the orad and lateral dendritic figures of the deltoids. In both cases we have the expression of a tendency to make fewer pores answer the purpose of many.

Much is to be learned from tracing the development of individual plates of the cotypes through a study of their surface ornamentation, but it will readily be seen that the finding of even a few of the separated and partially weathered plates of younger individuals would add materially to our knowledge of this very interesting form. As in so many cases the ossicles of pelmatozoa are abundant where complete specimens of the same species are rare, it is not too much to expect that the desired fragments of *Astrocystites* will yet be found.

BIBLIOGRAPHY.

1. Bather, F. A. "Steganoblastus," *Geological Magazine*, N. S., Decade VI, Vol. I, May, 1914.
2. Billings, E. "Figures and Descriptions of Canadian Organic Remains," Decade IV. Montreal, 1859.
3. Hudson, George H. "On Some Pelmatozoa from the Chazy Limestone of New York," *New York State Museum Bull. 107*. 1907.
4. ———. "Studies of Some Early Siluric Pelmatozoa," *ibid., Bull. 149*. 1911.
5. ———. "The Use of the Stereogram in Paleobiology," *ibid., Bull. 164*. 1913.
6. ———. "Some Fundamental Types of Hydrospires with Notes on *Porocrinus Smithi*, Grant," *ibid., Bull. 177*. 1915.
7. ———. "The Use of Gum Dammar in Paleohistology," *Ottawa Naturalist*, Vol. XXIX, December, 1915.
8. ———. "The Need of Improved Technique in Illustration," *The Journal of Geology*, Vol. XXXIII, No. 6, August-September, 1925.

THE STRATIGRAPHY OF THE TOWNSHIPS OF ADDISON, PANTON AND SOUTHWESTERN FERRISBURG, VERMONT.

III

EDWARD J. FOYLES.

INTRODUCTION.

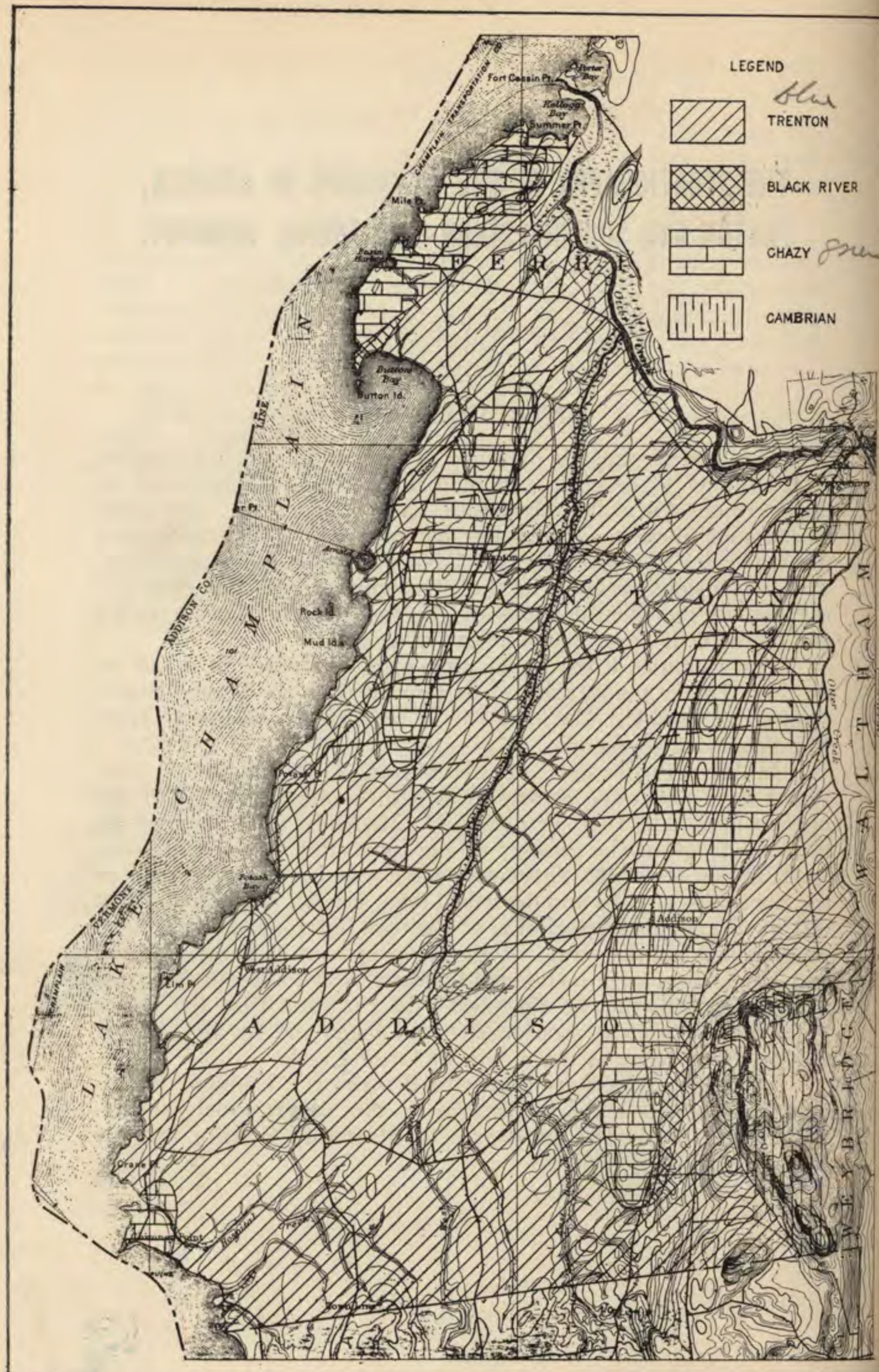
The present paper is the third in a series in which the writer is attempting to describe and map the geological formations of the Vermont townships bordering Lake Champlain. The work of mapping these townships has included a problem concerning the true ages of the rocks that have been called Beekmantown. The conclusions reached in the preceding papers necessitated a revision of the identifications of the famous Fort Cassin fauna and of the beds from which it was collected.

The localities listed in the title may be studied in detail on the Port Henry topographic sheet published by the United States Geological Survey. The area may be reached by automobile from Middlebury or Vergennes.

In 1861 Professor C. H. Hitchcock (10) mentioned occasional facts about the geological structure and the fossils of the present area. In 1910 Professor H. M. Seely (16) summed up the knowledge of the geology of the townships under discussion. In 1921 Professor C. E. Gordon (8) noted a few outcrops in the townships studied and described them briefly. In 1923 Gordon (9) gave a detailed description of the rock outcrops and structural relationships of the strata of the townships of Addison, Panton and Ferrisburg. He mentioned characteristic fossils proving the ages of the beds that he described. In 1923 and 1924 the writer (6, 7) described the stratigraphy and listed the fossils of Fort Cassin, Ferrisburg, at the mouth of Otter Creek.

I wish to express my thanks to Professor J. Edmund Woodman for his help in the preparation of this paper, which was accepted as a thesis for the degree of Master of Science in New York University.

PLATE XI.



Map of Addison, Panton and southwestern Ferrisburg.

STRATIGRAPHIC GEOLOGY.

CAMBRIAN.

In its entirety the Cambrian of Vermont is represented by several phases:

Potsdam quartzite		
Georgia slate		
Swanton conglomerate		
Williston limestone		Upper Cambrian
Shelburne marble		
Highgate slate		
Milton dolomite		
Colchester formation		
Mallett dolomite		Lower Cambrian
Winooski marble	Rutland dolomite	
Monkton quartzite	Chesire quartzite	

Of these divisions it is the Monkton quartzite only that is represented in the area concerned in this paper. This formation was formerly known as the "Red Sandrock," a term that included other beds than the quartzite itself.

In 1847 Professor C. B. Adams assigned the Red Sandrock to the Silurian, correlating it with the Medina sandstone. Dr. Emmons correlated the Red Sandrock with the Potsdam, and considered it to be conformably superjacent to the Taconic slate (Trenton shale) at Snake Mountain. In 1861 Mr. E. Billings noted the correlation of the Red Sandrock with the Medina sandstone and assigned it upon paleontological evidence to the Potsdam group. In 1867 Professor C. H. Hitchcock referred the Red Sandrock to the Potsdam group (5, p. 121).

The name Monkton Quartzite has been applied (11, p. 106) to a formation that shows much variation in color, ranging from white to yellow, brown, red and purple. The type locality is in the town of Monkton, where the relationship of the quartzite to the overlying beds is well shown. The formation is practically restricted in its outcrops to the west central and northwestern parts of the state. It is prominent at the present surface around Monkton, at Snake Mountain in Addison, at Buck Mountain in Waltham, and thence northward through Charlotte, Shelburne, Burlington and beyond; its last occurrence being in a small mass east of Highgate Springs.

Since this formation can only be seen to rest by thrust on Ordovician rocks along the shore of Lake Champlain at and near Burlington, its base is not known. In the southwestern part of Addison the most southerly exposure of the Monkton quartzite has been thrust upward to the west and now rests upon the black shaly limestone of the Trenton. The quartzite beds dip to the east, and their western faces form a high escarpment, known as Snake Mountain, overlooking the Champlain valley.

As one stands upon the top of Snake Mountain and views one after another the northward-reaching quartzite peaks with their sharp points and steep western faces, he sees most distinctly their geological character. The tough quartzite has resisted decomposition, and its ragged edges project pointedly to the west. The western face of Snake Mountain is the course of a great fault and is across the stratification, while the eastern slope is nearly conformable with it; and the east side of the mountain slopes gradually to the east because of the dip of the rocks.

At the top of Snake Mountain the strike of the rock is N. 20° E. and the dip 5° E. Here the Monkton quartzite has been uplifted until it is seven hundred feet above the level of the Trenton to the west, while at the south end of the mountain, four or five miles distant, it is much less elevated. The surface of the mountain falls off abruptly northward, probably indicating that there is a fault in the quartzite on the north end of Snake Mountain, separating it from Buck Mountain to the northeast.

Fossils are very rare in the Monkton quartzite, only obscure fucoids and worm borings, such as *Scolithus canadensis* Billings, having been reported from it (10, p. 338, figure 245).

ORDOVICIAN.

The following table of formations represents the relationships of the Ordovician sediments in Vermont as they are now understood:

Mohawkian group or Middle Ordovician:

- Cobourg .....*Fusispira, Hormotoma, Rafinesquina deltoidea.*
- Canajoharie ..*Graptolites.*
- Trenton .....*Prasopora.*
- Glens Falls ...*Cryptolithus, Parastrophia.*
- Black River...*Columnaria halli.*

Canadian group or Lower Ordovician:

Chazy:		
Valcour or Chazy C.		
Crown Point or Chazy B.	E	In part Cobourg?
Day Point or Chazy A.	D½	
Beekmantown.	D½, C	Beekmantown of Brainerd and Seely.
Tribes Hill.	B	
Little Falls.	A	

CHAZY FORMATION.

In the townships with which this paper is concerned no Ordovician rocks older than the Chazy were noted. In the area studied there are several exposures of the Chazy. Along the road running from Panton village south the Chazy rocks form a continuous outcrop for over two miles. *Spyroceras clintoni* (Miller) found in these rocks indicates them to be Middle Chazy. At Chazy, New York, the type locality of this formation, this species is found in the central dark limestone associated with *Maclurites magnus* (Lesquereux). The type of the species, which is in the American Museum of Natural History, is composed of fragments of two different species, for an inspection of the same after it had been taken out of its plaster packing revealed the fact that the anterior part is a fragment of a strongly annulated arcuate form, while the posterior one belongs to a straight, smooth form. The two fragments do not fit properly together. Only the anterior annulated fragment can be regarded as the type. To increase the troubles of this species, S. A. Miller in 1877 pointed out that Hall's original name, *Orthoceras subarcuatum*, was preoccupied, and substituted in its place the rather undesirable name, *Orthoceras clintoni*. It was placed in the genus *Spyroceras* by Dr. Rudolph Ruedemann (14, p. 566).

At Basin Harbor *Maclurites magnus* (Lesquereux), occurring in a fossiliferous, pinkish rock dipping 7° to 20° E., indicates the Middle Chazy. *Stromatocerium lamottense chazianum* Seely has also been found in the Middle Chazy of this locality.

At Adam's ferry, where the strike of the rock is N. 10° E. and the dip 25° E., there is an example of the conjunction of the Chazy and the Trenton limestones. At the waterfall at Vergennes the Chazy is faulted over onto the Trenton black shaly limestone. West of Vergennes the strike of the Chazy is N. 40° E. and the dip 50° W.

In Addison the Chazy may be seen at Chimney Point, where glaciated ledges dipping eight degrees to the northwest display cross-sections of fossil gastropods which are probably *Bucania* and *Maclurites*. The strike is northeast and southwest. There is some doubt in the writer's mind concerning the age of the rock at Chimney Point. Many years ago *Prasopora simulatrix orientalis* Ulrich was found at this locality, and the specimen is now in the American Museum of Natural History, catalogue number 637/6. It is labeled *Chaetetes lycoperdon* Say, but this species is not recognized. The writer observed in loose blocks of limestone at Chimney Point the Trenton fossils *Cryptolithus tesselatus* Green, *Dalmanella rogata* Sardeson, and *Prasopora simulatrix orientalis* Ulrich. Professor G. H. Perkins has collected *Isotelus gigas* DeKay a short distance north of Chimney Point. The

Chazy is exposed northeast of Chimney Point on the north bank of Hospital Creek.

From a point one and one-half miles south-southeast of Addison, fossiliferous ledges of the Chazy dipping five degrees east extend southward for a quarter of a mile. One and one-half miles north of the Bridport town line, on the road to Addison, there are ledges of Chazy. These Chazy outcrops under the shadow of Snake Mountain strike N. 46° E. and dip 25° S. E. They have yielded the fossils *Orthis, Maclurites* and *Orthoceras* (4, p. 413).

On the Addison-Panton town line, on the road from Addison to Vergennes, there is an old limekiln locality, where the Upper Chazy containing *Camarotoechia plena* (Hall) is represented by a coarse to a fine, light blue limestone dipping 20° S. E.

BLACK RIVER FORMATION.

In Addison some outcrops on the road north of Hospital Creek are suggestive of the Black River, but no fossils have been found in them. Two miles south of Addison and one hundred yards east of the road there are several outcrops that are assigned to the Black River on the evidence of obscure fossils that are thought to be *Columnaria halli* Nicholson. The Black River limestone west of the Snake Mountain fault has yielded *Columnaria* in great masses (4, p. 413).

One mile west of Panton village there are low ledges dipping east that are thought to be Black River, although no fossils have been identified in this rock. In Panton village, rocks of Black River age lie on the west side of the road north and south of the road to Vergennes. *Columnaria* has been found in boulders, but not in situ at this locality. One-half mile north of the village *Columnaria halli* Nicholson was collected from ledges of limestone dipping 20° E. Cross sections of cephalopods may be seen just north of the general store at Panton on the west side of the road.

At Button Bay, *Strophomena incurvata* (Shepard) has been found in the Black River formation. The specimens are in the American Museum of Natural History, catalogue number 597. On Button Island the strike of the Black River is N. 40° E. and the dip is 18° S. E.

The fossils found at Button Island are:

Stromatocerium rugosum Hall.
Columnaria halli Nicholson.
Phytopsis species.
Streptelasma corniculum Hall.
Streptelasma profundum Conrad.
Tetradium columnare (Hall).

Orthis pectinella Emmons.
Cycloceras olorus (Hall).
Spyroceras anellus (Conrad).

TRENTON FORMATION.

Beginning in Ferrisburg, two-thirds of a mile north of the Panton line, black shales dipping north contain graptolites and brachiopods. South of these are shales with limestone bands, which are followed by thin-bedded limestones yielding Trenton fossils and dipping north. South of these are massive, folded limestone beds that have been called Black River (9, p. 242), and that have at some places a westerly dip. South of these are strongly brecciated, massive beds containing obscure coils that suggest the Chazy, but that might also be called Trenton on the basis of their structural relationships. Southward the black shales of the Canajoharie appear, dipping south a short distance north of Arnold Bay and dipping north at Arnold Bay itself. At the Arnold Bay ferry landing the rocks dip 5° S. E. in a ten-foot ledge. At Button Bay the strike of the Trenton is N. 18° E. and the dip 15° W. At Vergennes *Diplograptus amplexicaulis* Hall has been found in the Trenton. The specimen is in the American Museum of Natural History, catalogue number 104⁄8.

In Addison the basal Trenton occurs north of Hospital Creek as fossiliferous, thin-bedded limestone weathering gray. The beds dip fifteen degrees west with a slight north pitch. North of these are interbedded dark limestones and shales of gentle westerly dip that have yielded graptolites. *Calymene senaria* Conrad and *Cryptolithus tesselatus* Green, two Trenton fossils, are reported from Chimney Point (10, p. 300), but this has been thought also to be a Chazy locality. The age of the Chimney Point rocks will remain uncertain until identifiable and critical fossils have been obtained from them. The Trenton beds, which yield *Prasopora simulatrix orientalis* Ulrich, continue along shore to Potash Bay. Along the Addison shore the strike is N. 45° W. and the dip 12° N. W. At Elm Point the strike is N. 32° E. At Cobble Hill the strike is N. 20° E. From Chimney Point northward the beds display an unbroken series of considerable thickness extending from the base of the Trenton well up into the shale formation. One mile southeast of Addison village, on the northwestern slope of Snake Mountain, there are beds of shaly limestone dipping 30° E. and striking N. 20° E. These beds contain characteristic Trenton fossils. The Trenton west of the Snake Mountain fault yields *Cryptolithus tesselatus* Green. These rocks have a strike east of north and dips 15°, 25° and 38° E. One-half mile north of the Bridport town line on the road to Addison there are shaly limestones with westerly dip containing characteristic Trenton fossils. One-half mile northwest of Addison there is an exposure of the Trenton shaly limestone.

CANAJOHARIE FORMATION.

The Canajoharie formation is exposed upon the shore of Lake Champlain from Arnold Bay to Button Bay. It consists at the base of shale which is succeeded by limestone above. This is followed by about 50 to 100 feet of transition beds of limestone, about two feet thick with soft black shale between. Four hundred feet or more of black shale overlie the transition beds. Together, these beds constitute the lower and upper parts of the Canajoharie.

This locality was visited and a collection of fossils made in 1899 and 1919 by Dr. Rudolph Ruedemann. In 1918 and 1919 the Reverend E. W. Gould of Bristol secured fossils at this place. The writer visited and collected fossils at the locality in 1925. Dr. Ruedemann at first identified these shales as Utica (13, p. 37). He later recognized them to be Trenton and concluded that there was no Utica shale in Vermont. In an article in the Twelfth Report of the Vermont State Geologist (15), Dr. Ruedemann has listed the fossils collected by himself and Mr. Gould.

COBOURG FORMATION.

The Cobourg facies of the Trenton may be the highest part of the Ordovician in Vermont and is characterized by a *Fusispira* and *Hormotoma* fauna. The Cobourg is typical at Picton, Prince Edward County, Ontario, and is applied to the heavy-bedded limestone with the gastropod fauna, and the underlying, thinner-bedded limestone with *Rafinesquina deltoidea* (Conrad) (12, p. 349).

The Cobourg fauna is possibly found in the two uppermost beds at Fort Cassin at the mouth of Otter Creek. These beds have been called Black River by the writer (7, p. 212), but further study has led him to believe that they may be still younger in age. They are composed at the top of three feet of dolomite weathered yellow, underlain by six feet of black siliceous limestone.

At the close of Cobourg time the sea withdrew entirely from Vermont, and we find no deposition of sediments for vast ages. It was not until the Pleistocene that the Champlain clays were deposited by an arm of the sea extending southward from the St. Lawrence.

PLEISTOCENE

CHAMPLAIN CLAYS.

In the Champlain basin of Vermont marine deposits are found that were formed since the last ice age and that lie as high as six hundred feet above sea-level. Their post-glacial origin is indicated by their relation to glacial deposits, such as drumlins that were cut into or cliffed by the sea in which these deposits were formed, and by their superposition upon the glacial till.

The Champlain clays are divided into the deeper "blue clays," and the upper "brown clays"; the former characterized by *Leda portlandica* (*Yoldia arctica* Gray), the latter by *Macoma fusca* (*Macoma groenlandica* Beck), *Saxicava* and *Mya arenaria*.

Marine shells have been reported (10, p. 159) from Elgin Spring, East Panton. In Vergennes marine shells occur at two hundred and fifty feet above sea-level. From Addison northward marine shells may be found at any place in the brown clays.

In Addison, Panton and Ferrisburg the clays rise in broad terraces, often a mile wide, each terrace thirty to fifty feet above the one below. In East Panton the clay rises to two hundred and fifty feet above sea-level, and other marine deposits have been observed up to three hundred and fifty feet. At Snake Mountain, where banks of glacial drift rest at places against the escarpment, faint shorelines have been cut in the till up to five hundred and eighty-six feet. The more decided levels up to three hundred and fifty feet would leave Snake Mountain as an island.

BIBLIOGRAPHY.

1. Baldwin, S. P. Pleistocene History of the Champlain Valley. Amer. Geol.; XIII, pp. 170-184. 1894.
2. Bassler, R. S. Bibliographic Index of American Ordovician and Silurian Fossils. Smith. Inst., U. S. Nat. Mus.; Bull. 92, Vols. I, II. 1915.
3. Brainerd, E. and Seely, H. M. (a) The Calciferous Formation in the Champlain Valley. Amer. Mus. Nat. Hist.; Bull. III, pp. 1-25. 1890. (b) The Calciferous Formation in the Champlain Valley. Geol. Soc. Amer.; Bull. I, pp. 501-511. 1890.
4. Dana, J. D. A. Wing's Discoveries in Vermont Geology. *Amer. Jour. Sci.;* (3), Vol. XIII, pp. 332-347, 405-419. 1877.
5. Edson, G. E. Historical Sketch of the Cambrian Age as Related to Vermont Geology. Rept. Vermont State Geologist; V, pp. 117-132. 1906.
6. Foyles, E. J. Preliminary Report on the Ordovician Formations of Vermont. Rept. Vermont State Geologist; XIII, pp. 71-86. 1923.
7. ———. The Geology of Shoreham, Bridport and Fort Cassin, Vermont. Rept. Vermont State Geologist; XIV, pp. 204-217. 1924.
8. Gordon, C. E. Studies in the Geology of Western Vermont. Rept. Vermont State Geologist, XII, pp. 114-279. 1921.
9. ———. Studies in the Geology of Western Vermont, Second Paper. Rept. Vermont State Geologist; XIII, pp. 143-285. 1923.
10. Hitchcock, C. H. Report on the Geology of Vermont; I, p. 558. 1861.
11. Keith, A. Cambrian Succession in Northwestern Vermont. *Amer. Jour. Sci.;* (5), Vol. V, pp. 97-139. 1923.

12. Raymond, P. E. The Trenton Group in Ontario and Quebec. Geol. Survey, Dept. Mines, Summary Rept. 1912; pp. 342-350. 1914.

13. Ruedemann, R. Graptolites of New York. N. Y. State Museum; Memoir 7, Part I, pp. 455-803. 1903.

14. ———. Cephalopods of the Beekmantown and Chazy Formations of the Champlain Basin. N. Y. State Museum; Bull. 90, p. 611. 1906.

15. ———. Report on Trenton Fossils from the so-called Trenton and Utica Beds of Grand Isle, Vermont. Rept. Vermont State Geologist; XII, pp. 90-100. 1921.

16. Seely, H. M. Preliminary Report of the Geology of Addison County. Rept. Vermont State Geologist; VII, pp. 257-314. 1910.

THE FINDING OF THE ST. ALBANS CAMBRIAN "FISH-PLATE."

B. F. HOWELL.

For many years it has been known that there lived in Devonian times queer fish-like animals, called ostracoderms, whose bodies were covered with bony plates, for many of these plates have been found as fossils. Such fossil fish-plates have also been collected at a few localities in America and Europe from rocks formed during the Silurian and Ordovician periods, which preceded the Devonian. Ever since the first discovery of them in rocks of Ordovician age thirty-five years ago, paleontologists have believed that fish-like chordates—very ancient ancestors of the modern vertebrates—probably lived in Cambrian times; and students of Cambrian rocks and fossils all over the world have been searching for traces of them. The Ordovician fish-plates are about as big as the head of a large tack. Paleontologists assumed that, although the hypothetical Cambrian chordates would have been older and, therefore, more primitive, and would consequently probably not have had such large skin-plates as their Ordovician descendants, they would nevertheless have possessed plates large enough and hard enough to be preservable as fossils. It was not, however, until 1925 that anyone found a fossil which looked enough like the skin-plate of a chordate to seem to justify his calling it to the attention of the scientific world. And when it was found, it was, strangely enough, in Vermont in rocks which, although they had been seen by many geologists, had been until twenty years ago considered to be nearly or quite barren of organic remains, and which have even yet yielded only a handful of fossils in comparison with many of the other Cambrian strata of the world.

For three generations the Cambrian beds of northwestern Vermont and their contained fossils have been debatable subjects of discussion among American geologists and paleontologists, and such wordy battles have been waged over them that Franklin County might almost, like Kentucky, be called a "dark and bloody ground." The geology of the region is difficult of interpretation, but, by the studies of a number of workers during three generations, it has been gradually elucidated, until now we are beginning to understand its general framework, even though many of its details are still unknown.

One of the men who, through a lifetime of searching for fossils in this region, became intimately acquainted with its rocks and accumulated a great collection of fossils, was Mr. George E. Edson of St. Albans. He found fossils in certain beds near St. Albans and sent them to Professor Perkins. As they were the first fossils to be discovered in those particular rocks, and as they seemed to be different from any previously collected in Vermont, Professor Perkins submitted them for examination to Dr. Charles D. Walcott, of Washington, the world's foremost authority on Cambrian faunas. Dr. Walcott concluded that they were probably members of a *Paradoxides* fauna; and this opinion was published by Professor Perkins in 1908,[1] and by Dr. Walcott in 1910[2] and 1912.[3] Dr. Walcott named the beds from which the fossils came the St. Albans Formation.[4]

Assemblages of fossils characterized by species of the trilobite genus, *Paradoxides,* had been known for many years in Bohemia, France, Spain, Scandinavia, and Great Britain, in Europe, and in eastern Massachusetts, southern New Brunswick, and southeastern Newfoundland, in America, but no good evidence of the existence of such a fauna in Vermont had been published before, and, as the references to the fossils in Dr. Perkins' and Dr. Walcott's papers were brief ones, paleontologists who were especially interested in faunas of that type desired to know more about the new "find." Of this group of interested students of the Cambrian the writer was one. In 1922 he spent a month in Franklin County, searching for fossils in the band of shales that stretches for several miles north and south of the pasture in the western outskirts of the city of St. Albans in which Mr. Edson had found his specimens. A few were found, and evidence was gathered which indicated that a true *Paradoxides* fauna did actually exist in a strip of country extending north and south through the western part of St. Albans, but the search for field evidence was not completed at that time, and other duties caused its resumption to be deferred until the summer of 1925.

In the meantime, other men interested in the geology of eastern New York and western New England had been studying the rocks of northwestern Vermont. Two of these gentlemen, Dr. Arthur Keith, of the United States Geological Survey, and Professor Charles Schuchert, of Yale University, were especially interested in the series of Cambrian strata of which the *Paradoxides* shale was found to be a member, and the result of the writer's 1922 field work was, therefore, communicated to them. They took up the field work where he had dropped it and, in company with several other interested geologists, not only traced the beds in question north and south from St. Albans, but also placed them in the succession of Lower Paleozoic rocks which they had been working out in western Vermont, and found fossils in them at several places. They did not, however, do all the field work that needed to be done on the problem, and in 1925 Professor Schuchert and the writer visited the region again to investigate some of the still doubtful details of the stratigraphy. It was at this time that they discovered, in an outcrop of shale about half a mile south of St. Albans, the little fossil which appears to be probably the first discovered example of the long-sought-for Cambrian chordate skin-plate, or "fish-plate," as it is commonly called—though its original owner may have been too lowly, or too different from the true vertebrates in its anatomy, to be properly called a fish. Since then other plates, possibly also those of chordates, have been collected from the same beds, but they are not as well preserved as the first one found, and have not the same interest that attaches to it.

If this fossil, which is now on exhibition in the paleontological museum of Princeton University, is in fact the skin-plate of a chordate, as Dr. W. L. Bryant (who, as one of our greatest authorities on early chordates, has made a thorough examination of it) thinks that it probably is, then it pushes back by perhaps fifty million years the known fossil record of chordate life. For the rocks in which it was found are of what is now known as Middle Cambrian age, and the creature which wore the tiny plate lived, as far as we can estimate it, about six hundred million years ago, and probably fifty million or more years before the next younger known chordates swam in the waters of Ordovician days.

The rocks in which this fossil was found are micaceous, sandy, dark gray shales. They must originally have been deposited as sandy muds in some body of water; and this body of water was presumably marine, because the shales now hold fossils of trilobites and brachiopods, which have always been, as far as we know, restricted to the sea. Since their consolidation into shales, the beds have been squeezed and cleaved in the folding which the rocks of northwestern Vermont have undergone.

This same folding, and the erosion which has succeeded it, have removed the evidence which must once have existed by which we might have determined whether the mud in which the plate became entombed was accumulating at a point on the sea bottom that was not far from the shore. This is unfortunate, because the apparent absence of similar plates from all the many other

[1] Perkins, G. H., Preliminary report on the geology of Franklin County. Report of the State Geologist on the mineral industries and geology of certain areas of Vermont for 1907 and 1908, pp. 208, 209; 1908.

[2] Walcott, C. D., Cambrian geology and paleontology, No. 6—Olenellus and other genera of the Mesonocidæ; Smithsonian Miscellaneous Collections, Vol. 53, No. 6, pp. 254, 255; 1910.

[3] Walcott, C. D., Cambrian Brachiopoda. Monograph U. S. Geological Survey, No. 51, p. 251; 1912.

[4] Walcott, C. D., Cambrian geology and paleontology, No. 6—Olenellus and other genera of the Mesonocidæ; Smithsonian Miscellaneous Collections, Vol. 53, No. 6, p. 254; 1910.

known, often richly fossiliferous, marine Cambrian rocks of the world would seem to indicate that no plate-bearing chordates were living in the sea in Cambrian times, and that our plate may have been washed into the ocean from some fresh-water stream. That the shore may not have been very far away from the place where the plate dropped to its final resting place on the bottom is shown by the sandy nature of the sediments accumulating there and by the fact that we have some reason to suppose that there was land at that time on the site of the Adirondack Mountains, which rise only a few miles west of St. Albans. That some at least of the early chordates lived in fresh water is made to seem probable by the evidence of a possible fresh-water origin for the beds in which some of the known Silurian chordate fossils are found.

If our Cambrian chordate was actually a fresh-water animal, it perhaps adds weight to the theory that the notochord of the early chordates, from which the backbone of the vertebrates is believed to have evolved, was developed in response to the demands of a running fresh-water habitat that required the powers of locomotion which come with a notochord and which are not so necessary in the relatively slow-moving ocean waters as they are in the more rapid waters of the land.

Whatever may have been its exact nature, the animal that wore our little plate so many years ago must have been different from any whose fossilized remains have heretofore been recognized in Cambrian rocks. It thus adds one more element of interest to the study of the Cambrian strata which are exposed in northwestern Vermont and of the rich faunas which are contained in them.

EVIDENCE OF THE PRESENCE OF CHORDATES IN THE CAMBRIAN.

WILLIAM L. BRYANT.

Ever since the discovery in 1893 of Ordovician Ostracoderms in western North America, I have more or less confidently expected that ancestral forms with calcified dermal skeletons would ultimately be brought to light from the older rocks.

Although mostly fragmentary, the Ordovician remains exhibit scales or plates of highly specialized structure, including dentine tubercles fused with underlying bony tissue, while these in turn sometimes coalesce into more or less extensive armor plates.

Previous to the discovery of these Ordovician fossils it seemed almost hopeless to search for remains of fishes much older than the Silurian Ostracoderms, for the reason that the primitive structure of such generalized forms as Lasanius and Thelodus suggested that the ancestral Ostracoderms were only beginning to evolve a hard dermal skeleton represented by tubercles of dentine in early Silurian times. Lasanius in particular occurs as hardly more than a mere stain in the rock with a few rows of pointed scales on certain parts of the head and trunk.

But when we find robust and complicated dermal plates in the Ordovician, showing a bony structure comparable with that of the advanced order of the diplorine Osteostracans, it seems certain that the Silurian Anaspidae were only survivors of much older forms, inheriting their primitive strucure so far as the exoskeleton is concerned, and that we may look even below the Ordovician for evidence of their origin. For there must have been a long period of development from the primordial Shagreen denticle to specialized plates like these if our conception of the history of such structures is correct.

A possible realization of this hope lies in a small fossil recently discovered by Professors Howell and Schuchert in the Cambrian Shales of Franklin County, Vermont and now preserved in the geological museum of Princeton University. The fossil exhibits only an impression of the external surface of a scale or plate, but apparently shows its complete outline. The discovery of a Cambrian fossil whose sculptured surface is extremely suggestive of an ichthyc origin, seem to me of sufficient importance to justify a description and name, if only to attract attention to the find and to the probability that fish remains may be expected to occur in Cambrian rocks, even though one may only hazard a guess as to the true character and ordinal rank of the fossil in question.

Eoichthys howelli, n. gen. n. sp., Plate XII.

Type.—Impression in shale of a small plate 3 mm. in length by slightly more than 2 mm. in width.

Formation and locality.—St. Albans shale, near St. Albans. Franklin County, Vermont.

PLATE XII.

Eoichthys howelli Bryant (enlarged about ten times).

An elipsoid plate truncated at one end. Ornament consisting of smooth, conical tubercles whose bases are more or less confluent into rows radiating fan-wise from a focal point near the truncate border, where there are one or more detached (non-confluent) tubercles. Below this focal point a stronger pair of these tuberculate costae diverge towards the outer margins of the the truncated border. A deep sulcus crossing the plate separates this pair of costae from the others. On the same slab with the type there are to be seen other plates in section, one of which is four or five millimeters in length and seems to exhibit the cancellous tissue characteristic of the Ostracoderms, but this appearance may be due to weathering as the plates are badly decomposed.

If this plate is as seems probable of vertebrate origin it is quite certainly one of those polygonal tesserae which defended the head and fore trunk of some hitherto unknown diplorhine Ostracoderm, and we have here the surprising evidence that at even this early period certain Chordates had undergone a complicated and presumably long extended evolution of the exoskeleton, resulting in a fusion of dentine tubercles and the development of an underlying calcified tissue with which these have coalesced.

THE GEOLOGY AND PETROGRAPHY OF BARNARD, POMFRET AND WOODSTOCK, VERMONT.

CHARLES H. RICHARDSON,
Syracuse University, Syracuse, N. Y.

INTRODUCTION.

The report upon the Geology and Mineralogy of Barnard, Pomfret and Woodstock, Vermont, is of necessity brief. The time available for detailed field work and the petrographic study of microscopic slides in the laboratory demand brevity. The report may be regarded as one of progress in the solution of the many intricate problems dealing with the highly metamorphosed sediments and their associated intrusives in the eastern half of the State. The purpose is to present in concise form the results of new field work and new petrographic study of the closely folded, faulted and intruded rocks of Barnard, Pomfret and Woodstock, Vermont, and to draw therefrom certain conclusions as to their origin, stratigraphic relation, mineralogical composition and age. It is extremely difficult, if not impossible, to determine whether some of the terranes involved were originally of sedimentary origin or of igneous origin. They are now highly metamorphosed rocks. It is, furthermore, difficult to determine the actual age of some of the formations involved, because of the absence of fossils in the pre-Ordovician terranes.

The townships of Barnard, Pomfret and Woodstock are situated some thirty miles southeast of the geographic center of the State. The western boundary of Barnard is a little east of the central meridian traversing the State. The village of Woodstock is thirteeen miles southwest of White River Junction, which is situated on the eastern border of Vermont at the confluence of the White and Connecticut Rivers. It also is located thirty-one miles east of Rutland, Vermont. The area involved is bounded on the northeast by Bethel, Royalton and Sharon, on the southeast by Hartford and Hartland, on the south by Reading, on the west by Bridgewater and Stockbridge. It lies between north latitude, forty-three degrees and thirty minutes and forty-three degrees and forty-seven minutes. Also between longitude seventy-two degrees and twenty-five minutes and seventy-two degrees and forty-three minutes west of Greenwich.

There are five definite reasons for the selection of Barnard,

PLATE XIII.

Map of Woodstock Quadrangle.

Pomfret and Woodstock for field work: (1) They lie to the southeast of Bethel whose geology and petrography was published in the Biennial Report of the State Geologist for 1923-1924. (2) They make the work continuous in a southeasterly direction in the eastern half of the State. (3) They fall in the line of the erosional unconformity beween the Ordovician and the pre-Ordovician, probably Cambrian, formations on the eastern side of the Green Mountains. (4) The presence of both acid and basic intrusives whose mineral composition has never been published. (5) The fact that no detailed field work has ever been done and no petrographic study ever made upon either the sedimentaries or their associated intrusives.

The author traversed a considerable part of this area in reconnaissance work during the summer of 1895. Detailed work has been done during the summers of 1924, 1925 and 1926.

Professor L. W. Currier of the School of Mines and Metallurgy, Rolla, Missouri, has worked out a detailed petrographic study of both the sedimentaries and their associated intrusives.

The field relations of the different terranes in Barnard, Pomfret and Woodstock are often difficult to determine. The townships as a unit are hilly, glaciated and in part densely wooded. The latter condition holds especially true of the western part of Barnard and Woodstock, where all roads and all farms are abandoned, and a dense growth of underbrush occupies the area. Under such conditions actual contacts between the different formations are seldom found.

An areal map showing roughly the distribution of the different terranes accompanies this report as Plate XIII.

The uncertainty of the planes of bedding in many instances renders a structural map difficult of correct interpretation and, therefore, it is omitted. The area involved in this report has always been mapped as purely sedimentary, but both acid and basic intrusives have been discovered and their location will be shown on the areal map.

Forty new rock samples have been collected in Barnard, Pomfret, Woodstock and their adjacent townships, trimmed to regulation size, 3 x 4 inches, and placed in the museum at Montpelier. This brings the number of State samples collected in the eastern half of Vermont up to nine hundred forty.

This report is not published under the caption of the Woodstock Quadrangle for two reasons: (1) Elwyn L. Perry, Instructor in Princeton University has been doing very detailed work in Bridgewater and Plymouth, both of which townships are included in the Woodstock Quadrangle. (2) The northern part of Barnard lies in the Randolph Quadrangle and the eastern part of Pomfret in the Hanover, N. H., Quadrangle.

DRAINAGE.

The chief drainage of the area involved in this report is effected by two rivers. The northernmost of these two streams is the White River which rises in Granville and empties into the Connecticut River at White River Junction. The other river is the Ottaquechee which rises in Sherburne, flowing in a southeasterly direction to West Bridgewater, then easterly through Bridegwater and Woodstock to the village of Quechee, then in a southeasterly direction through Hartland and empties into the Connecticut River just above the village of North Hartland. Each of these rivers receives many small streams from both the north and south sides. These need no description here and many of them have only local names.

TOPOGRAPHY.

(Plate XIV)

There are two broad "U"-shaped fertile valleys traversing the area involved in this report. The more northern valley is that of the White River, which receives the drainage of the northern part of Barnard and the eastern part of Pomfret. The second broad valley is that of the Ottaquechee River. This valley extends in an east and west direction across the entire townships of Woodstock and Bridgewater. In the flood plains of this valley are some of the most fertile farms in Vermont. Pomfret Brook, Barnard Branch and Gulf Stream afford intermediate valleys on the north side of the Ottaquechee River and South Branch yields the only intermediate valley on the south side of the Ottaquechee. These valleys are essentially pre-glacial. There are, however, numerous transverse valleys that are in part at least post-glacial.

The altitude of Barnard village at the outlet of Silver Lake is 1,334 feet, U. S. Bench Mark. The highest altitude in Barnard is 2,670 feet. This point is located on the Delectable Mountains in the extreme southwestern part of the township. The lowest altitude in Barnard is approximately 583 feet. This is in the extreme northwest corner of Barnard.

The lowest altitude found in Pomfret is 390 feet. This point is in the extreme eastern part of the township on the south bank of the White River. The highest altitude in Pomfret is on Thistle Hill, which affords 2,010 feet. This hill is on the Hanover Quadrangle and in the eastern part of Pomfret. The village of South Pomfret has a U. S. Bench Mark of 736 feet.

The lowest altitude found in Woodstock was the U. S. Bench Mark at Taftsville in the extreme eastern part of the township. This mark records 668 feet. The village of Woodstock itself is 705 feet. The highest altitude found is on Long Hill in the

PLATE XIV.

General topography of the region. Woodstock Quadrangle, Barnard.

extreme western part of the township. The altitude here recorded was 2,330 feet. The topography of Barnard, Pomfret and Woodstock as a unit is rugged and may be regarded as in the stage of late maturity.

GLACIATION.

The townships of Barnard, Pomfret and Woodstock are mantled with morainic material to such an extent that the geologist is seriously hampered in the study of the field relations of the different terranes. This condition holds especially true in the western part of Barnard and Woodstock where the mountainous area is densely wooded. The outcrop of a diabase dike can be followed with certainty for only a short distance, sometimes for only a few feet, on account of the heavy overburden of glacial material. Presumably, a second exposure of a diabase dike only a few rods distant from a given outcrop and with the same strike belongs to the same dike, but it is not proved. Even the strike changes frequently in short distances. It is said to be a characteristic of Vermont that where one dike appears in a given area several others are very apt to be present. This condition does hold true two miles northwest of Royalton on the farm of A. A. Turner, where in a small area in an open pasture five distinct diabase dikes were found. This does not hold true of the basic dikes in Woodstock unless the heavy overburden of glacial material conceals what would otherwise be outcrops.

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 the nearly pure white vein quartz and the broad dike-like quartz outcrops are particularly prone to furnish this evidence. The Cambrian quartzites, Ordovician phyllites and Woodstock schists occasionally afford good illustrations of glacial grooving. The variations in directions recorded range from south twenty degrees east to south thirty degrees west. On Thistle Hill in Pomfret the direction of the striations is due south.

The terminal moraine of recession has often left boulder trains in its course and by following in the direction of some boulder train the intrusive rock was discovered which gave rise to these erratics. The stock of granite on Seaver Hill in Pomfret and the diabase dike on Oak Hill in Bethel have furnished this evidence. Morainic boulders are especially abundant on the south side of the Ottaquechee River in the western part of Woodstock near Bridgewater village and in the open pasture southwest of the village of Woodstock. These boulders near Woodstock are identical in mineral composition and texture with the region around Mt. Tom on the north side of the Ottaquechee River and

doubtless were derived from that source. They could not have been transported down the Ottaquechee valley by a local glacier for there are no outcrops of the same type of rock to the west of this boulder-strewn area.

There is no positive evidence that local glaciers moved down any of the valleys in Barnard, Bridgewater, Pomfret and Woodstock. Many valleys are gorge-like and crooked in their upper courses and no cirques were found in the higher altitudes of Barnard, Bridgewater and Woodstock. The numerous sand and gravel deposits in the valleys represent the outwash of some terminal moraine of recession.

QUECHEE LOCAL GLACIER.

As far back as 1854 the existence of the Quechee Local Glacier was detected by Edward Hitchcock, then President of Amherst College, and his son, Charles H. Hitchcock, for over forty years Professor of Geology at Dartmouth College. The results of their investigations were briefly described in the report of 1861. As the Quechee Local Glacier of the Hitchcock's, if it existed, must have traversed both Bridgewater and Woodstock it seems better to cite here the two most recent publications dealing with the subject, than to enter into a discussion of the reasons for and against the existence of such a glacier. The first of these reports is entitled, "Geology of the Hanover, N. H., Quadrangle," by Prof. Charles H. Hitchock, and was published in the Biennial Report of the State Geologist, 1907-1908, pp. 139 to 188, inclusive. The second of these reports is entitled, "Evidence for and against the Former Existence of Local Glaciers in Vermont," by Prof. James W. Goldthwait of Dartmouth College, and published in the Biennial Report of the State Geologist, 1915-1916, pp. 42 to 73, inclusive. Both reports are illustrated and very interesting. Dr. Goldthwait rejects the idea of local glaciers altogether and adopts Agassiz's great ice sheet as the agency responsible for all the glacial features in Vermont.

LAKES.

All lakes and ponds in Barnard, Pomfret and Woodstock are of glacial origin and indicate more or less youthful topography. The largest of these lakes is Silver Lake in Barnard. It is on the shore of this lake that the village of Barnard is situated. The lake is more or less circular in shape, about one-half mile in diameter, and about three-fourths of the lake is surrounded by wooded hills. The lake is celebrated for its clear, cold waters and the charming scenery that surrounds its shores.

Lakota Lake is situated in the hilly and wooded area in the southern part of Barnard township. It is about one-third of a mile in length, and one-fifth of a mile in breadth. It is noted for its delightful scenery and most excellent fishing.

The Pogue is the one natural lake or pond worthy of mention in Woodstock. It is situated about one mile north of the village of Woodstock. It is circular in form, about one-fourth mile in either diameter, and surrounded by wooded hills. It is on private property on what is known as the Billings Estate.

GEOLOGY AND PETROGRAPHY.

The geology of Barnard, Pomfret and Woodstock, like the geology of other townships in eastern Vermont is intricate and complex. The sedimentaries consist of a series of highly folded and faulted metamorphics that are often cut by intrusives. These intrusives range from the very acidic aplite to the basic diabase. Some of the rocks involved are so highly metamorphosed that in the field it is extremely difficult to say with certainty whether they are of sedimentary or of igneous origin. This difficulty is not entirely eliminated in the petrographic laboratory, for while the microscope tells what the minerals now are, it can not reveal with certainty the mineralogical composition of the original rock. In some instances what constituents have been subtracted and what added we do not know. Both the sedimentaries and the intrusives differ widely in age and in mineral composition. A careful study of the field relations has been made to avoid the introduction of errors in interpretation and more than one hundred microscopic slides have been prepared for petrographic study from Barnard, Pomfret, Woodstock and their adjacent townships. A detailed study of these slides has brought out several exceedingly interesting facts, which may be listed as follows: (1) A large decrease in the percentage of magnetite in the pre-Ordovician terranes. Magnetite was very abundant in the slides from Braintree, Randolph, Bethel and Rochester. (2) A rapid increase in the feldspar content (albite) in the sericite schists and the sericitic quartzites. In the more northern areas feldspars have been sparingly present in the sericite schists save in one locality in Roxbury, and wanting in the sericitic quartzites save near contacts with intrusives. (3) A rapidly increasing biotite content in the sericite schists so that the rock frequently becomes a biotitic sericite schist instead of a typical sericite schist. (4) The feldspar of many of the igneous rocks appears to have been albitized or else the feldspar of the original intrusive was albite which has not been proved.

In the western part of Barnard and Woodstock the stratigraphy has largely been determined by apparent field relations, but the planes of bedding can not always be distinguished from the planes of schistosity. In fact, in Woodstock they seem to coincide with each other. In the eastern part of the area involved the stratigraphy has been determined by the discovery of new beds of graptolites in Barnard, Pomfret, Reading and Woodstock. These diagnostic features are not abundant in the townships cited save in the northwest corner of Pomfret and then only in a limited area. It is interesting to note that graptolites have now been found in more than thirty townships in eastern Vermont, and that each township traversed by the erosional uncomformity between the Ordovician and the pre-Ordovician from the international boundary on the north to Reading on the south, a distance of more than one hundred thirty miles has yielded these important diagnostic fossils. The width of the belt carrying crushed graptolites is sometimes fifteen miles, and sometimes it is narrow. It is only by diligent search and by splitting open along planes of bedding of hundreds of samples of impure slates and limestones that the graptolites are usually found. In a few instances they have been found on the surface of a decomposed shell of massive limestone. It is regretted that thus far no fossils have been found in the pre-Ordovician terranes of eastern Vermont. This record of age if once recorded has been obliterated by the metamorphism of the terranes.

ALGONKIAN.

The Algonkian, or pre-Cambrian terranes, do not occur in Barnard, Pomfret and Woodstock. However, they do occur in the southwestern part of Stockbridge, which joins Barnard on the west, in Sherburne, which lies west of Bridgewater, and in Plymouth, which falls to the west of Reading. The Sherburne conglomerate is post-Algonkian for it is flanked on the west by the Algonkian gneiss. It is regarded as constituting the base of the Cambrian on the eastern side of the Green Mountains. This conglomerate was discovered by the author of this report in 1892 and named by him the Sherburne conglomerate. It carries pebbles and boulders up to one foot in diameter of quartzites, granites and gneisses. A good outcrop of this conglomerate can be seen about two miles southeast of North Sherburne at the head of the narrow valley leading down to Sherburne.

CAMBRIAN.

The term Cambrian as here used denotes 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 terranes from the Ordovician. That they are pre-Ordovician is proved by the fact that they underlie the Irasburg conglomerate which constitutes the base of the Ordovician series in eastern Vermont. This inferior position has been followed southward in Canada and Vermont for over two hundred miles. That these rocks are post-Algonkian in age is proved by the facts that they overlie the Algonkian gneiss and that the lowest member of the series is a basal conglomerate, Sherburne conglomerate. These formations consist of a basal conglomerate already noted, hydromica schists, sericite schists and quartzites. They are considered to have been derived from the erosion of the Algonkian terranes during Cambrian times. These terranes occupy the western half of Barnard and the extreme western part of Woodstock. They are entirely absent in Pomfret. The terranes of Bridgewater and Plymouth are essentially Cambrian, but these townships are covered by the work of E. L. Perry.

If the Cambrian terranes as they appear on the Woodstock Quadrangle are divided into two groups, the Lower Cambrian and the Upper Cambrian, the division must be purely arbitrary, for no conglomerate was found that would lead to a sharp line of demarcation and no fossil content has yet been discovered in the Cambrian terranes in eastern Vermont. It would appear rational to conclude that the Sherburne conglomerate and several of the lower overlying schists are Lower Cambrian and that the uppermost schists of the Cambrian series are Upper Cambrian. Several questions can here be raised. Was deposition continuous on the eastern side of the Green Mountain axis throughout Cambrian time? Did deposition begin with the Sherburne conglomerate in Lower Cambrian time and cease with the Middle Cambrian? Did deposition begin with the Upper Cambrian and cease with the uplift that came at the close of the Cambrian? The great thickness of the Cambrian terranes as a unit would imply that the sediments were deposited in both Lower and Upper Cambrian time. The Cambrian terranes are regarded as sedimentaries added to the Algonkian land mass by the Green Mountain disturbance at the close of the Cambrian period. How much of the present schistosity of the rocks was introduced at that time is not known. It is, however, definitely proved that both acid and basic intrusives were introduced into the Cambrian terranes prior to the Ordovician time, for boulders of these intrusives appear in the Irasburg conglomerate which forms the base of the Ordovician series in eastern Vermont.

LOWER CAMBRIAN.

These terranes consist of conglomerates, quartzites, dolomites, albite schists, feldspathic quartzites, and various mica schists that are prominent features in Bridgewater and Plymouth. They are covered in the work of E. L. Perry. They do not appear in Barnard, Pomfret and Woodstock, and, therefore, they do not properly belong in this discussion and may be dismissed without further comment.

UPPER CAMBRIAN.

The terranes here included as Upper Cambrian may be subdivided into two distinct groups: (1) The Bethel Group which embraces the hydromica schist of earlier reports and the chlorite schists. (2) The Missisquoi Group which consists of the sericite schists and the sericitic quartzites.

BETHEL SCHIST.

The Bethel schist (Plate XV) traverses the entire western part of the township of Bethel from which it derived its name. In its southern extension it should strike only the southwest corner of Barnard. It is absent in both Pomfret and Woodstock, but forms a continuous terrane through Bridgewater and Plymouth.

In the typical development of the Bethel schists they are fine grained, greenish, schistose, highly metamorphosed, sedimentary rocks, which are more or less intimately associated with chlorite. These schists are, furthermore, characterized by numerous lenses, or eyes, and stringers of granular quartz. The quartz lenses, or eyes, vary in width from a small fraction of an inch up to five or six inches, and in length from an inch up to a foot or even more. The smaller of these lenses sometimes suggest elongated quartz pebbles. Sometimes they cross the schistosity, but more often they are elongated in the direction of the schistosity. The quartz in the lenses, or eyes, and the stringers is all of the same granular type. It is doubtful if the presence of actual pebbles can be proved. Prof. C. H. Hitchcock regarded the Bethel schists in the southwestern part of Bethel as a conglomerate at the base of the Upper Cambrian, and the lenses, or eyes, as quartz pebbles elongated by the intense pressures to which the terrane has been subjected.

In Bethel the strike of this terrane varies from north twenty degrees east in the northwestern part of the township to north twenty degrees west in the southwestern part of Bethel. In Bethel the dip is at a high angle, often vertical, usually to the east, but westerly dips were recorded. In Bridegwater the dip is to the east. A good exposure of this terrane is found near the second bridge over the Ottaquechee River west of Bridgewater Corners. No evidence of bedding planes was found in this outcrop. One-half mile further to the west the terrane is very garnetiferous and the schistosity dips east. The lenses, or eyes of quartz, in this outcrop are very abundant.

The Bethel schists are unquestionably older than the members of the Missisquoi Group, for these latter terranes lie conformably upon the eastern flank of the Bethel schist in Bethel and

PLATE XV.

Bethel schist, showing quartz lenses.

Bridgewater, but in some more northern localities an apparent disconformity has been observed.

CHLORITE SCHIST.

The chlorite schists occasionally conform in dip and strike with the Bethel schists with which they are often intimately associated. In such instances they may be regarded as of sedimentary origin and their discussion would then belong here, for they would form a part of the Bethel Group. In Roxbury to the north where they cross the sedimentaries at angles varying from zero to eighty-five degrees they cannot be of sedimentary origin and their discussion would then fall with the igneous rock. Narrow beds of chlorite schist may occur also in the Missisquoi Group.

The chlorite schists are fine grained, green, schistose, highly metamorphic rocks. The mineral chlorite, or some related mineral of the chlorite group is their determinant constituent. Epidote is exceedingly abundant and magnetite is invariably present. Quartz and plagioclase feldspar are sparingly present. The quartz lenses, or eyes, that characterize the Bethel schists are wanting, but stringers of granular quartz are common.

MISSISQUOI GROUP.

The Missisquoi Group of terranes comprises sericite schists and sericitic quartzites as its chief constituents with minor beds of chlorite schists, hornblende schist, and gneiss that may not be of sedimentary origin in all instances. This group of terranes has been followed southward from the international boundary on the north for approximately one hundred thirty miles. The mineralogical content of the sericite schists and quartzites has been fairly constant for the entire distance traversed. In Bethel, biotite began to appear in the sericite schists, replacing a part of the sericite, but only as a minor accessory constituent. In Barnard, the biotite in certain localities is sufficiently abundant to warrant the term biotitic sericite schist. In Barnard and Woodstock the albite content of the sericite schists is more abundant than it is to the northward. However, a plagioclase content in the sericite schist in the southern part of Roxbury is more abundant than the albite content of the sericite schist in either Barnard or Woodstock.

SERICITE SCHISTS.

The sericite schists flank the Bethel schist on the east in Barnard and Woodstock and are, therefore, younger. They also occupy an inferior position to the Ordovician terranes on the east and are, therefore, older. The Missisquoi Group is regarded as the youngest of the Upper Cambrian terranes in eastern Vermont. Where the sericite predominates the rock is classified as a sericite schist. Where well-rounded quartz grains are in large excess over the sericite the rock is classified as a quartzite, but even then sericite is invariably present.

In Barnard the sericite schists occupy the western third of the township. They are wanting in Pomfret and appear in Woodstock only in the southwestern part of the township. They traverse the entire length of Bridgewater and Plymouth, which townships are covered in the research work of Mr. Perry. In the extreme northwest corner of Barnard the strike of the sericite schist varies from north and south to north ten degrees east and the planes of schistosity dip from fifty-five to sixty-five degrees east. On the west side of Locust Creek the sericite schist becomes very quartzose and often hornblendic. The hornblende appears to be secondary in origin, for the crystals frequently cross the schistosity and are often bifurcated. These hornblendic rocks are usually garnetiferous. In the western part of Barnard some fifty rods south of the turn to Mt. Hunger school house abundant outcrops of the sericite schist afford ledges some twenty to twenty-five feet in height in which the dip of the schistosity is from eighty to eighty-five degrees, both east and west. In one instance the sericite encases a bed of chlorite schist in such a manner as to strongly suggest an igneous origin of the chlorite, for the exposed portion of the chlorite schist is completely surrounded by the sericite schist. The dip of the schistosity in the chlorite is nearly vertical.

On Mt. Hunger there is a fine-grained, black, splintery mica schist that affords excellent outcrops a few hundred feet from the U. S. Bench Mark near the flag staff on the summit. The strike of this schist varied from north ten degrees east to north twenty-five degrees east and the dip of the schistosity was eighty to eighty-five degrees both east and west. Lower down on the east slope of the hill the dip was eighty degrees east. Mt. Hunger on the map is called Cowdrey Outlook and the U. S. Triangulation Station records 2,055 feet. No attempt has been made to differentiate the above black, splintery schist from the silvery white sericite schist. The splintery phase has appeared in several townships to the north as in Middlesex, Wolcott and Newport. It is a part of the Missisquoi Group.

Near the sawmill on Locust Creek and at the site of an abandoned mill the sericite schist is cut by an intrusive now altered to chlorite. The sericite and chlorite schists are cut by ten or more aplite dikes, or sills, and the sericites, chlorites and aplites are all cut by quartz veins at right angles to the strike of the rocks.

Just west of the village of Bridgewater and not one-eighth mile from the Woodstock town line the sericite is closely folded with strata nearly vertical and with drag folds dipping east and west on either side. A little to the west of this outcrop the dip of the schistosity and bedding varies markedly. The planes of the schistosity dip forty degrees east, while the bedding is nearly vertical. In its southern extension the sericite schist is found in the southwestern corner of Woodstock and forms a broad belt in the western part of Reading.

In structure the sericite schists are finely laminated, schistose and granular. In texture they are fine to medium grained. In color they range from a silvery white to a slightly greenish tint. The greenish color is usually due to a little chlorite derived from biotite. In some instances it is due to the chloritization of hornblende.

The essential minerals in the sericite schist are muscovite, var. sericite, and quartz. The normal accessory minerals are biotite, magnetite, apatite, pyrite. The plagioclase feldspar, albite, is not uncommon in Barnard and Woodstock. Outcrops frequently are garnetiferous.

QUARTZITE.

The quartzites as they appear in Barnard and Woodstock are always sericitic and graduate by insensible gradations into the sericite schist. In fact the quartzite is only a very quartzose phase of the sericite schist. In some instances there is little else than well-rounded quartz grains present.

The quartzite is well developed in the northern part of Barnard. Plate XVI. It is absent in Pomfret. It appears again in the southwestern corner of Woodstock. Its strike and dip always conform to the strike and dip of the sericite schist. All of the outcrops as they appear on the Woodstock Quadrangle may well be mapped in as sericite schist.

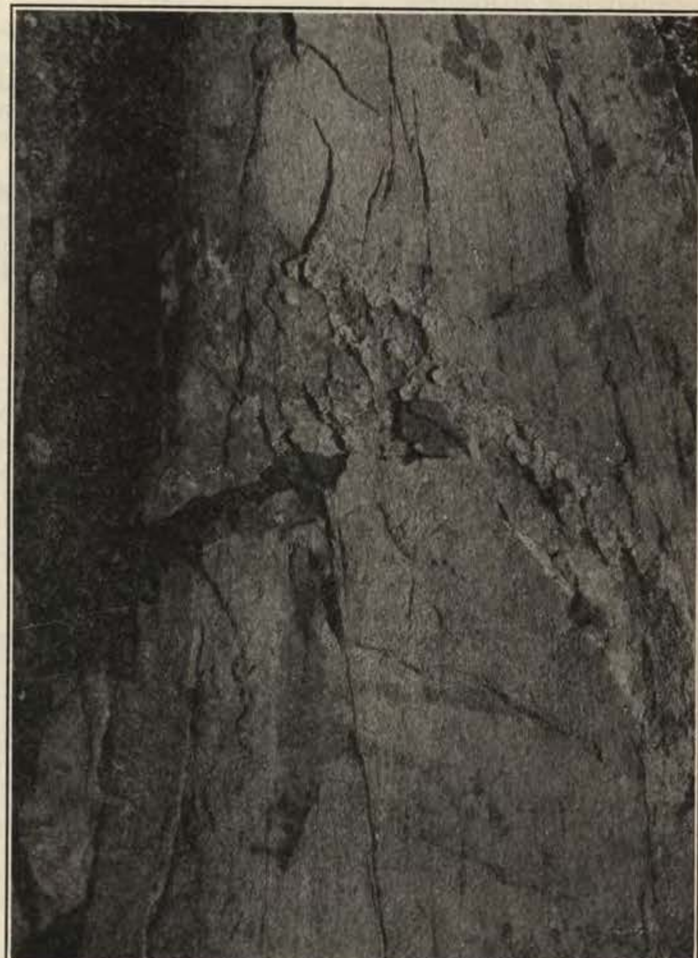
Megascopically considered, the sericitic quartzites are schistose in structure, fine to medium grained in texture, silvery white to slightly greenish in color, and highly metamorphic. The only essential minerals are quartz and muscovite, var. sericite. The accessory minerals usually present in Barnard and Woodstock are biotite, corroded apatite, magnetite, pyrite. Occasionally albite is sparingly present. Chlorite and epidote may appear.

CHLORITE SCHISTS.

Where the chlorite schists conform in dip and strike to the enclosing sericite schists and sericitic quartzites they may be regarded as of sedimentary origin. Such beds as found in the western half of Barnard are often only a few inches in width. Sometimes they are a few feet in width, and again they are hundreds of feet across the strike.

Chlorite, or some related mineral of the chlorite group, drawn out into more or less parallel layers is the one essential constituent.

PLATE XVI.



Segregation of layer rich in hornblende. Base hornblende; top sericite, Woodstock.

More or less quartz is usually present. Magnetite is invariably present. Crushed or granulated plagioclase feldspars have been observed in some slides. Epidote is a common associate.

A ferruginous clay by metamorphism could yield iron-aluminum silicates which could be subsequently altered to chlorite. Secondary hornblende which is not uncommon in Bethel and Barnard in the Upper Cambrian terranes may have furnished a part, at least, of the chlorite. Biotite, in some instances, is known to be the source.

The reasons for believing that these narrow beds of chlorite schist associated with the sericite schists and quartzites are of sedimentary origin may be listed as follows: (1) The narrowness of the beds. (2) Their conformity in dip and strike to beds of unquestioned sedimentary origin. (3) The presence of an appreciable amount of quartz in some slides. (4) The absence of any alteration by igneous intrusions in the walls of the enclosing sediments. If the above interpretation is correct then the age of these chlorite schists would be the same as that of the enclosing sericites and quartzites, Upper Cambrian.

HORNBLENDE SCHISTS.

If any of the hornblende schists associated with the Cambrian terranes of Barnard and Woodstock are of sedimentary origin, then their discussion belongs here. If they are not of sedimentary origin, then the proper place for treatment would be under the caption of intrusives. However, there are hornblende schists in Pomfret and Woodstock associated with the Ordovician terranes whose discussion properly falls under the Ordovician.

Two belts of hornblendic rocks occur in Barnard. One is found on the east side of Locust Creek, and the other on the west side, but further to the south. It is not proved that these two belts are connected. The strike conforms with the strike of the sericite schists and sericitic quartzites with which they are associated.

The structure of the rock is schistose. The texture is fine to medium and granular. The color is some shade of gray, but the sections richer in hornblende have the darker hues. The light gray shades are often spotted with long crystals of black hornblende. Much of the hornblende is arranged in parallel lines, often alternating with fine granular quartz. Some of the hornblende crystals cross the schistosity of the rock and often bifurcate.

The essential minerals are hornblende and quartz. The common accessory minerals are the plagioclase feldspar, albite, biotite, chlorite, calcite, epidote, magnetite, occasionally pyrite. In certain localities garnets are abundant.

The arguments for a sedimentary origin of the hornblende schists may be listed as follows: (1) The gradation from outcrops particularly rich in hornblende to sericite schists and quartzites in which hornblende crystals are only sparingly present. (2) The occasional alternation of narrow bands particularly rich in hornblende with equally narrow bands extremely low in hornblende. (3) The bifurcation of long crystals of hornblende that appear fresh and of later generation than the main mass of the rock. (4) The presence of many well-developed crystals of hornblende whose longer axis is across the schistosity of the rock. (5) The absence of any definite visible contact with rocks of unquestioned igneous origin.

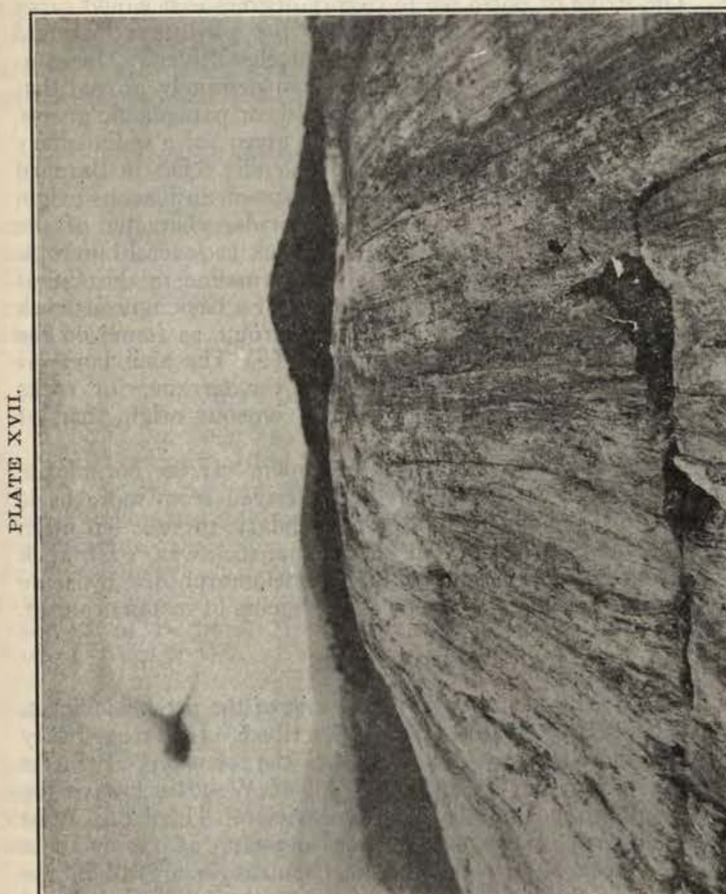
The western Woodstock area of hornblendic rocks crosses the Ottaquechee valley just east of the village of Bridgewater and occupies the eastern part of Bridgewater as well as the western part of Woodstock. The outcrop is lenticular in shape with its longer axis extending nearly north and south for a distance of about two miles. The widest portion of the outcrop is just South of the Ottaquechee River. North of Bridgewater near the Bridgewater-Woodstock town line the outcrops can be found almost, but not quite, in contact with the phyllite schist of Ordovician age. Only a few feet of drift-covered area prevents finding the actual contact. On the south side of the river excellent outcrops can be found under the bridge over the Curtis Hollow Brook and around its entrance into the Ottaquechee River. In this outcrop certain layers are particularly rich in hornblende while in others the hornblende content is low. Some of the layers are so rich in albite that the rock could be catalogued as an albitic hornblende schist. Plate XVII. On the right-hand side of the road leading to Curtis Hollow, and in the pasture, one outcrop is very dark gray, almost black and strikingly suggests a basic igneous rock. At Curtis Hollow tourmalines are quite abundant.

There are four distinct phases of this lenticular hornblendic rock: (1) A micaceous quartzite containing a few crystals of hornblende. (2) A schistose hornblendic rock in which the hornblende is drawn into parallel layers in such a manner as to suggest a well-defined gneiss. (3) A very dark gray, almost black, schistose phase in which the hornblende crystals are much smaller than in either of the other phases. (4) An albitic phase in which phenocrysts of albite are very abundant.

The general strike of the rock varies from north ten degrees east to north twenty degrees east and the dip varies from sixty to eighty degrees east. On the west side of the road leading to Curtis Hollow one outcrop was found with strike north thirty degrees east and dip thirty degrees east.

A little north of the village of Bridgewater and just west of

PLATE XVII.



Quartzite, Barnard, showing steep dip.

the Woodstock -Bridgewater town line the line of contact between these hornblendic rocks and the phyllite schist which is Ordovician turns abruptly to the southeast and continues in this direction into Woodstock for about one-half mile south of the Ottaquechee River, where the line of contact turns again toward the southwest. The strike of north ten to twenty degrees east would carry these hornblendic rocks directly under the phyllite schist and limestones on the north side of the Ottaquechee River. This condition strikingly suggests a fault. It is not definitely proved that this lenticular terrance of hornblende schist, or paragenetic gneiss, is of sedimentary origin. The arguments given for a sedimentary origin as listed in the discussion of hornblendic rocks in Barnard will largely apply here. Arguments in favor of an igneous origin may be listed as follows: (1) The lenticular character of the formation. (2) The massiveness of the rock in several outcrops. (3) The presence of good crystals of tourmaline in the Curtis Hollow section. (4) Apparent apophyses of a basic igneous rock in the quartzitic phase of the Missisquoi Group, as found on the west side of the road to Curtis Hollow. (5) The abundance of plagioclase feldspar in certain layers of the terrane, for rocks highly feldspathic are more apt to be of igneous origin than of sedimentary origin.

What the original rock was is unknown. If the hornblende is all secondary, if the albite has been derived from more basic feldspars, and if the quartz is in part secondary, there is but little, if any, positive evidence of what the original rock was. The rock now suggests one that has been highly metamorphosed by some deep-seated intrusive acting as one of the agents of metamorphism.

ORDOVICIAN.

The Ordovician terranes lie to the east of the pre-Ordovician, probably Cambrian, terranes already described. In Barnard they cover a little more than the eastern half of the township. Pomfret lies entirely within the Ordovician. All of Woodstock save the extreme southern position is also Ordovician. Hartland, West Windsor and the eastern two-thirds of Reading as far as these townships appear on the Woodstock Quadrangle are all in the Ordovician. In the northern half of the state the Cambrian and the Ordovician terranes have been separated from each other by an erosional unconformity. In Woodstock there is a marked unconformity near Bridgewater for the hornblende schist just south of the river with dips as high as eighty degrees east is flanked on the east by phyllite schist with a dip of only ten to fifteen degrees east. Just where this contact enters Massachusetts on the south is only a matter of conjecture. Outcrops of unquestioned Ordovician age, in both the limestones and phyllite schists were found

this summer south of Reading in Cavendish and Chester. These are regarded as important discoveries because these formations have been considered by earlier geologists as pre-Ordovician. All of Hartland, and West Windsor as they appear on the Woodstock Quadrangle, together with the eastern part of Reading have been mapped by these authorities as pre-Ordovician. Now these areas are definitely proved to be of Ordovician age. The terranes involved are limestones, marbles, phyllites, mica schists and garnetiferous hornblende schists.

IRASBURG CONGLOMERATE.

The Irasburg Conglomerate with its striking characteristics as seen in Coventry, Irasburg, Albany, Craftsbury and Northfield does not appear as such in either Barnard or Woodstock. The erosional unconformity in Western Woodstock marks the continuation of the line of break between the Cambrian and Ordovician terranes.

WAITS RIVER LIMESTONE.

The Waits River limestone with its associated beds of marble traverses Barnard in two distinct belts. The largest one is found in the eastern part of the township. This extends northward into Royalton and southward through the eastern part of Bridgewater, across the entire township of Woodstock, and through Reading as far as Reading appears on the Woodstock Quadrangle. The other and much smaller belt is situated in the central part of Barnard. From Silver Lake, on whose shores is Barnard Village, this narrow belt of limestone extends northward into Royalton and southward for about two miles towards Bridgewater where it is replaced by phyllite.

The general strike of the limestones in Barnard varies from north ten degrees east to north twenty degrees east. North thirty degrees east was recorded in the eastern part of the township. Near the Barnard-Pomfret town line the dip is eighty degrees west. About two miles east of Silver Lake and one mile north of Lime Pond there is a very sharp anticline which would demand a synclinal trough in the limestones in the eastern part of Barnard.

The Waits River limestone with its associated marble beds occupies nearly all of the township of Pomfret. The two exceptions would be a narrow belt of phyllite in the northwestern part of the township, and a belt of mica schist extending southward across the township from Thistle Hill.

The general strike of the limestones varies from north ten degrees east to north twenty degrees east, but local beds vary widely from these figures. From the White River on the east to the crest of Bunker Hill the strike is at a low angle to the east. On the extreme east side the dip is thirty degrees east, while on the top of Bunker Hill the dip is zero. The strike here is due north and south. On the west leg of this anticline the dip soon becomes seventy to eighty degrees west. There is therefore a major anticline in the structure of the Waits River limestone in Pomfret.

In Woodstock about three-fourths of the area is occupied by the Waits River Limestone and its associated marble beds. The belt traverses ths entire length of the township and at its widest point is about five miles in width. This belt extends southward into Reading as far as Reading is represented on the Woodstock Quadrangle, and covers all of Hartland and West Windsor as far as they are represented on the Woodstock Quadrangle. A little south of the southern limit of Reading as represented on the Woodstock Quadrangle there appears to be a fault and the rocks change in composition abruptly. In general the strike of these limestones varies from north and south to north twenty degrees east, but an east and west strike was recorded in the western part of Hartland and also in Woodstock. As a rule the dips are at low angles both to the east and west, but in many outcrops the actual dip of both bedding planes and schistosity was uncertain.

Many of the beds are sufficiently massive and recrystallized to receive a handsome polish and are therefore a marble. It is often said that both the Washington phase which is uniformly a dark gray, and the Waits River phase which is light gray and closely plicated, are best suited for decorative interior work. The Washington phase especially as it appears in Woodstock is well suited for the purpose of massive construction. This is proved by numerous stone houses in Woodstock which are still in a good state of preservation. About one mile west of South Woodstock the J. P. Benedict house was erected in 1848 and still stands in good condition. The stone was quarried on the Benedict farm. The Alonzo S. Mack house in the Beaver Brook valley was erected in 1852 with limestone quarried on the Mack farm. This structure is also well preserved.

The school house at Prosper about one mile north of Woodstock was built in 1867 of stone quarried in the immediate vicinity. There is also a stone dwelling in which the stone is well preserved about one mile north of South Woodstock. This house was constructed with stone quarried on the farm but the date of erection was not ascertained.

On the hill road toward Bridgewater, and about one-half mile from the turn in the road to Meetinghouse Hill, the limestones and phyllites are interbedded in an interesting manner. In

a distance of one hundred feet across the strike there are seventeen beds of limestone and seventeen beds of phyllite. The strike here is north thirty degrees east. Near the point where the northeastern corner of Bridgewater joins both Pomfret and Woodstock

PLATE XVIII.

Interbedding of limestone and phyllite, Barnard Falls, Barnard.

there is an outcrop one hundred fifty feet across the strike that contains twelve beds of phyllite. At Barnard Falls on Barnard Brook the limestone is interstratified with the phyllite. Plate XVIII. Strikes were recorded here varying from north ten degrees east to north thirty degrees east, and with a dip of eighty degrees west. It must therefore not be expected that beds of phyllite are entirely absent from the area mapped in as limestone or that limestone beds are absent in areas mapped in as phyllite. The areas are mapped according to which type of rock appears to predominate.

In structure some of the beds are massive while others are shaly. In texture these limestones and marbles are fine to medium grained. In color the Washington phase is uniformly medium to dark gray. The Waits River phase is light gray and closely plicated. The Washington phase occupies a large part of the Woodstock area. On the farm of Cullen Bryant Snell near South Woodstock uniformly dark gray massive beds occur. Blocks ten feet or more in length and breadth can be secured. This area together with those listed above as furnishing constructional stone may all be listed as marble reserves. The limestones and marbles in Pomfret are mostly all of the Waits River phase. On the summit of Bunker Hill the limestone is very light in color. On the southeast side of Seaver Hill some beds are nearly white.

The only essential minerals in these rocks are calcite and quartz. In many instances the calcium carbonate has been completely recrystallized, and under the petrographic microscope shows perfect rhombohedral cleavages. The accessory minerals are a few scales of muscovite, occasionally biotite, sometimes seen on the weathered surface of exposed outcrops, and either microlites of pyrite, or a carbonate containing a little iron. A few crystals of phlogopite were found in the southern part of Woodstock and in Reading. Zoisite is sometimes an accessory mineral especially in Pomfret. Uncombined carbon provides the pigment. The rock is best classified as a quartzose marble and a quartzite combined.

MEMPHREMAGOG GROUP.

The Memphremagog Group consists of slates and phyllites. From Bethel northward to the international boundary the slates have been practically continuous, but with their best development in Northfield, Montpelier, Coventry and Newport. The phyllites have been more or less broken in their continuity by beds of limestone with which they are often interstratified.

SLATE.

The Memphremagog slate which has been so persistent a terrane to the northward does not appear as such either in Barnard or Woodstock. The terrane has lost its fissility so that it is no longer a commercial possibility as a roofing material. The position normally occupied by the slate belt is now represented by

the more highly metamorphosed, fine grained, graphitic, phyllite schist.

RANDOLPH PHYLLITE.

The Randolph phyllite which is a member of the Memphremagog group forms a very prominent terrane in Royalton, Barnard, Bridgewater, Woodstock and Reading. It extends as far south as Reading and is represented on the Woodstock Quadrangle. How much further to the southward it extends is unknown. When Reading and Cavendish are worked as such for the survey some interesting discoveries will be made. It is interesting already to note that the Randolph phyllite and the Waits River limestone were both found this summer in Cavendish.

The general strike of the Randolph phyllite in Barnard, Bridgewater and Woodstock varies from north and south to north ten degrees east. Local strikes of north twenty degrees east and north twenty degrees west were recorded. In Barnard the phyllites are closely folded into anticlines and synclines, but in Woodstock the dips became low both to the east and to the west.

In the northern extension of this phyllite into Royalton in the neighborhood of Kents Ledge the terrane is closely folded and often plicated. Plate XIX illustrates this folding. The strike varies from north and south to north twenty-five degrees east and the dip from forty-five degrees east to vertical. In the pasture on the farm of H. C. Harrington the closely folded anticlines and synclines are very abundant.

The crest of Long Hill which in western Woodstock attains an altitude of 2,350 feet carries in the phyllite numerous well-defined garnets which stand out in bold relief on the weathered surface. This phyllite is also calcitic.

WOODSTOCK SCHIST.

The term Woodstock schist is here introduced for the first time into Vermont geological literature. The terranes involved seem unquestionably to belong to the Ordovician group. It may be considered by some field geologists to be the Vershire schist of earlier reports. The Vershire schist in its broad expanse in the township of Bradford and to a more limited extent in St. Johnsbury overlies the Waits River limestone. The Woodstock schist apparently underlies the Waits River limestone. If this interpretation is true then the Vershire schist and the Woodstock schist represent two different geological formations and a new name is needed, hence the termination Woodstock schist. The Woodstock schist therefore is represented by two beds intercalated in the Waits River limestone that are very quartzose, micaceous, and grade into a micaceous quartzite. Certain beds carry abundant garnet and hornblende.

There are two belts of the Woodstock schist in the area involved in this report. The larger one is confined almost entirely to Pomfret. Its northern terminus is on Thistle Hill in Pomfret

PLATE XIX.

Crumpled phyllite, Royalton.

and its southern limit as far as shown on the Woodstock Quadrangle is on the south slope of Blake Hill in Woodstock. The Skunk Hollow Valley to the east of Blake Hill is occupied by limestone. The general strike varies from north and south to

north twenty degrees east. The dip on the eastern side of the formation is to the east and on the western side to the west. The structure is an anticline and represents the southern extension of the major anticline in the limestone series as represented on Bunker Hill and to the northward.

The second and smaller belt of the Woodstock schist occupies a limited area around Mt. Tom in Woodstock. It extends south of the Ottaquechee River for perhaps one-half mile. It may be an open question whether the garnetiferous, hornblendic rock under the iron bridge on Elm Street, Woodstock, belongs to this schist or whether it represents a highly altered igneous rock.

The classifications and delineations of this terrane around the village of Woodstock must be taken tenatively and the work considered only as reconnaissance, for time did not permit this summer the detailed field work so much needed. It is hoped that next summer this area can be worked out in greater detail for the next Biennial Report of the State Geologist.

ACID INTRUSIVES.

GRANITE.

The only granite outcrop in the area covered by this report is located on the southwest side of Seaver Hill in the township of Pomfret. The Pomfret granite exposure is approximately one-half mile in length and five hundred feet in breadth in the widest place observed. It is furthermore situated about four miles from Taftsville, practically due north of Taftsville, and five miles from Quechee. It is down grade all the way to Quechee, which favors haulage. A little stone has been quarried but no systematic quarry opening was found. The stone is a constructional granite rather than a monumental one. It is very light gray in color due to a paucity of biotite, but it is not as white as either the Bethel granite or the Randolph granite. It receives a good polish but the contrast in colors on the polished face is not strong. It has been used somewhat for constructional work in Woodstock.

The mineral composition of this granite is quartz, albite, microcline and muscovite. A few grains of epidote and a few plates of biotite were observed. As the albite is in excess of the microcline the rock may be classified as a soda granite. In texture this granite is from fine to medium. The supply is ample.

APLITE.

A very interesting array of aplite dikes occurs near the sawmill on Locust Creek in Barnard and at the site of an abandoned mill. In this creek bed the sericite is cut by an intrusive now altered to chlorite. The sericite schists and the chlorite schists are cut by ten or more aplite dikes and sills. These three different types of rock are all cut by quartz veins which are at right angles to the strike of the sedimentary schists.

This aplite is slightly porphyritic with a very fine ground mass that is largely feldspar. The phenocrysts are albite-oligoclase. Quartz is fairly abundant in the ground mass. There is a paucity of muscovite but this is mostly, if not all, primary. There are a few grains of epidote and calcite present. There is present also a nearly isotropic, colorless mineral of high index of refraction. Biotite, chlorite and hornblende are absent.

BARNARD GNEISS.

The rocks included under this caption as found in Barnard and Woodstock are foliated granitoid rocks that correspond in their mineralogical composition to some of the plutonic rocks. As a rule in texture they are medium to coarse grained, but there is one outcrop of this gneiss on the west side of Locust Creek that is fine grained.

The Barnard gneiss was first observed in the railroad cut about two miles north of Bethel village. It appears again on the east slope of the hill just west of Bethel. It appears also in the southeastern corner of Royalton. In Barnard, where it is best developed, and from which township it receives its name, it provides a continuous outcrop for several miles. One belt lies between Cleveland Brook and Locust Creek, in the northern part of Barnard near the Barnard-Royalton town line. Here it forms a very prominent terrane.

A second and larger outcrop appears on the west side of Locust Creek and again on the east side of Locust Creek south of the confluence of Silver Lake Brook with Locust Creek about one mile north of the village of Barnard. This narrow belt of gneiss continues southward through Barnard into Bridgewater. This southern extension can be observed around the western half of Lakota Lake. A third outcrop of the Barnard gneiss can be found about three miles southwest of Barnard and west of Locust Creek. This may be regarded as an outlier. The sericite schists on either side dip away from the gneiss.

A fourth outcrop of this gneiss appears in the extreme southwestern corner of Woodstock, a little to the northeast of Meccawe Pond. A good exposure can be seen near the crest of the hill and near the fork of the road one-half mile northeast from Meccawe Pond. Twinned plagioclase feldspars are very abundant even in hand specimens. The strike of the outcrop as a whole is north twenty degrees east and, if a sediment, the dip is forty-five degrees west.

On the west slope of the hill leading down to Meccawe Pond this gneiss shows a sharp dome-like structure. The gneiss is here particularly rich in its twinned plagioclase feldspars. Microscopic slides prove this outcrop a granite gneiss.

In structure the Barnard gneiss in all its outcrops is gneissoid. The beds are quite thick and massive in certain instances north of Meccawe Pond. In texture it is medium to coarse grained. In color it is light gray tinged with green from the presence of chlorite and epidote. North of Meccawe Pond the epidote is very abundant. In mineral composition quartz and albite to albite-oligoclase are the most abundant constituents. In most cases biotite exceeds the muscovite, and orthoclase, chlorite, epidote, magnetite (ilmenite or titanite), are the accessories. Rarely a few crystals of hornblende have been observed.

BASIC INTRUSIVES.

Basic intrusives are fairly abundant in the eastern half of Vermont. They have invaded both the Cambrian and the Ordovician terranes, but are more abundant in the former than in the latter formations. The converse holds true of the acid intrusives. The granites are far more abundant in the limestones and their associated phyllites than in the sericite schists and sericitic quartzites. The basic intrusives consist of diorites, diabases, gabbros, camptonites, epidosites, pyroxenites and peridotites. They are not all present in any given township. The epidosites that were so abundant on McIntosh Hill in Bethel, the amphibotites that were prominent on Oak Hill in Bethel, the camptonite that is so well developed by the side of the state road in Bridgewater, the pyroxenite that appears in Reading at Hammondsville, and the peridotite such as furnished the verd antique marble of Roxbury, are all wanting in the area covered by this report.

DIORITE AND DIORITE GNEISS.

The diorites are granitoid igneous rocks whose chief feldspar is plagioclase, usually andesine, and whose chief ferromagnesium mineral is hornblende, but augite may be present in an appreciable amount and the rock becomes an augite diorite. An appreciable amount of quartz gives rise to the term quartz diorite. Chlorite, epidote, magnetite, or ilmenite, and apatite are common accessories.

On the crest of the hill road about one mile west of Barnard there occurs a diorite dike with strike approximately north twenty degrees east. In this dike the hornblende is well developed and very prominent. The dike is in the Cambrian terranes.

On the high altitudes in the extreme southwestern corner of Woodstock there occurs a diorite dike with strike of north ten degrees west. This dike is also in the Cambrian terranes.

By far the largest and the most interesting of the diorite outcrops in the area involved in this report occurs in and around the village of Woodstock. The hornblende has largely been arranged in more or less parallel layers and the rock is here classified as a diorite gneiss. Excellent exposures can be found on Crusher Street within the village. This street is on the south side of the Ottaquechee River. In these exposures where the rock has been worked as a road metal, the plagioclase is andesine. This diorite is in the Ordovician terranes.

A rock here listed as a diorite gneiss extends southward from Woodstock for about one mile. It includes the Mt. Peg area, but not Blake Hill. A gabbroic phase appears about one mile south of Woodstock on the road to Hartland. This diorite gneiss appears also on the north side of the Ottaquechee River. It may embrace a considerable portion of the Mt. Tom area although the western part at least of this area is the Woodstock schist. The gneiss occurs also about one-half mile east of Woodstock on the north side of the river. Probably the mass under the Elm Street Bridge in the village of Woodstock belongs to the same formation. This area is highly garnetiferous. Some of the garnets are two inches in diameter. The form is that of a rhombic dodecahedron. Excellent museum samples can here be secured. Secondary hornblende occurs in crystals up to four and five inches in length. The outcrop also carries a small pegmatite vein. The strike of the beds in the river appears to vary from north ten degrees east to north twenty degrees east and the planes of schistosity to dip forty-five degrees east. Whether this outcrop represents a highly metamorphosed Ordovician sediment or a basic igneous rock is not yet proved. Very detailed field work and the careful study of many petrographic slides are necessary before a final conclusion can be drawn as to the origin of these rocks. In the Mt. Peg area plagioclase feldspar, albite to albite-oligoclase, is very abundant. It is not certain that this albite was not derived through metamorphism from a more basic feldspar. There may have been two periods of intrusion here, one of which furnished the larger area of the highly garnetiferous diorite gneiss and the other the smaller area on Crusher Street which now carries the definite plagioclase feldspar, andesine.

GABBRO AND CHLORITE SCHIST.

Normally a discussion of these two types of igneous rocks would be given separately but their intimate association in one locality in Barnard and Royalton renders their separate discussion impractical in this report. The area involved falls in the extreme northern part of Barnard and the southwestern corner of Royalton and lies between Cleveland Brook and Locust Creek. The area is flanked on the east by the Barnard gneiss and on the west by the sericite schist of Cambrian age.

The gabbro varies in texture from medium to coarse grained. In structure it is gneissoid to massive. The plagioclase feldspar, albite-oligoclase, is subordinate to the hornblende. Chlorite, epidote and magnetite are accessories. Perhaps a part of the magnetite was secondarily formed during the process of chloritization.

The chlorite schist in one exposure measured fifteen feet by ten feet by eight feet. In another outcrop it was in actual contact with the gabbro with little stringers of chlorite schist from one to three inches in width extending into the gabbro. Between these stringers the gabbro sometimes was in excess reaching as high as six inches in width. There seemed to be no doubt as to this particular chlorite schist being derived from the gabbro.

While chlorite is the one essential mineral in this schist a considerable amount of green hornblende is present. Epidote and magnetite are fairly abundant. Large grains of zircon are fairly abundant. Limonite is also present.

DIABASE.

Dikes of diabase occur in the area involved in this report in both the Cambrian and the Ordovician terranes. As a rule these dikes are dark colored, massive, fine grained, ophitic rocks whose essential mineral constituents are the pyroxene, augite, and the plagioclase feldspar, labradorite. Magnetite is invariably present. Sometimes the magnetite is very abundant and sometimes it appears only as a minor accessory mineral. In some slides a part of the magnetite is secondary. Hornblende is frequently present perhaps derived from augite. Epidote is common. Quartz is absent. Some of the dikes bear many solution cavities subsequently filled with secondary calcite.

In Royalton, about one mile west of Royalton Center on the farm of A. A. Turner, five different dikes occur within a very limited area, cutting Ordovician phyllite. These dikes may or may not be of the same age. They vary in both texture and composition.

No. 1. Strike north fifty-five degrees east. Dip thirty-five degrees northwest. Width two feet.

No. 2. Strike north forty-five degrees east. Dip nearly vertical. Width ten inches.

No. 3. Strike north seventy-six degrees east. Dip nearly vertical. Width eighteen inches.

No. 4. Strike north sixty-five degrees west. Dip nearly vertical. Width varies from one to two feet.

No. 5. Strike north sixty degrees west. Dip nearly vertical. Width varies widely.

In the northwestern part of Barnard as represented on the Woodstock quadrangle there are four dikes, three of which have a strike nearly east and west while the fourth dike has a strike of approximately north thirty degrees west. This dike is found on the west slope of the hill road to Gaysville. It shows the characteristic diabasic texture. The lath-shaped feldspar is labradorite and the pyroxene is augite. Long prismatic crystals of hornblende are present. Magnetite is very abundant. Calcite, chlorite and epidote are secondary. In some of the dikes the feldspar appears more acid than labradorite.

About two miles west of South Woodstock there is a diabase dike that shows spheroidal weathering well. The spheroids vary in diameter from a few inches up to eighteen inches. The width of the dike is eleven feet. The strike is north forty degrees east, and the dip nearly vertical.

On the road over the southern end of Bailey Hill and about one-half mile west of the A. B. Morgan farm there is a large diabase dike whose strike is nearly east and west. This dike is from twenty to twenty-five feet in width and very massive.

In Reading some two miles west of the Brown school house, now Camp Balsam, there is a diabase dike about two feet in width. Its strike is north ten degrees east.

A very interesting dike occurs in the gorge at Quechee Gulf. This dike is twenty feet in diameter and of much finer texture on either side than in the center. The petrography of these last dikes is not yet ready for publication.

PALEONTOLOGY.

As yet no fossils have been found in the pre-Ordovician terranes on the eastern side of the Green Mountains. It is hoped each year that some important diagnostic feature will be discovered, but diligent search in the most promising localities thus far has failed to reveal the presence of a fossil. The relative age of these formations has been determined by their stratigraphic position, continuity and lithological characteristics. They are unquestionably post-Algonkian for the base of the series is the Sherburne conglomerate which overlies the Algonkian. They occupy an inferior position to the Irasburg conglomerate which forms the base of the Ordovician in eastern Vermont. Therefore the terranes listed as Cambrian are unquestionably pre-Ordovician.

The discovery of new beds of graptolites in scattered occurrences in Barnard, Pomfret, Woodstock, Reading and Cavendish is significant. The graptolites are not numerous nor are they as well preserved as in some of the more northern sections.

Perhaps the best exposure is in the northern part of Pomfret in the area represented by the northeast corner of the Woodstock Quadrangle.

ECONOMICS.

The economic possibilities of Barnard, Pomfret and Woodstock are not striking features. Within the area involved there are no metallics of commercial significance. Talc, verd antique marble and slate which have been somewhat prominent factors in the more northern townships are wanting. The Pomfret granite on the southwest slope of Seaver Hill is a good constructional stone. The supply is ample. The distance of haulage, downgrade, five miles to Quechee for shipment by rail is not prohibitive. Its uniform light gray color would render it pleasing in the finished structure.

The Waits River limestone, Washington phase, furnishes several merchantable beds in Woodstock. The numerous stone houses in the township of Woodstock will show its value in constructional work. Some of these have stood for over seventy-five years and the stone is still well preserved. It must be remembered that the stone used was only surface rock. This marble is susceptible of a high polish. The contrast between the polished and hammered faces is strong. The marble can be used as a monumental stone and must be classified as a marble reserve.

Drift boulders along the Ottaquechee River are now being used in the construction of the Episcopal Church in Woodstock.

Excellent road building metal occurs in large abundance in the diorite outcrops just south of the village of Woodstock. The supply is ample for every road in the township. Several small quarries have been opened and the stone crushed for road work. These quarry openings have all been abandoned. No systematic quarry opening has ever been made here although the location is ideal.

REPORT

OF THE

STATE GEOLOGIST

ON THE

MINERAL INDUSTRIES AND GEOLOGY

OF

VERMONT

1925-1926

FIFTEENTH OF THIS SERIES

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STAFF OF THE VERMONT GEOLOGICAL SURVEY, 1925-1926.

GEORGE H. PERKINS, *State Geologist, Director.*
University of Vermont.
ELBRIDGE C. JACOBS, *Assistant Geologist.*
University of Vermont.
CHARLES H. RICHARDSON, *Assistant Geologist.*
Syracuse University.
CLARENCE E. GORDON, *Assistant Geologist.*
Massachusetts Agricultural College.
E. J. FOYLES, *Field Assistant.*
Rochester University.
G. W. BAIN, *Field Geologist.*
Amherst College.

CONTRIBUTING GEOLOGISTS.

G. H. HUDSON, Plattsburg, N. Y.
ROBERT BALK, Columbia University.
B. F. HOWELL, Princeton University.
W. L. BRYANT, Providence, R. I.

CONTENTS.

SUMMARY REPORT ON THE GEOLOGY OF PLYMOUTH AND BRIDGEWATER, VT.

E. L. Perry.

The field work upon which this present summary report is based, was carried out during the field seasons of 1925-26 in the townships of Plymouth and Bridgewater, located in the eastern foothills of the Green Mountains and about fifteen miles east of the city of Rutland. The rocks of the Plymouth-Bridgewater area are of particular interest since they include the older or lower part of a series of metamorphosed sediments, the younger members of which have been the subject of a long continued study by Dr. C. H. Richardson of the Vermont State Geological Survey.

The region is a maturely dissected upland with a relief of about one thousand feet. Features of two cycles of erosion are now present; glaciated, mature, large valleys and upland, and youthful post-glacial tributary valleys. No direct evidence of former peneplaination is visible in the district and during the Cretaceous period the area was probably a portion of a belt of low hills, intermediate between the monadnock ridge of the Green Mountains to the westward and a peneplain to the eastward.

The principal rocks comprise a series of metamorphosed sediments ranging in age from Ordovician through probable Cambrian to pre-Cambrian. The various formations outcrop in parallel bands oriented approximately north and south, the youngest on the east and successively older bands appearing in order westward.

The formations, in order of age from youngest to oldest and of outcrop from east to west, are:

1. The Waits River Limestone and Randolph Phyllite, outcropping in the northeast corner of Bridgewater, shown to be of Ordovician age by the work of Dr. C. H. Richardson in central Vermont and representing former interbedded sandy limestones and carbonaceous shale.
2. The Missisquoi formation, of probable Cambrian age, sericite-quartz schist in the upper part and micaceous and hornblendic schists of considerable variety in the lower part, representing impure quartz sandstone and shales.
3. The Bethel Schist, underlying the Missisquoi, a very uniform gray-green quartz-chlorite-sericite schist bearing numerous small lenses of granular quartz and which is a metamorphosed equivalent of a shale.

4. The Ottauquechee formation, named by the writer from the type exposures on the Ottauquechee River in Bridgewater, a black phyllite with shaly parting, interbedded with massive grey quartzite streaked with white quartz veinlets, the whole formation representing original interstratified carbonaceous shale and sandstone.
5. The Pinney Hollow Schist, named by the writer from type exposures in Pinney Hollow in Plymouth, a uniform pale green quartz-chlorite-sericite schist usually intensely plicated and resembling the Bethel Schist in lithology and origin.
6. A group of light brown or gray quartzites, often with slaty parting, underlain by dolomite and massive, feldspathic quartzite, and latter grading into a metamorphosed conglomerate in southern Plymouth. These strata are the equivalent of impure sandstones with beds and lenses of dolomite.
7. A dark quartz-chlorite-mica schist with abundant small metacrysts of albite, the whole representing a metamorphosed shale, as indicated by protected fragments found in overlying dolomite.
8. White or pink dolomite closely associated with feldspathic, occasionally pebbly, quartzite comprising the lowest member of the Cambrian (?) section.
9. The highly metamorphosed pre-Cambrian mica schists and gneisses of the Green Mountain axis, outcropping in the southwestern part of Plymouth.

Intruding the sedimentary series are plutonic rocks of at least four different ages. 1. Pre-Cambrian gneisses ranging in composition from granitic to gabbroic. 2. Amphibolites and steatite representing early Paleozoic (?) intrusions of basic rocks, common in the pre-Ordovician section. 3. Unmetamorphosed albite granite, similar to the Bethel Granite, a rock composed essentially of quartz and albite, and of late Paleozoic age. 4. Unmetamorphosed basaltic dikes, commonly either diabase or camptonite, probably in part related to the nearby Mount Ascutney and Cuttingsville intrusives and possibly in part related to the Triassic diabase intrusives of the Connecticut valley. Vein quartz, and more rarely pegmatite, is common throughout the Paleozoic rocks in the form of small veins and irregular masses, probably of early Paleozoic age.

The structures of the strata in the area are often obscure because of lack of indication of original bedding. In the upper pre-Cambrian rocks the beds are probably folded in large isoclines overturned strongly to the west and the dip of the strata is about twenty-five degrees east. The Lower Cambrian (?) section is a homocline with dip approximately forty-five degrees east.

In the higher members of the section the dip approaches the vertical and small isoclinal folds are very abundant. The Ordovician phyllite and limestone is closely folded and the dips range within a few degrees of the vertical, either east or west. The strike is consistently near north and south throughout the section, but varies locally.

Glacial stream deposits, kames and terraces, are common in the large valleys and unsorted till deposits cover much of the upland. Deranged drainage is well shown by the presence of abandoned stream channels, associated particularly with the Black River drainage system.

Mineral deposits of economic importance are limited to dolomite, used for making lime, white granite for exterior construction, and gravels for local road metal. Deposits of gold and soapstone are present, but are of doubtful commercial value, judged from present surface exposures.

LOCALITY LIST OF VERMONT INVERTEBRATE FOSSILS.

EDWARD J. FOYLES

The list of Vermont localities at which fossils have been observed or collected was derived from references in literature. Where possible, the reference to localities as listed in the Vermont State Geologist Reports is given. All references are abbreviated as much as possible.

Although many of the localities and ages could not be specifically indicated, it is hoped that this list will interest the layman in the remains of ancient life in his district and serve for groundwork in the investigations of the specialist.

EXPLANATION OF ABBREVIATIONS

A. J. S.—American Journal of Science.
Ann. R. U. S. G. S.—Annual Report of the United States Geological Survey.
A. M. N. H.—American Museum of Natural History.
B. A. M. N. H.—Bulletin of the American Museum of Natural History.
B. G. S. A.—Bulletin of the Geological Society of America.
B. U. S. N. M.—Bulletin of the United States National Museum.
B. U. S. G. S.—Bulletin of the United States Geological Survey.
Geol. Vt.—Geology of Vermont, C. H. Hitchcock, 1861.
R. N. Y. S. M. N. H.—Report of the New York State Museum of Natural History.
R. V. S. G.—Report of the Vermont State Geologist.
Tr. N. Y. A. S.—Transactions of the New York Academy of Sciences.

The references given in the following list will indicate other references of value to the investigator. For the sake of economy of space all unnecessary references are omitted.

ADDISON, 2 mi. E., road to New Haven Jct., N. of mt.
Trenton.
Diplograptus foliaceous (Murchison). R. V. S. G., XII, p. 242.

ADDISON COUNTY.
Chazy.
Girvanella ocellata (Seely). R. V. S. G., III, p. 156, pls. 56, 57, figs. 3, 4, LIX.

ADDISON, Chimney Point.
Trenton.
Calymene senaria Conrad. Geol. Vt. I, p. 300.
Cryptolithus tessellatus Green. Geol. Vt. I, p. 300.
Endoceras proteiforme Hall. R. V. S. G., VII, p. 49.
Orthoceras junceum Hall. R. V. S. G., VII, p. 49.
Prasopora simulatrix orientalis Ulrich. A. M. N. H., No. $\frac{637}{6}$.

ADDISON, Snake Mountain.
Cambrian.
Scolithus canadensis Billings. B. U. S. N. M., 92, p. 1153.

ALBURG.
Trenton.
Diplograptus foliaceous (Murchison). R. V. S. G., X, p. 212.

ALBURG, E. shore.
Trenton.
Triarthrus becki Green. R. V. S. G., X, p. 212.

ALBURG PENINSULA.
Trenton, Canajoharie.
Glossograptus quadrimucronatus (Hall). R. V. S. G., XIII, p. 167.

ALBURG, Windmill Point.
Canajoharie.
Glossograptus quadrimucronatus (Hall). R. V. S. G., XII, p. 97.
Lasiograptus eucharis (Hall). R. V. S. G., XII, p. 97.
Leptobolus insignis Hall. R. V. S. G., XII, p. 97.

ALBURG, Coon Point.
Trenton.
Triarthrus becki Green. R. V. S. G., XIII, p. 166.

ALBURG, 1½ mi. E. of Windmill Point.
Canajoharie to northern Trenton transition.
Calymene senaria Conrad. R. V. S. G., XII, p. 97.
Dalmanella rogata (Sardeson). R. V. S. G., XII, p. 97.
Lepidocoleus jamesi (Hall and Whitfield). R. V. S. G., XII, p. 97.
Lingula curta Conrad. R. V. S. G., XII, p. 97.
Palaeoglossa trentonensis (Conrad). R. V. S. G., XII, p. 97.
Primitia sp. R. V. S. G., XII, p. 97.
Primitiella unicornis (Ulrich). R. V. S. G., XII, p. 97.
Tetradella subquadrans radiomarginata Ruedemann. R. V. S. G., XII, p. 97.
Ulrichia bivertex (Ulrich). R. V. S. G., XII, p. 97.
Zygospira exigua (Hall). R. V. S. G., XII, p. 97.

ARNOLD BAY.
Glens Falls.
Bythocypris cylindrica (Hall). R. V. S. G., XII, p. 94.
Spyroceras bilineatum (Hall). R. V. S. G., XII, p. 94.
Trenton.
Aparchites minutissimus (Hall). R. V. S. G., XII, p. 93.
Calymene senaria Conrad. R. V. S. G., XII, p. 93.
Ceraurus pleurexanthemus Green. R. V. S. G., XII, p. 93.
Climacograptus typicalis Hall. R. V. S. G., XII, p. 94.

Ctenodonta levata (Hall). R. V. S. G., XII, p. 94.
Dalmanella rogata (Sardeson). R. V. S. G., XII, pp. 93, 94, 95.
Dinorthis meedsi Winchell & Schuchert. R. V. S. G., XII, p. 94.
Isotelus sp. R. V. S. G., XII, p. 93.
Leperditia sp. R. V. S. G., XII, p. 93.
Liospira americana (Billings). R. V. S. G., XII, p. 94.
Mesotrypa quebecensis (Ami). R. V. S. G., XII, pp. 93, 94.
Parastrophia hemiplicata Hall. R. V. S. G., XII, p. 93.
Plectambonites sericeus (Sowerby). R. V. S. G., XII, p. 93.
Primitia sp. R. V. S. G., XII, p. 94.
Rafinesquina sp. R. V. S. G., XII, pp. 93, 94.
Rhynchotrema increbescens (Hall). R. V. S. G., XII, p. 94.
Streptelasma corniculum Hall. R. V. S. G., XII, p. 94.
Zygospira exigua (Hall). R. V. S. G., XII, p. 93.
Canajoharie.
Amplexograptus macer Ruedemann. R. V. S. G., XII, p. 95.
Bathyurus cf. spiniger (Hall). R. V. S. G., XII, p. 94.
Calymene senaria Conrad. R. V. S. G., XII, p. 95.
Ceraurus sp. R. V. S. G., XII, p. 95.
Climacograptus spiniferus Ruedemann. R. V. S. G., XII, p. 94.
Climacograptus spiniferus Ruedemann (*bicornis auct*). R. V. S. G., XII, p. 94.
Climacograptus strictus Ruedemann. R. V. S. G., XII, p. 94.
Climacograptus strictus Ruedemann (*putillus auct*). R. V. S. G., XII, p. 94.
Corynoides calicularis Nicholson. R. V. S. G., XII, pp. 94, 95.
Cryptolithus tessellatus Green. R. V. S. G., XII, pp. 94, 95.
Diplograptus amplexicaulis Hall. R. V. S. G., XII, pp. 94, 95.
Diplograptus vespertinus (Ruedemann). R. V. S. G., XII, p. 95.
Geisonoceras sp. R. V. S. G., XII, p. 95.
Glossograptus quadrimucronatus cornutus Ruedemann. R. V. S. G., XII, p. 95.
Lasiograptus eucharis (Hall). R. V. S. G., XII, pp. 94, 95.
Lepidocoleus jamesi (Hall and Whitfield). R. V. S. G., XII, p. 94.
Leptobolus insignis Hall. R. V. S. G., XII, pp. 94, 95.
Lingula sp. R. V. S. G., XII, p. 95.
Lingula curta Conrad. R. V. S. G., XII, p. 94.
Mastigograptus sp. R. V. S. G., XII, p. 95.
Mesograptus mohawkensis Ruedemann. R. V. S. G., XII, pp. 94, 95.
Orthoceras sp. R. V. S. G., XII, p. 95.
Primitiella unicornis (Ulrich). R. V. S. G., XII, p. 94.
Schizambon canadensis (Ami). R. V. S. G., XII, p. 94.
Trematis terminalis (Emmons). R. V. S. G., XII, p. 95.
Ulrichia bivertex (Ulrich). R. V. S. G., XII, p. 94.

BARNARD, N. of.
Ordovician.
Graptolites. R. V. S. G., XIV, p. 101.

BARNARD, ¼ mi. E. of.
Ordovician.
Graptolites. R. V. S. G., XIV, p. 101.

BENNINGTON.
Cambrian
Hyolithes communis Billings. 10 Ann. R. U. S. G. S., p. 574.

Hyolithes impar. A. J. S. (4), 30, p. 268, 1910.
Nothozoe sp. R. V. S. G., X, p. 230.
Nothozoe vermontana Whitfield. 10 Ann. R. U. S. G. S., p. 574.
Scolithus linearis (Haldemann). 10 Ann. R. U. S. G. S., p. 572

BENNINGTON, 2 mi. E. Weeks farm N. of Windham turnpike.
Cambrian.
Hyolithes sp. R. V. S. G., V, p. 124.
Nothozoe sp. R. V. S. G., V, p. 124.
Olenellus sp. R. V. S. G., V, p. 124.

BENNINGTON, 3 mi. S.
Trenton.
Dendrocrinus gracilis (Hall). R. V. S. G., V, p. 126.
Orthoceras sp. R. V. S. G., V, p. 126.
Rhynchonella sp. R. V. S. G., V, p. 126.

BENSON, 3 mi. N. of.
Cambrian.
Hyolithes communis Billings. 19 Ann. R. U. S. G. S., p. 182.
Leperditia dermatoides Walcott. 19 Ann. R. U. S. G. S., 1899, p. 182.
Lingulella coelata Hall. 19 Ann. R. U. S. G. S., 1899, p. 182.
Lingulella granvillensis Walcott. 19 Ann. R. U. S. G. S., 1899, p. 182.
Linnarssonia sagittalis var. taconica Walcott. 19 Ann. R. U. S. G. S., 1899, p. 182.
Orthis salemensis Walcott. 19 Ann. R. U. S. G. S., 1899, p. 182.
Solenopleura tumida Walcott. 19 Ann. R. U. S. G. S., 1899, p. 182.

BENSON, NW.
Lowville, 6 ft. bed.
Phytopsis tubulosa (Hall). Geol. Vt., I, p. 277, fig. 175.

BENSON, road to Forbes Hill.
Chazy B.
Maclurites magnus (Lesueur). R. V. S. G., XII, p. 168.

BENSON, Bangall, E. side of road through to Hortonville ½ mi. E. of Howard Hill.
Chazy B.
Maclurites magnus (Lesueur). R. V. S. G., XII, p. 167.

BENSON, Stony Point, 200 yds. E. of Wm. White place.
Beekmantown.
Ophileta complanata Vanuxem. R. V. S. G., XII, p. 165.

BETHEL, sh. ls. N. of granite on Fifield farm, road to quarries on Christian Hill.
Ordovician.
Graptolites. R. V. S. G., XIV, p. 101.

BETHEL, EAST, W. of.
Ordovician.
Graptolites. R. V. S. G., XIV, p. 101.

BRANDON.
Stromatopora. A. J. S. (3), VI, p. 276, 1873.

BRIDPORT.
Trenton.
Mesotrypa quebecensis (Ami). B. U. S. N. M., 92, p. 804.

BRIDPORT, NW., H. Smith farm.
Canajoharie.
Diplograptus amplexicaulis Hall. R. V. S. G., XIV, p. 212.

BRIDPORT, NW corner.
Trenton.
Calymene senaria Conrad. R. V. S. G., XIV, p. 212.
Conularia trentonensis Hall. R. V. S. G., XIV, p. 212.
Cryptolithus tessellatus Green. R. V. S. G., XIV, p. 212.
Dalmanella rogata (Sardeson). R. V. S. G., XII, p. 212.
Geisonoceras tenuitextum (Hall). R. V. S. G., XIV, p. 212.
Orthoceras amplicameratum Hall. R. V. S. G., XIV, p. 212.
Plectambonites sericeus (Sowerby). R. V. S. G., XIV, p. 212.
Prasopora simulatrix orientalis Ulrich. R. V. S. G., XIV, p. 212.
Schizocrania filosa Hall. R. V. S. G., XIV, p. 212.
Sinuites cancellatus (Hall). R. V. S. G., XIV, p. 212.

BRIDPORT, 2 mi. on Middlebury road.
Trenton.
Cryptolithus tessellatus Green. R. V. S. G., XIV, p. 212.
Dalmanella rogata (Sardeson). R. V. S. G., XIV, p. 212.
Prasopora simulatrix orientalis Ulrich. R. V. S. G., XIV, p. 212.
Zygospira recurvirostris (Hall). R. V. S. G., XIV, p. 212.

BRIDPORT, WEST, ferry landing.
Glens Falls.
Calymene senaria Conrad. R. V. S. G., XIV, p. 210.
Cryptolithus tessellatus Green. R. V. S. G., XIV, p. 210.
Endoceras proteiforme Hall. R. V. S. G., XIV, p. 211.
Isotelus gigas deKay. R. V. S. G., XIV, p. 210.
Orthis tricenaria Conrad. R. V. S. G., XIV, p. 210.
Palaeoglossa trentonensis (Conrad). R. V. S. G., XIV, p. 210.
Plectambonites sericeus (Sowerby). R. V. S. G., XIV, p. 210.
Prasopora simulatrix orientalis Ulrich. R. V. S. G., XIV, p. 210.
Trematis terminalis (Emmons). R. V. S. G., XIV, p. 210.
Zygospira recurvirostris (Hall). R. V. S. G., XIV, p. 210.

BURLINGTON, Phelps quarry.
Cambrian.
Algae casts. R. V. S. G., X, p. 223.
Worm borings. R. V. S. G., X, p. 223.

BURLINGTON, W. side Muddy Brook near Williston road.
Trenton.
Cryptolithus tessellatus Green. R. V. S. G., X, p. 224.

BURLINGTON.
Pleistocene.
Macoma balthiea Linn. R. V. S. G., VII, p. 55.
Saxicava rugosa Linn. R. V. S. G., VII, p. 55.

BUTTON BAY.
Upper Chazy.
Solenopora compacta (Billings). R. V. S. G., X, p. 226.

Black River.
Strophomena incurvata (Shepard). A. M. N. H., Cat. No. 597.
Canajoharie.
Corynoides calicularis Nicholson. R. V. S. G., XII, p. 95.
Glossograptus quadrimucronatus (Hall). R. V. S. G., XII, p. 95.
Leptobolus insignis Hall. R. V. S. G., XII, p. 95.
Worms, new species. R. V. S. G., XII, p. 95.

BUTTON ISLAND.
Black River.
Columnaria alveolata Goldfuss. Geol. Vt. I, p. 281.
Columnaria halli Nicholson. R. V. S. G., X, p. 226.
Cycloceras olorus (Hall). Geol. Vt. I, p. 281.
Leperditia fabulites (Conrad). R. V. S. G., VII, p. 49.
Phytopsis sp. Geol. Vt., I, p. 281.
Spyroceras anellus (Conrad). Geol. Vt., I, p. 281; p. 298, fig. 209.
Streptelasma profundum Conrad. Geol. Vt., I, pp. 281, 291.
Stromatocerium rugosum Hall. R. V. S. G., X, p. 226.
Stromatocerium rugosum Hall. Geol. Vt., I, pp. 281; 290, fig. 190. R. V. S. G., IV, p. 144, pl. 74, fig. 5; pl. 70.
Strophomena incurvata (Hall). R. V. S. G., VII, p. 49.
Trenton.
Leperditia sp. Tr. N. Y. A. S., 1895, XV, p. 23.
Orthis pectinella (Conrad). Geol. Vt., I, p. 281.
Streptelasma corniculum Hall. Geol. Vt., I, p. 281; p. 291, fig. 191.
Tetradium columnare (Hall). Geol. Vt., I, p. 281.

CHARLOTTE.
Trenton.
Lingula elongata Hall. A. M. N. H., Cat. No. $\frac{677}{1}$.

CHARLOTTE, Cove Island, Balls Bay.
Cambrian.
Salterella sp. R. V. S. G., VI, p. 231.
As Beekmantown.
Isochilina cristata (Whitfield). R. V. S. G., VII, pl. 61, fig. 15. R. V. S. G., VI, p. 251.
Isochilina gragaria (Whitfield). R. V. S. G., VII, pl. 61, figs. 16, 17. R. V. S. G., VI, p. 251.
Chazy.
Wingia congregata Seely. R. V. S. G., V, p. 178, pl. 39.

CHARLOTTE, 1/3 mi. E. of McNeil Bay.
Chazy.
Girvanella ocellata (Seely). R. V. S. G., XIII, p. 231.

CHARLOTTE, Thompson's Point.
Beekmantown.
Liostegium quadratum (Billings). R. V. S. G., VI, p. 251.
Maclurites acuminatus (Billings). R. V. S. G., VI, p. 261.
Fusispira subfusiformis (Hall). R. V. S. G., VI, p. 251.
Trenton.
Plectoceras ? undatum (Conrad). R. V. S. G., VI, p. 251.
Raphistoma rotuloides (Hall). R. V. S. G., VI, p. 251.
Schroederoceras eatoni (Whitfield). R. V. S. G., VII, pl. 54.
Spyroceras bilineatum (Hall). R. V. S. G., VI, p. 251.
Syntrophia lateralis (Whitfield). R. V. S. G., VI, p. 251.

Cameroceras brainerdi (Whitfield). R. V. S. G., VI, p. 251.
Hormotoma obelisca (Whitfield). R. V. S. G., VI, p. 251.
Maclurites affinis (Billings). R. V. S. G., VI, p. 251.
Oncoceras constrictum Hall. R. V. S. G., VI, p. 251.
Protocycloceras whitfieldi Ruedemann. R. V. S. G., VI, p. 251.
Trocholites internistriatus (Whitfield). R. V. S. G., VI, p. 251.

CHITTENDEN COUNTY, Fox Hill, E. side.
Cambrian.
Hyolithes sp. R. V. S. G., VI, p. 232.
Salterella sp. R. V. S. G., VI, p. 232.

CHITTENDEN COUNTY, E. side of bay N. of Marshes Bay.
Pleistocene.
Macoma balthica Linné. R. V. S. G., VI, p. 230.
Saxicava rugosa (Lamarck). R. V. S. G., VI, p. 230.

COLCHESTER.
Cambrian.
Cruziana sp. R. V. S. G., VI, p. 239.
Hyolithes communis Billings. R. V. S. G., VI, p. 239.
Ptychoparia arenosa Billings. R. V. S. G., VI, p. 239.
Ptychoparia miser Billings. R. V. S. G., VI, p. 239.
Ptychoparia teucer Billings. R. V. S. G., VI, p. 239.
Ptychoparia vulcanus Billings. R. V. S. G., VI, p. 239.
Salterella pulchella Billings. R. V. S. G., VI, p. 239.
Scenella varians Walcott. R. V. S. G., VI, p. 239.
Scolithus sp. R. V. S. G., VI, p. 239.
Stenotheca rugosa Hall. R. V. S. G., VI, p. 239.

COLCHESTER, near road to Sandbar Bridge.
Cambrian.
Olenellus thompsoni Hall. R. V. S. G., VI, p. 224.
Ptychoparia miser Billings. R. V. S. G., VI, pp. 224, 227.

COLCHESTER, Catfish Point.
Cambrian.
Ptychoparia adamsi Billings. R. V. S. G., VI, p. 227.

COLCHESTER, Johnson's, N. of Burns-Martin valley.
Cambrian dolomite.
Olenellus sp. R. V. S. G., VI, p. 233.
Microdiscus speciosus (Ford). R. V. S. G., VI, p. 239.
Nisusia festinata Billings. R. V. S. G., VI, p. 239.
Planolites sp. R. V. S. G., VI, p. 239.
Protypus desiderata Walcott. R. V. S. G., VI, p. 239.

COLCHESTER, bed of brook.
Beekmantown B, Tribes Hill.
Cryptozoon wingi Seely. R. V. S. G., X, p. 221.

COLCHESTER, Malletts Bay, banks near the shore.
Pleistocene.
Leda minuta Fabr. R. V. S. G., VI, p. 256.
Macoma balthica Linné. R. V. S. G., VI, p. 256.
Macoma proxima Broquiart. R. V. S. G., VI, p. 256.
Mya arenaria Linné. R. V. S. G., VI, p. 256.
Nucula tenuis Mont. R. V. S. G., VI, p. 256.
Saxicava arctica Linné. R. V. S. G., VI, p. 256.
Saxicava rugosa (Lamarck). R. V. S. G., VI, pp. 231, 256.
Yoldia obesa. R. V. S. G., VI, p. 256.

COLCHESTER, Malletts Bay, cliffs on shore.
Cambrian.
Cruziana sp. R. V. S. G., VI, p. 227.
Olenellus thompsoni Hall. R. V. S. G., X, p. 221.
Worm borings and tracks. R. V. S. G., X, p. 221.
Hyolithes communis Billings. R. V. S. G., VI, p. 332.
Olenellus thompsoni Hall. R. V. S. G., VI, p. 232.
Pleistocene.
Macoma balthica Linné. R. V. S. G., VI, p. 231.
Macoma balthica L. R. V. S. G., VII, p. 55.
Mya arenaria L. R. V. S. G., VII, p. 55.
Saxicava rugosa (Lamarck). R. V. S. G., VI, p. 231.
Saxicava rugosa Linn. R. V. S. G., VII, p. 55.
Spicules. R. V. S. G., VII, p. 55.
Tethia sp. R. V. S. G., VII, p. 55.
Yoldia obesa. R. V. S. G., VII, p. 55.
Yoldia siliqua R. R. V. S. G., VII, p. 55.

CORNWALL.
Cambrian.
Lloydia saffordi (Billings). B. G. S. A., II, p. 299.
Beekmantown.
Bathyurus angelini Billings. R. V. S. G., VII, pl. 32, figs. 11, 12. B. G. S. A., II, p. 299.
Ophileta complanata Vanuxem. B. G. S. A., II, p. 299.
Chazy B, 150 ft. layer.
Maclurites magnus (Lesueur). B. G. S. A., II, p. 299.

CORNWALL, eastern.
Trenton.
Prasopora simulatrix orientalis Ulrich. R. V. S. G., XIII, p. 260.
Chazy.
Stromatopora sp. A. J. S. (3), VI, p. 276, 1873.
Zaphrentis sp. A. J. S. (3), VI, p. 276, 1873.

FERRISBURG, Basin Harbor.
Chazy B.
Stromatocerium lamottense Seely. R. V. S. G., IV, p. 147, pls. 69; 72; 74, fig. 1.
Stromatocerium lamottense chazianum Seely. R. V. S. G., IV, p. 148, pl. 73, upper fig.
Wingia lapilla Seely. R. V. S. G., VII, p. 48.

FERRISBURG, Balls Bay.
As Beekmantown.
Wingia discoidea Seely. R. V. S. G., VII, p. 47.

FERRISBURG, Fields Bay.
Chazy, Lower.
Lingula brainerdi Raymond. R. V. S. G., V, p. 183, pl. 41.

FERRISBURG, bend in road 2/3 mi. E. of Kingsland Bay.
Chazy B.
Maclurites magnus (Lesueur). R. V. S. G., XIII, p. 235.

FERRISBURG, N. of Shellhouse Mt.
Trenton.
Cryptolithus tessellatus Green. R. V. S. G., XIII, p. 237.

FERRISBURG, Fort Cassin.
Chazy.
Bathyurus extans (Hall). R. V. S. G., XIV, p. 217.
Dalmanella testudinaria (Dalman). R. V. S. G., XIV, p. 217.
Eccyliomphalus (*Orthostoma*) *lituiformis* (Whitfield). R. V. S. G., XIII, p. 80.
Hormotoma? cassina (Whitfield). R. V. S. G., XIV, p. 217.
Isotelus platymarginatus Raymond. R. V. S. G., XIV, p. 214, pl. 17, fig. 2. R. V. S. G., VII, p. 225, pl. 34, fig. 4. R. V. S. G., VII, p. 225, pl. 37, figs. 2-5. R. V. S. G., VII, p. 225, pl. 39, fig. 3.
Wingia congregata Seely. R. V. S. G., V, p. 178, pl. 39.
Trenton.
Actinoceras bigsbyi Stokes. R. V. S. G., XIV, p. 214, pl. 17, fig. 3.
Amphilichas trentonensis (Conrad). R. V. S. G., XIV, p. 216.
Archinacella simplex (Billings). R. V. S. G., XIV, p. 215.
Cameroceras brainerdi (Whitfield). R. V. S. G., XIV, p. 216.
Clathrospira subconica (Hall). R. V. S. G., XIV, p. 215.
Clisospira lirata Whitfield. R. V. S. G., XIV, p. 215.
Cyrtoceras? acinacellum Whitfield. R. V. S. G., XIV, p. 216.
Cyrtoceras confertissimum Whitfield. R. V. S. G., XIV, p. 216.
Dalmanella testudinaria (Dalman). R. V. S. G., XIV, p. 215.
Eccyliomphalus perkinsi (Whitfield). R. V. S. G., XIV, p. 215.
Eccyliopterus volutatus (Whitfield). R. V. S. G., XIV, p. 215.
Eotomaria? cassina (Whitfield). R. V. S. G., XIV, p. 215.
Eoharpes cassinensis (Whitfield). R. V. S. G., XIV, p. 216.
Fusispira subfusiformis (Hall). R. V. S. G., XIV, p. 215.
Helicotoma similis Whitfield. R. V. S. G., XIV, p. 215. R. V. S. G., VII, pl. 56, fig. 2.
Holopea paludiniformis Hall. R. V. S. G., XIV, p. 215.
Holopea ventricosa Hall. R. V. S. G., XIV, p. 216.
Hormotoma bellicincta (Hall). R. V. S. G., XIV, p. 216.
Isotelus maximus Locke. R. V. S. G., XIV, p. 216.
Liospira vitruvia (Billings). R. V. S. G., XIV, p. 216.
Maclurites acuminatus (Billings). R. V. S. G., VII, pl. 57, figs. 9, 10. R. V. S. G., XIV, p. 215.
Maclurites crenulatus (Billings). R. V. S. G., XIV, p. 215.
Maclurites logani (Salter). A. M. N. H., No. 455.
Nileus striatus Whitfield. R. V. S. G., XIV, p. 216. R. V. S. G., VII, pl. 55, figs. 5, 6.
Oncoceras constrictum Hall. R. V. S. G., XIV, p. 216.
Orthoceras multicameratum Emmons. R. V. S. G., XIV, p. 216. Geol. Vt., I, p. 298, fig. 212.
Orthoceras sordidum Billings. R. V. S. G., XIV, p. 216.
Orygoceras cornuoryx (Whitfield). R. V. S. G., XIV, p. 216. R. V. S. G., VII, pl. 56, fig. 3.
Piloceras explanator Whitfield. R. V. S. G., XIV, p. 216.
Plectambonites cf. sericeus (Sowerby). R. V. S. G., XIV, p. 215.
Plectoceras ? undatum (Conrad). R. V. S. G., XIV, p. 216.
Poterioceras apertum Whiteaves. R. V. S. G., XIV, p. 216.
Raphistoma compressum Whitfield. R. V. S. G., XIV, p. 216.
Raphistoma rotuloides (Hall). R. V. S. G., XIV, p. 216.
Receptaculites oweni Hall. R. V. S. G., XIV, p. 215.
Ribeiria compressa Whitfield. R. V. S. G., XIV, p. 216.
Ribeiria ventricosa Whitfield. R. V. S. G., XIV, p. 216.

Scenella cassinensis Bassler. R. V. S. G., XIV, p. 216. R. V. S. G., VII, pl. 62, figs. 26, 27, 32, 33.
Schroederoceras eatoni (Whitfield). R. V. S. G., XIV, p. 216.
Spyroceras bilineatum (Hall). R. V. S. G., XIV, p. 216.
Streptelasma corniculum Hall ? R. V. S. G., XIV, p. 214, pl. 17, fig. 1.
Syntrophia lateralis (Whitfield). R. V. S. G., XIV, p. 215. A. M. N. H., Cat. No. 442.
Tarphyceras champlainensis (Whitfield). R. V. S. G., XIV, p. 216.
Trochonema umbilicatum (Hall). R. V. S. G., XIV, p. 215.
Tryblidium ovale Whitfield. R. V. S. G., XIV, p. 216.
Tryblidium ovatum Whitfield. R. V. S. G., XIV, p. 216.

GEORGIA.

Cambrian.

Arenicolites sp.
Bathynotus holopyga Hall. R. V. S. G., V, p. 118; VI, p. 197. 10th Ann. R. U. S. G. S., p. 575.
Billingsella orientalis Walcott. R. V. S. G., VI, p. 197.
Bradoria scrutata Matthew. R. V. S. G., XIII, p. 213.
Camerella antiquata Billings. p. 46.
Climacograptus emmonsi Walcott. R. V. S. G., VI, p. 197. B. U. S. G. S., 30, p. 46. 10 Ann. R. U. S. G. S., p. 512.
Dactyloides asteroides Fitch. R. V. S. G., VI, p. 197.
Dikelocephalus marcoui Whitfield. B. A. M. N. H., V, pl. 14, fig. 7.
Diplograptus? simplex Emmons.
Eocystites? sp.
Fucoids. R. V. S. G., V, p. 118.
Hyolithes billingsi Walcott.
Indiana dermatoides (Walcott). R. V. S. G., XIII, p. 213.
Indiana pyriformis Matthew. R. V. S. G., XIII, p. 213.
Indiana secunda Matthew. R. V. S. G., XIII, p. 213.
Iphidea labradorica swantonensis Walcott. R. V. S. G., VI, p. 197.
Kutorgina cingulata (Billings). R. V. S. G., VI, p. 197. B. U. S. G. S., 30, p. 46.
Kutorgina cingulata (Billings). 10 Ann. R. U. S. G. S., p. 573.
Kutorgina labradorica Billings.
Leptomitus zitteli Walcott. 10 Ann. R. U. S. G. S., p. 572. B. U. S. G. S., 30, p. 45.
Mesonacis vermontana Hall. R. V. S. G., VI, p. 197. B. U. S. G. S., 30, p. 47.
Microdiscus parkeri Walcott. R. V. S. G., VI, p. 197. B. U. S. G. S., 30, p. 47.
Nisusia festinata Billings. R. V. S. G., VI, p. 197.
Nisusia festinata transversa Walcott. R. V. S. G., VI, p. 197.
Obolus franklinensis Walcott. R. V. S. G., VI, p. 197.
Olenellus thompsoni Hall. B. A. M. N. H., V, pl. 15, fig. 2.
Olenellus thompsoni Hall. Dana's Manual, p. 473, fig. 536. B. U. S. G. S., 30, p. 47.
Olenellus thompsoni Hall. 13 R. N. Y. S. M. N. H., p. 116, fig. 1.
Olenellus thompsoni Hall. R. V. S. G., V, p. 117.
Olenoides marcoui Whitfield. 10 Ann. R. U. S. G. S., p. 575.
Olenoides marcoui Whitfield. R. V. S. G., VI, p. 197. B. U. S. G. S., 30, p. 47.

Orthisina festinata Billings. B. U. S. G. S., 30, p. 46. 10 Ann. R. U. S. G. S., p. 573.
Orthisina orientalis Whitfield. 10 Ann. R. U. S. G. S., p. 573.
Orthisina orientalis Whitfield. Dana's Manual, p. 471, fig. 518. B. U. S. G. S., 30, p. 46.
Orthisina orientalis Whitfield. R. V. S. G., VI, p. 207.
Orthisina transversa Walcott. 10 Ann. R. U. S. G. S., p. 573.
Palaeophycus congregatus Billings.
Palaeophycus incipiens.
Phyllograptus cambrensis Walcott. 10 Ann. R. U. S. G. S., p. 572. R. V. S. G., VI, p. 197.
Planolites congregatus Billings. 10 Ann. R. U. S. G. S., p. 572.
Planolites congregatus Hall. R. V. S. G., VI, p. 197.
Planolites virgatus Hall. R. V. S. G., VI, p. 197. 10 Ann. R. U. S. G. S., p. 572.
Protocaris marshi Walcott. 10 Ann. R. U. S. G. S., p. 574.
Protypus hitchcocki Whitfield. R. V. S. G., VI, p. 197.
Protypus senectus Billings. R. V. S. G., VI, p. 197.
Protypus senectus var. parvulus Billings. R. V. S. G., VI, p. 197.
Ptychoparia adamsi Billings. 10 Ann. R. U. S. G. S., p. 575. R. V. S. G., VI, p. 197. B. U. S. G. S., 30, p. 47.
Ptychoparia arenosa Billings. R. V. S. G., VI, p. 197.
Ptychoparia miser Billings. R. V. S. G., VI, p. 197.
Ptychoparia miser var. A. R. V. S. G., VI, p. 197.
Ptychoparia teucer Billings. R. V. S. G., VI, p. 197.
Ptychoparia vulcanus Billings. R. V. S. G., VI, p. 197.
Rustella edsoni Walcott. R. V. S. G., VI, p. 197.
Salterella pulchella Billings. 10 Ann. R. U. S. G. S., p. 574.
Scenella varians Walcott. R. V. S. G., VI, p. 197. B. U. S. G. S., 30, p. 46.
Stenotheca rugosa Hall. R. V. S. G., VI, p. 197.
Worm trail. R. V. S. G., V, p. 118.

GRAND ISLE.

Beekmantown B.

Cryptozoon saxiroseum Seely. R. V. S. G., V, p. 162, pl. 36, 37, figs. 4, 5, 6. R. V. S. G., V, p. 169.

Chazy, zone 3c. *Modiolopsis fabaformis* zone.

Camarotoechia plena (Hall). A. J. S., XX, p. 358.
Modiolopsis fabaeformis Raymond. A. J. S. (4), 1905, XX, p. 358.

GRAND ISLE, 1 mi. NE. Phelps Point.

Chazy, base of.

Lingula brainerdi Raymond. R. V. S. G., V, p. 183. R. V. S. G., VII, pl. 51. R. V. S. G., X, p. 216.

GRAND ISLE, S. of Gordons (Centers).

Trenton.

Calymene senaria Conrad.

GRAND ISLE, W. shore N. of Gordon Landing.

Trenton.

Calymene senaria Conrad. As *callicephala.* R. V. S. G., IV, p. 107.
Cryptolithus tessellatus Green. R. V. S. G., IV, p. 107.
Cycloceras olorus (Hall). R. V. S. G., IV, p. 107.
Dalmanella testudinaria (Dalman). R. V. S. G., IV, p. 107.
Diplograptus foliaceous (Murchison). R. V. S. G., IV, pp. 106, 107.

Endoceras proteiforme Hall. R. V. S. G., IV, p. 107.
Holopea paludiniformis Hall. R. V. S. G., IV, p. 107.
Isotelus gigas deKay. R. V. S. G., IV, p. 107.

GRAND ISLE, Wilcox Cove and N. S. of Gordons (Centers).
Trenton.
Isotelus gigas deKay.
Orthoceras coralliferum Hall. R. V. S. G., IV, p. 106.
Orthoceras strigatum Hall. R. V. S. G., IV, p. 107. Geol. Vt., I, p. 298, fig. 211.
Phragmolites compressus Conrad. R. V. S. G., IV, p. 107.
Plectambonites sericeus (Sowerby). R. V. S. G., IV, p. 107.
Rafinesquina alternata (Emmons). R. V. S. G., IV, pp. 107, 108.
Schizocrania filosa Hall. R. V. S. G., IV, p. 106.
Sinuites cancellatus (Hall). R. V. S. G., IV, p. 107.
Tetradium fibratum Safford. R. V. S. G., IV, p. 108.
Triarthrus becki Green. R. V. S. G., IV, p. 106.
Zygospira exigua (Hall). R. V. S. G., IV, p. 107.
Zygospira recurvirostris (Hall). R. V. S. G., IV, p. 107.

GRAND ISLE, Cumberland Head ferry landing.
Trenton.
Sinuites cancellatus (Hall). R. V. S. G., XIII, p. 153.
Black River.
Columnaria alveolata Goldfuss. R. V. S. G., IV, p. 108.
Maclurites logani (Salter). R. V. S. G., IV, p. 108.
Orthoceras junceum Hall. R. V. S. G., IV, p. 107.
Stromatocerium rugosum Hall. R. V. S. G., IV, p. 108.
Normanskill.
Climacograptus bicornis (Hall). R. V. S. G., IV, p. 106.
Glens Falls.
Bucania punctifrons (Emmons). R. V. S. G., IV, p. 107.

GRAND ISLE, between Table Bay and Rockwell Bay.
Upper Chazy.
Solenopora compacta (Billings). R. V. S. G., X, p. 216. R. V. S. G., VII, p. 274, fig. 24.
Orthoceras amplicameratum Hall. R. V. S. G., IV, p. 107. Geol. Vt., I, p. 298, fig. 210.

HIGHGATE.
Cambrian.
Dactyloides. R. V. S. G., VI, 205.
Olenoides desiderata Walcott. R. V. S. G., VI, p. 197.
Protorthis wingi Walcott. R. V. S. G., VI, p. 197.
Lingulepis acuminata (Conrad). R. V. S. G., XII, p. 132.
Agraulos adamsi Billings. A. M. N. H., Cat. No. 237.

HIGHGATE, north of.
Cambrian.
Asaphellus sp. ind. R. V. S. G., XIV, pl. XIII, fig. 19.
Leptopilus declivis Raymond. R. V. S. G., XIV, p. 173, pl. 13, fig. 20.

HIGHGATE, 4½ mi. N.
Cambrian, Georgia formation.
Hystricurus mammatus Raymond. R. V. S. G., XIV, p. 153, pl. 12, fig. 17.

HIGHGATE, 1 mi. S. of Can. line, road Moores Corner to Saxes Mills.
Cambrian.
Conocephalites arenosus. R. V. S. G., V, p. 119.

HIGHGATE, Rock River, bridge near Johnson's farm.
Cambrian.
Microdiscus speciosus (Ford). R. V. S. G., XIII, p. 285.
Orthisina festinata Billings. R. V. S. G., XIII, p. 285.

HIGHGATE CENTER.
Cambrian, Highgate formation.
Maryvillia triangularis Raymond. R. V. S. G., XIV, p. 155, pl. 12, fig. 21.

HIGHGATE CENTER, north of.
Georgia.
Asaphellus sp. ind. R. V. S. G., XIV, pl. XIII, fig. 16.
Cambrian, lower Highgate limestone.
Lloydia seelyi (Walcott). R. V. S. G., XIV, p. 155.

HIGHGATE CENTER, 1½ mi. N. of.
Cambrian, lower part Highgate formation.
Liostegium cingulosum Raymond. R. V. S. G., XIV, p. 195, pl. 14, figs. 18, 21.

HIGHGATE CENTER, 2 mi. N. of.
Highgate.
Hemigyraspis sp. ind. R. V. S. G., XIV, p. 172.
Cambrian, lower part Highgate limestone.
Liostegium puteatum Raymond. R. V. S. G., XIV, p. 194, pl. 14, figs. 12, 13, 16, 19.

HIGHGATE CENTER, 1½ and 2 mi. N. of.
Highgate limestone.
Pilekia extenuata Raymond. R. V. S. G., XIV, p. 196, pl. 14, figs. 17, 20.

HIGHGATE CENTER, 4½ mi. N. of.
Highgate.
Cholopilus vermontanus Raymond. R. V. S. G., XIV, p. 188, pl. 14, figs. 8, 11, 15.
Cambrian, Georgia formation.
Gignopeltis rara (Billings). R. V. S. G., XIV, p. 194.
Lloydia saffordi (Billings). R. V. S. G., XIV, p. 156.
Georgia, base.
Pilekia eryx (Billings). R. V. S. G., XIV, p. 197.

HIGHGATE CENTER, 5 mi. north of.
Georgia, base.
Bellefontia obtecta Raymond. R. V. S. G., XIV, p. 171, pl. 13, figs. 14, 18.
Cambrian, Georgia formation.
Niobe ? sp. ind. R. V. S. G., XIV, p. 170.

HIGHGATE FALLS.
Cambrian, Missisquoi, main zone.
Agnostus trisectus Salter. R. V. S. G., XIV, p. 139, pl. 12, fig. 3.
Peronopsis planulata Raymond. R. V. S. G., XIV, p. 142, pl. 12, fig. 9.

Phalacroma cyclostigma Raymond. R. V. S. G., XIV, p. 144, pl. 12, fig. 4.
Phylacterus saylesi Raymond. R. V. S. G., XIV, p. 149, pl. 12, figs. 14, 15, 18.

Cambrian, Missisquoi zone.
Asaphiscus inornatus Raymond. R. V. S. G., XIV, p. 154, pl. 12, fig. 23.
Dikelocephalus insolitus Raymond. R. V. S. G., XIV, p. 175, pl. 13, fig. 22.
Pseudosalteria laevis Raymond. R. V. S. G., XIV, p. 145, pl. 12, fig. 11.
Richardsonella laeviuscula Raymond. R. V. S. G., XIV, p. 181.

Cambrian, Missisquoi, zones 1, 2, and 3.
Acheilus macrops Raymond. P. B. S. N. H., XXXVII, p. 423, pl. 13, fig. 11, 1924.
Apatokephaloides clivosus Raymond. R. V. S. G., XIV, p. 169, pl. 13, figs. 13, 17.
Plethopeltis lata Raymond. R. V. S. G., XIV, p. 163, pl. 13. fig. 5.

Cambrian, Missisquoi, zone 2.
Acheilus spicatus Raymond. P. B. S. N. H., 37, p. 424, pl. 13, fig. 12.
Blountia imitator Raymond. R. V. S. G., XIV, p. 154, pl. 12, fig. 22.
Corynexochus juvenis Raymond. R. V. S. G., XIV, p. 165, pl. 13, fig. 10.
Hungaia minuta Raymond. R. V. S. G., XIV, p. 183, pl. 14, fig. 1.
Phalacroma parilis (Hall). R. V. S. G., XIV, p. 143, pl. 12, fig. 8.
Phoreotropis puteatus Raymond. R. V. S. G., XIV, p. 146, pl. 12, fig. 12.
Plethopeltis angusta Raymond. R. V. S. G., XIV, p. 162, pl. 13, figs. 4, 8.
Stenopilus brevis Raymond. R. V. S. G., XIV, p. 165, pl. 13, fig. 9.
Zacompsus clarki Raymond. R. V. S. G., XIV, p. 148, pl. 12, fig. 13.

Cambrian, Missisquoi, zones 2 and 3.
Ambolonium lioderma Raymond. R. V. S. G., XIV, p. 192, pl. 14, figs. 10, 14.
Apatokephaloides inflatus Raymond. R. V. S. G., XIV, p. 170.
Idiomesus tantillus Raymond. R. V. S. G., XIV, p. 144, pl. 12, fig. 10.
Onchonotus nasutus (Walcott). R. V. S. G., XIV, p. 152.
Plethopeltis armata (Billings). R. V. S. G., XIV, p. 161.

HIGHGATE FALLS.
Cambrian, Missisquoi, zone 3.
Agnostus insuetus Raymond. R. V. S. G., XIV, p. 140.
Illaenurus breviceps Raymond. R. V. S. G., XIV, p. 186. pl. 14, fig. 2.
Illaenurus laevis Raymond. R. V. S. G., XIV, p. 186, pl. 14, fig. 4.
Illaenurus quadrata Hall. R. V. S. G., XIV, p. 185.
Keithia schucherti Raymond. R. V. S. G., XIV, p. 191, pl. 14, figs. 5, 9.

Lloydia seelyi (Walcott). R. V. S. G., XIV, p. 155.
Maryvillia triangularis Raymond. R. V. S. G., XIV, p. 155, pl. 12, fig. 21.
Phoreotropis transversus Raymond. R. V. S. G., XIV, p. 147, pl. 12, fig. 16.
Phylacterus fraternus Raymond. R. V. S. G., XIV, p. 150, pl. 12, fig. 19.
Platycolpus dubius (Billings). R. V. S. G., XIV, p. 187.
Plethopeltis convergens Raymond. R. V. S. G., XIV, p. 163, pl. 13, fig. 2.
Plethopeltis laevis Raymond. R. V. S. G., XIV, p. 162, pl. 13, fig. 3.
Pseudagnostus extumidus Raymond. R. V. S. G., XIV, p. 141, pl. 12, fig. 7.
Ptychaspis affinis Raymond. R. V. S. G., XIV, p. 190, pl. 14, fig. 6.
Richardsonella germana Raymond. R. V. S. G., XIV, p. 180, pl. 14, fig. 3.
Saukia dunbari Raymond. R. V. S. G., XIV, p. 178, pl. 14, fig. 7.
Saukia lodensis (Whitfield). R. V. S. G., XIV, p. 177.
Saukia stosei Walcott. R. V. S. G., XIV, p. 178.
Stenopilus pronus Raymond. R. V. S. G., XIV, p. 164, pl. 13, figs. 6, 7.

HIGHGATE SPRINGS, E. of.
Cambrian.
Ptychoparia teucer Billings. 10 Ann. R. U. S. G. S., p. 575.

HIGHGATE SPRINGS, 1½ mi. E. of.
Cambrian, as Potsdam.
Ptychoparia adamsi Billings. R. V. S. G., V, p. 119.
Ptychoparia vulcanus Billings. R. V. S. G., V, p. 119.
Scenella varians Walcott. 10 Ann. R. U. S. G. S., p. 573.

HIGHGATE SPRINGS.
Chazy.
Ampyx halli (Billings). R. V. S. G., VII, p. 216.

Chazy C.
Ampyx halli (Billings). B. G. S. A., II, p. 298.

HIGHGATE SPRINGS, E. bands S. of lime kilns.
Black River.
Actinoceras bigsbyi Stokes. R. V. S. G., VI, p. 191.
Columnaria alveolata Goldfuss. R. V. S. G., VI, p. 191.
Helicotoma planulata Salter. R. V. S. G., VI, p. 191.
Lingula perryi Billings. B. U. S. N. M., 92, p. 732.
Lophospira perangulata (Hall). R. V. S. G., VI, p. 191.
Loxoceras allumettense (Billings). R. V. S. G., VI, p. 191.
Streptelasma profundum Conrad. R. V. S. G., VI, p. 191.
Stromatocerium rugosum Hall. R. V. S. G., VI, p. 191.

HIGHGATE SPRINGS, E. and W. of axis.
Trenton.
Calymene senaria Conrad. R. V. S. G., VI, p. 192.
Cryptolithus tessellatus Green. R. V. S. G., VI, p. 192.
Dalmanella testudinaria (Dalman). R. V. S. G., VI, p. 192.
Orthoceras strigatum Hall. R. V. S. G., VI, p. 192.

Pachydictya acute (Hall). R. V. S. G., VI, p. 192.
Platystrophia biforata (Schlotheim). R. V. S. G., VI, p. 192.
Rhynchotrema increbescens (Hall). R. V. S. G., VI, p. 192.
Stenopora fibrosa Billings. R. V. S. G., VI, p. 192.

HIGHGATE SPRINGS, E. side anticline ½ mi. N. of Franklin's house.
Chazyan, Crown Point.
Ampyx halli (Billings). R. V. S. G., VI, p. 191. R. V. S. G., VII, p. 216, pl. 32, figs. 3-6.
Chazy, B, C.
Dinorthis platys Billings. R. V. S. G., VI, p. 191. B. G. S. A., II, p. 298.

HIGHGATE SPRINGS, promontory SW. of Limekiln Point.
Trenton.
Rafinesquina alternata (Emmons). R. V. S. G., XIII, p. 180. Geol. Vt., I, p. 293, fig. 199.
Rafinesquina incrassata (Hall). R. V. S. G., XIII, p. 180.

HUBBARDTON.
Trenton.
Cryptolithus tessellatus Green. R. V. S. G., XII, p. 143.

ISLE LA MOTTE, south end.
Middle Cambrian.
Palaeomya seelyi Whitfield. A. M. N. H., Cat. No. 277.
Upper Cambrian.
Lingulepis acuminata (Conrad). A. M. N. H., Cat. No. 275.

ISLE LA MOTTE.
Beekmantown.
Algae casts. R. V. S. G., IX, p. 121.
Beekmantown, top layer.
Isochilina sp. R. V. S. G., IX, p. 121.
Worm borings. R. V. S. G., IX, p. 121.

ISLE LA MOTTE, Cloak Island.
Lower Chazy.
Lingula brainerdi Raymond. R. V. S. G., XIII, p. 169.
Chazy.
Camarotoechia plena (Hall). R. V. S. G., XIII, p. 169.

ISLE LA MOTTE, Holcomb Point, Phelps pasture, road N. of point.
Chazy B, 150 ft. layer.
Stromatocerium sp. R. V. S. G., IX, p. 126.

ISLE LA MOTTE, 50 rods S. of Jordon Point.
Chazy B.
Maclurites magnus (Lesueur). R. V. S. G., XIII, p. 171.

ISLE LA MOTTE.
Lower Chazy.
Lamottia heroensis Raymond. R. V. S. G., XIV, p. 76.
Lingula brainerdi Raymond. R. V. S. G., V, p. 183, pl. 41.

ISLE LA MOTTE, Fisk Quarry.
Chazy B.
Stromatocerium lamottense Seely. R. V. S. G., IX, p. 143.

ISLE LA MOTTE, Goodsells, N. of Duba's house; Phelps' pasture; S. on W. side of road and on main N-S road N. of Holcomb Point.
Chazy B.
Maclurites magnus (Lesueur). R. V. S. G., IX, p. 126.

ISLE LA MOTTE, ¾ mi. NE. of Fleury's on Reynolds farm.
Chazy.
Stromatocerium sp. R. V. S. G., IX, p. 134.
Stylaraea parva (Billings). R. V. S. G., IX, p. 134.

ISLE LA MOTTE, Goodsell's ridge S. of village.
Chazy.
Stromatocerium eatoni Seely. R. V. S. G., IV, p. 146, pl. 71, 74, fig. 2.
Stromatocerium moniliferum Seely. R. V. S. G., IV, p. 149, pls. 73, lower fig., 74, figs. 3, 4.
Amphion canadensis Billings. R. V. S. G., VII, p. 47.
Ampyx halli (Billings). R. V. S. G., VII, p. 216.
Archinacella simplex (Billings). R. V. S. G., VII, p. 48.
Bolboporites sp. R. V. S. G., V, p. 182.
Bucania sulcatine (Emmons). R. V. S. G., VII, p. 48.
Bumastus limbatus Raymond. R. V. S. G., VII, p. 230.
Cameroceras curvatum Ruedemann. R. V. S. G., VII, p. 47.
Cameroceras tenuiseptum (Hall). R. V. S. G., VII, p. 47.
Cryptozoon perkinsi Seely. R. V. S. G., IV, p. 150.
Cyrtactinoceras boyci (Whitfield). R. V. S. G., VII, p. 48.
Eoharpes antiquatus (Billings). R. V. S. G., VII, p. 214.
Glaphurus pustulatus (Walcott). R. V. S. G., VII, p. 47.
Isoteloides angusticaudus (Raymond). R. V. S. G., VII, p. 223.
Isotelus platymarginatus Raymond. B. U. S. N. M., 92, p. 679.
Isotelus harrisi Raymond. A. J. S., 1905, XX, p. 356.
Isotelus angusticaudum Raymond. R. V. S. G., VII, p. 47.
Lingula brainerdi Raymond. R. V. S. G., V, p. 183, pl. 41. R. V. S. G., VII, pl. 51. R. V. S. G., X, p. 216. R. V. S. G., XII, p. 139.
Maclurites magnus (Lesueur). B. G. S. A., II, p. 298. B. A. M. N. H., VIII, p. 310.
Onchometopus obtusus (Hall). R. V. S. G., VII, p. 222.
Ooceras (?) lativentrum Ruedemann. R. V. S. G., VII, p. 48.
Ooceras (?) perkinsi Ruedemann. R. V. S. G., VII, p. 48.
Ooceras seelyi Ruedemann. R. V. S. G., VII, p. 48.
Orthis acutiplicata Raymond. A. J. S., 1900, XX, p. 356.
Orthis costalis Hall. B. G. S. A., II, p. 298.
Orthoceras modestum Ruedemann. R. V. S. G., VII, p. 49.
Orthoceras (?) vagum Ruedemann. R. V. S. G., VII, p. 48.
Plectoceras exfoliata (Raymond). A. J. S., 1905, XX, p. 356.
Protarea sp. R. V. S. G., IX, p. 134.
Rafinesquina incrassata (Hall). A. J. S., XX, p. 356, 1905.
Rhaphistoma staminea (Hall). R. V. S. G., VII, p. 48.
Sphaerexochus parvus Billings. R. V. S. G., VII, p. 246.
Thaleops arcturus (Hall). R. V. S. G., VII, p. 227.
Thaleops ovatus Conrad. A. J. S., XX, p. 356, 1905.
Chazy, Group C, 120 ft. layer.
Amphilichas minganensis (Billings). B. A. M. N. H., VIII, p. 310.
Bucania sp. B. A. M. N. H., VIII, p. 310.
Cyrtactinoceras boycii (Whitfield). B. G. S. A., II, p. 298. B. A. M. N. H., VIII, p. 310.

Illaenurus sp. B. A. M. N. H., VIII, p. 310.
Orthoceras titan? B. A. M. N. H., VIII, p. 310.

Chazy, zone 3a.

Amphilichas minganensis (Billings). A. J. S., XX, p. 358, 1905. R. V. S. G., VII, p. 232, pl. 36, figs. 1-3; pl. 38, fig. 6; pl. 39, fig. 14.
Bucania sulcatina (Emmons). A. J. S., XX, p. 358, 1905.
Bumastus erastusi (Raymond). A. J. S., XX, p. 358, 1905. B. G. S. A., II, p. 297. B. A. M. N. H., VIII, p. 310. R. V. S. G., VII, p. 229, pl. 35, figs. 8, 9.
Bumastus globosus (Billings). A. J. S., XX, p. 358. R. V. S. G., VII, p. 228, pl. 35, fig. 6, 7; pl. 39, fig. 9.
Camarotoechia plena (Hall). A. J. S., XX, p. 358.
Conocardium beecheri Raymond. A. J. S., 1905, XX, p. 358.
Glaphurus pustulatus (Walcott). A. J. S., 1905, XX, p. 358. R. V. S. G., VII, p. 234.
Isotelus harrisi Raymond. A. J. S., 1905, XX, p. 358.
Pliomerops canadensis (Billings). A. J. S., XX, p. 358, 1905. R. V. S. G., VIII, pl. 18, fig. 14. R. V. S. G., VII, p. 238.
Pseudosphaerexochus vulcanus (Billings). A. J. S., XX, p. 358, 1905.
Remopleurides canadensis Billings. A. J. S., XX, p. 358, 1905. R. V. S. G., VII, p. 217, pl. 32, figs. 8-10.

Chazy; Day Pt., Crown Pt., Valcour.

Lingula columba Raymond. A. J. S., 1905, XX, p. 368.

Chazy, Day Pt.-Valcour.

Raphistoma stamineum (Hall). B. U. S. N. M., 92, p. 1092.

Chazy, Crown Pt.-Valcour.

Isotelus harrisi Raymond. R. V. S. G., VII, p. 221.
Nileus perkinsi Raymond. R. V. S. G., VII, p. 224, pl. 38, figs. 7, 8. R. V. S. G., VIII, pl. 18, figs. 7, 8.
Spyroceras clintoni (Miller). R. V. S. G., VII, p. 48.
Stylaraea parva (Billings). R. V. S. G., VII, p. 48.
Tarphyceras multicameratum Ruedemann. R. V. S. G., VII, p. 48.
Thaleops ovatus (Conrad). R. V. S. G., VII, p. 47.
Vaginoceras oppletum Ruedemann. R. V. S. G., VII, p. 48.

Glens Falls.

Bucania punctifrons (Emmons). R. V. S. G., XIV, p. 70.
Ceraurus pleurexanthemus Green. R. V. S. G., XII, p. 71.

ISLE LA MOTTE, shores and quarries.

Chazy A, 55 ft. layer. Beekmantown of Quebec.

Camerella breviplicata Billings. B. G. S. A., II, p. 297. B. A. M. N. H., VIII, p. 310.
Clitambonites porcia (Billings). B. G. S. A., II, 297. B. A. M. N. H., VIII, p. 310.
Girvanella ocellata (Seely). R. V. S. G., XIII, p. 171.
Rafinesquina aurora (Billings). B. G. S. A., II, p. 297. B. A. M. N. H., VIII, p. 310.
Remopleurides schlotheimi Billings. B. G. S. A., II, p. 297. B. A. M. N. H., VIII, p. 310.
Stylaraea parva (Billings). B. G. S. A., II, p. 298. B. A. M. N. H., VIII, p. 310.
Zygospira acutirostris Hall. B. G. S. A., II, p. 297. B. A. M. N. H., VIII, p. 310.

Black River.

Columnaria alveolata Goldfuss.

Trenton.

Cryptolithus tessellatus Green. R. V. S. G., XIV, p. 71.
Ctenodonta cf. nasuta (Hall). R. V. S. G., XIV, p. 70.
Dalmanella rogata Sardeson. R. V. S. G., XIV, p. 70.
Eridotrypa aedilis (Eichwald). R. V. S. G., XIV, p. 70.
Geisonoceras tenuitextum (Hall). R. V. S. G., XIV, p. 70.
Holopea symmetrica Hall. R. V. S. G., XIV, p. 70.
Isotelus gigas deKay. R. V. S. G., XIV, p. 71.
Modiolopsis sp. R. V. S. G., XIV, p. 70.
Orbiculoidea lamellosa (Hall). R. V. S. G., XIV, p. 70.
Orthoceras amplicameratum Hall. R. V. S. G., XIV, p. 70.
Orthodesma sp. R. V. S. G., XIV, p. 70.
Pachydictya acuta (Hall). R. V. S. G., XIV, p. 70.
Parastrophia hemiplicata Hall. R. V. S. G., XIV, p. 70.
Platystrophia amoena McEwan. R. V. S. G., XIV, p. 70.
Platystrophia biforata (Schlotheim). R. V. S. G., VII, p. 49.
Plectembonites cf. punctostriatus Mather. R. V. S. G., XIV, p. 70.
Prasopora simulatrix orientalis Ulrich. R. V. S. G., XIV, p. 70.
Rafinesquina alternata (Emmons). R. V. S. G., XIV, p. 70.
Rafinesquina deltoidea (Conrad). B. G. S. A., II, p. 297. B. A. M. N. H., VIII, p. 310.
Sinuites cancellatus (Hall). R. V. S. G., XIV, p. 70.
Strophomena incurvata (Shepard). R. V. S. G., XIV, p. 70.
Trematis terminalis (Emmons). R. V. S. G., XIV, p. 70.

ISLE LA MOTTE, north shore.

Pleistocene.

Macoma fusca Holmes. R. V. S. G., XIV, p. 67.
Mya arenaria Linné. R. V. S. G., IV, p. 119. R. V. S. G., IX, p. 128.
Mytillus edulis Linné. R. V. S. G., XIV, p. 67.
Saxicava rugosa (Lamarck). R. V. S. G., XIV, p. 67.

ISLE LA MOTTE, Corners.

Pleistocene.

Macoma balthica Linné. R. V. S. G., IV, p. 119.

MALLETTS BAY.

Pleistocene.

Cryptodon gouldii Ph. R. V. S. G., VII, p. 55.
Helix striatella. R. V. S. G., VII, p. 55.
Leda arctica. R. V. S. G., VII, p. 55.
Leda arctica var. intermedia. R. V. S. G., VII, p. 55.
Leda minuta Fab. R. V. S. G., VII, p. 55.
Lepralia sp. R. V. S. G., VII, p. 55.
Macoma calcarea Chemn. R. V. S. G., VII, p. 55.
Nucula abyssicola. R. V. S. G., VII, p. 55.
Nucula expansa Reeves. R. V. S. G., VII, p. 55.
Nucula tenuis M. R. V. S. G., VII, p. 55.
Ophioglypha sarsii Lut. R. V. S. G., VII, p. 55.

MEMPHREMAGOG, LAKE, Owls Head.

Devonian?

Zaphrentis sp. A. J. S. (3), VI, p. 276, 1873.

MIDDLEBURY.

Orthoceras primigenium Vanuxem. R. V. S. G., XIII, p. 250. R. V. S. G., VII, p. 301, fig. 29.

MIDDLEBURY, EAST.
Chazy.
Stromatopora. A. J. S. (3), VI, p. 276, 1873.

MONKTON, boulder probably from Georgia or St. Albans.
Cambrian.
Graptolithus milesi (Hall). R. V. S. G., V, p. 118.

MONKTON, erratic.
Levis beds.
Loganograptus milesi Hall. Geol. Vt., I, p. 372, pl. 12, figs. 2-4. A. M. N. H., Cat. No. $\frac{433}{1}$.

MONTPELIER, Sabine slate quarry E. of Cemetery Hill.
Normanskill.
Climacograptus parvus Hall. R. V. S. G., X, p. 144.

MONTPELIER, near Catholic cemetery.
Deepkill.
Tetragraptus amii (Lapworth). R. V. S. G., X, p. 145.

NEW HAVEN.
Chazy.
Stromatopora. A. J. S. (3), VI, p. 276, 1873.

NORTH HERO.
Canajoharie.
Climacograptus typicalis Hall. R. V. S. G., XIV, p. 69.
Echinognathus sp. R. V. S. G., XIV, p. 69.
Geisonoceras cf. tenuistriatum (Hall). R. V. S. G., XIV, p. 69.
Glossograptus quadrimucronatus (Hall). R. V. S. G., XIV, p. 69.
Triarthrus becki Green. R. V. S. G., XIV, p. 69. R. V. S. G., III, p. 169, fig. Geol. Vt., I, pp. 308, 322.

ORWELL, Mt. Independence.
Beekmantown B, Tribes Hill.
Cryptozoon wingi Seely. R. V. S. G., V, p. 163, pl. 38. R. V. S. G., V, p. 166.

ORWELL, NE. of village.
Chazy, div. 2, 60 ft. beds.
Camarotoechia plena (Hall). A. J. S., XX, p. 365.
Chazy B, 50 ft. layer.
Maclurites magnus (Lesueur). B. G. S. A., II, p. 200.
Trenton.
Cryptolithus tessellatus Green. R. V. S. G., XII, p. 156.

ORWELL, S. of Orwell-Sudbury road in 2 valleys.
Trenton.
Cryptolithus tessellatus Green. R. V. S. G., XII, p. 162.
Stromatopora. A. J. S. (3), VI, p. 276, 1873.

PANTON VILLAGE.
Black River.
Columnaria halli Nicholson. R. V. S. G., XIII, p. 243.

POULTNEY, 2 mi. SE. of.
Normanskill Ig and G.
Climacograptus parvus Hall. 19 Ann. R. U. S. G. S., 1899, p. 189.

Didymograptus sagitticalis Gurley. 19 Ann. R. U. S. G. S., 1899, p. 189.
Diplograptus angustifolius Hall. 19 Ann. R. U. S. G. S., 1899, p. 189.
Diplograptus foliaceous (Murchison). 19 Ann. R. U. S. G. S., 1899, p. 189.
Glossograptus ciliatus Emmons. 19 Ann. R. U. S. G. S., 1899, p. 189.
Glossograptus ciliatus Emmons. 19 Ann. R. U. S. G. S., 1899, p. 189.
Nemagraptus exilis (Lapworth). 19 Ann. R. U. S. G. S., 1899, p. 189.
Nemagraptus gracilis (Hall). 19 Ann. R. U. S. G. S., 1899, p. 189.

POULTNEY, EAST, 1½ mi. N. of.
Normanskill, Ig and G.
Climacograptus parvus Hall. 19 Ann. R. U. S. G. S., 1899, p. 189.
Didymograptus sagitticaulis Gurley. 19 Ann. R. U. S. G. S., 1899, p. 189.
Diplograptus angustifolius Hall. 19 Ann. R. U. S. G. S., 1899, p. 189.
Diplograptus foliaceous (Murchison). 19 Ann. R. U. S. G. S., 1899, p. 189.
Nemagraptus gracilis (Hall). 19 Ann. R. U. S. G. S., 1899, p. 189.
Nemagraptus exilis (Lapworth). 19 Ann. R. U. S. G. S., 1899, p. 189.

POWNAL, ½ mi. N. Mass. line.
Trenton.
Hormotoma (?) major (Hall). R. V. S. G., V, p. 125.
Lophospira bicincta (Hall). R. V. S. G., V, p. 125.

PROVIDENCE ISLAND.
Chazy.
Bucania tripla Whitfield. R. V. S. G., III, p. 142.

PROVIDENCE ISLAND, 2 peninsulas on NW. shore.
Upper Chazy.
Camarotoechia plena (Hall). R. V. S. G., III, p. 141.

PROVIDENCE ISLAND.
Chazy (c-28 ft.).
Eccyliomphalus (Orthostoma) lituiformis (Whitfield). R. V. S. G., XIII, p. 85.
Isochilina seelyi (Whitfield). R. V. S. G., VII, pl. 61, fig. 17.
Maclurites affinis (Billings). R. V. S. G., XIII, p. 85.
Wingia congregata Seely. R. V. S. G., V, p. 178, pl. 39.
Trenton.
Cryptolithus tessellatus Green. R. V. S. G., XIII, p. 84.
Hormotoma confusa (Whitfield). R. V. S. G., III, p. 142.
Mesotrypa whiteavesi (Nicholson). R. V. S. G., XIII, p. 85.
Plectoceras ? undatum (Conrad). R. V. S. G., XIII, p. 85.
Plethospira cassina (Whitfield). R. V. S. G., XIII, p. 85. R. V. S. G., VII, pl. 59, fig. 5.
Prasopora simulatrix orientalis Ulrich. R. V. S. G., XIII, p. 84.

Schroederoceras eatoni (Whitfield). R. V. S. G., XIII, p. 85.
Tarphyceras seelyi (Whitfield). R. V. S. G., XIII, p. 85. R. V. S. G., VII, pl. 53, fig. 2; pl. 54, fig. 3.
Pleistocene.
Mya arenaria L. R. V. S. G., VII, p. 55.

RUTLAND, 1¼ mi. N., bank East Creek, N. of Clement house.
Cambrian.
Kutorgina sp. B. G. S. A., II, p. 334, 1891.
Lingula sp. B. G. S. A., II, p. 334.

RUTLAND, 2 mi. N., 400 yds. E. of Pittsford road; 100 yds. S. of branch road to Mendon.
Cambrian.
Kutorgina sp. B. G. S. A., 1891, II, p. 334.

RUTLAND, WEST, 100 yds. NW. of old quarry, 150 rods SW. of Barnes' hotel.
Chazy.
Palaeocystites tenuiradiatus (Hall). A. J. S. (3), VI, p. 275, 1873. A. J. S. (3), IV, p. 133, 1872.
Raphistoma stamineum (Hall). A. J. S. (3), VI, p. 275, 1873. A. J. S. (3), IV, p. 133, 1872.

RUTLAND, WEST, marble quarries.
Chazy B.
Maclurites magnus (Lesueur). R. V. S. G., XII, p. 212.

RUTLAND, WEST, ls. above Sheldon and Slason quarry.
Stictopora sp. A. J. S. (3), VI, p. 276, 1873.

ST. ALBANS.
Cambrian (erratic).
Billingsella orientalis Walcott. R. V. S. G., VI, p. 197.

ST. ALBANS, on Mill River.
Chazy B.
Maclurites magnus (Lesueur).

ST. ALBANS, W. side St. A. Bay at mouth of ravine to St. A.
Pleurotomaria quebecensis Billings. R. V. S. G., VI, p. 195.

ST. ALBANS, 1½ mi. E. of.
Cambrian.
Scolithus linearis (Haldemann). R. V. S. G., V, p. 118.
Trenton.
Ceraurus pleurexanthemus Green. R. V. S. G., V, p. 143.
Clionychia undata (Emmons). R. V. S. G., V, p. 143.
Conularia trentonensis Hall. R. V. S. G., V, p. 143.
Cryptolithus tessellatus Green. R. V. S. G., V, p. 143.
Cycloceras olorus (Hall). R. V. S. G., V, p. 143.
Dalmanella testudinaria (Dalman). R. V. S. G., V, p. 143.

ST. ALBANS, ½ mi. W. of school No. 10.
Trenton.
Diplograptus foliaceous (Murchison). R. V. S. G., XIII, p. 201.

ST. ALBANS, Adams' pasture.
Middle Cambrian.
Lingulepis acuminata (Conrad). R. V. S. G., VI, p. 214.

ST. ALBANS, Marye ledge 2 mi. S. 30° W.
Upper Cambrian, boulder in conglomerate.
Lingulella sp. R. V. S. G., XIV, p. 123.

ST. ALBANS BAY village.
Trenton.
Dinorthis subquadrata Hall. R. V. S. G., V, p. 143.
Holopea symmetrica Hall. R. V. S. G., V, p. 143.
Isotelus gigas deKay. R. V. S. G., V, p. 143.
Lingula elongata Hall. R. V. S. G., V, p. 143.
Liospira vitruvia (Billings). R. V. S. G., V, p. 143.
Orthoceras junceum Hall. R. V. S. G., V, p. 143.
Phragmolites compressus Conrad. R. V. S. G., V, p. 143.
Prasopora simulatrix orientalis Ulrich. R. V. S. G., V, p. 143.
Rafinesquina alternata (Emmons). R. V. S. G., V, p. 143.
Schizambon dodgei Winchell & Schuchert. R. V. S. G., V, p. 143.
Schizocrania filosa Hall. R. V. S. G., V, p. 143.
Sinuites cancellatus (Hall). R. V. S. G., V, p. 143.
Spyroceras subannulatum (D'Orbigny). R. V. S. G., V, p. 143.
Trematis terminalis (Emmons). R. V. S. G., V, p. 143.
Whitella ventricosa (Hall). R. V. S. G., V, p. 143.

ST. ALBANS, ½ mi. S. of rivulet flowing over escarpment in ravine to St. A. Bay.
Trenton.
Rafinesquina alternata (Emmons). R. V. S. G., VI, p. 195.

ST. ALBANS BAY village.
Canajoharie.
Lingula curta Conrad. R. V. S. G., V, p. 143.
Parastrophia hemiplicata Hall. R. V. S. G., V, p. 143.

ST. ALBANS, half way between Frank Young's and Stephen Albee's.
Pleistocene.
Sanguinolaria fusca ? R. V. S. G., V, p. 141.
Saxicava arctica Linné. R. V. S. G., V, p. 141.
Yoldia obesa. R. V. S. G., VII, p. 55.

SALISBURY (in boulders).
Cambrian.
Nothozoe sp. R. V. S. G., X, p. 230.

SALISBURY, Lake Dunmore, E. shore.
Cambrian.
Hyolithes communis Billings. A. J. S. (4), XXX, 1910, p. 268.
Hyolithes gibbosus Hall and Whitfield. A. M. N. H., No. 242.
Modiolopsis sp. R. V. S. G., V, p. 117.
Nothozoe vermontana Whitfield. B. A. M. N. H., V, p. 144, pl. 14, figs. 14, 15.
Olenellus sp. A. J. S. (4), 1910, XXX, p. 268.

SALISBURY, Sunset Hill, W. side of Lake Dunmore.
Cambrian.
Hyolithes communis Billings. R. V. S. G., V, p. 124.
Nothozoe vermontana. R. V. S. G., V, p. 124.

SHOREHAM.
Chazy or Beekmantown E.
Bathyurus extans (Hall). R. V. S. G., XIII, p. 74.

Bucania tripla Whitfield. R. V. S. G., XIII, p. 74. R. V. S. G., VII, pl. 60, fig. 7.
Eccyliomphalus (*Orthostoma*) *lituiformis* (Whitfield). R. V. S. G., XIII, p. 74.
Hormotoma confusa (Whitfield). R. V. S. G., XIII, p. 74.
Isochilina seelyi (Whitfield). B. U. S. N. M., 92, p. 674. R. V. S. G., XIII, p. 74.

SHOREHAM, old B. Chenette farm.
Beekmantown B, Tribes Hill.
Cryptozoon steeli Seely. R. V. S. G., V, p. 166. R. V. S. G., XII, p. 161, pl. 34, 36, fig. 1. R. V. S. G., XIII, p. 74.
Cryptozoon. R. V. S. G., V, p. 166.
Cryptozoon wingi Seely. R. V. S. G., XIII, p. 74.
Holopea sp. R. V. S. G., XIII, p. 74.
Chazy=Beekmantown D-4.
Wingia congregata Seely. R. V. S. G., XIII, p. 74.
Trenton, as Beekmantown D.
Schroederoceras eatoni (Whitfield). R. V. S. G., XIII, p. 74.
Maclurites affinis (Billings). R. V. S. G., XIII, p. 74.
Ophileta complanata Vanuxem. R. V. S. G., XIII, p. 74.
Orthoceras primigenium Vanuxem. R. V. S. G., XIII, p. 74.
Scolithus minutus Brainerd and Seely. R. V. S. G., XIII, p. 74.

SHOREHAM, Deignault Hill, west slope.
Chazy B.
Maclurites magnus (Lesueur). R. V. S. G., XII, p. 160.

SHOREHAM, Huff's Crossing, ¾ mi. S. of.
Beekmantown.
Ophileta complanata Vanuxem. R. V. S. G., XII, p. 157.

SHOREHAM, Huff's Crossing, 1½ mi. S. of; N. of road N. of Gristmill Falls, W. edge of woods.
Chazy B.
Maclurites magnus (Lesueur). R. V. S. G., XII, p. 157.

SHOREHAM, Larrabees Point.
Trenton.
Climacograptus strictus Ruedemann. R. V. S. G., XIV, p. 69.
Endoceras proteiforme Hall. R. V. S. G., VII, p. 49.

SHOREHAM, Larrabees Point, old quarry S. of.
Glens Falls.
Parastrophia hemiplicata Hall. R. V. S. G., X, p. 207.

SHOREHAM, Larrabees Point.
Canajoharie.
Diplograptus macer Ruedemann. R. V. S. G., XIV, p. 69.

SHOREHAM CENTER.
Beekmantown D-1.
Leperditia nana (Jones). R. V. S. G., XIII, p. 74.

SHOREHAM CENTER, White schoolhouse.
Chazy.
Wingia congregata Seely. R. V. S. G., V, p. 178, pl. 39.
Wingia discoidea Seely. R. V. S. G., XIII, p. 74. R. V. S. G., V. p. 179, pl. 39.
Wingia lapilla Seely. R. V. S. G., XIII, p. 74. R. V. S. G., V, p. 179, pl. 40.

SHOREHAM, EAST, Bascom ledge.
Chazy, div. D-3.
Isotelus platymarginatus Raymond. R. V. S. G., XIV, p. 206.

SOUTH HERO, Phelps Point.
As Beekmantown.
Isochilina gragaria (Whitfield). R. V. S. G., VII, p. 47.

SOUTH HERO, brow of hill back of house of Mr. Hall, 2 mi. SW. of station.
Upper part of Lower Chazy.
Lamottia heroensis Raymond. R. V. S. G., XIV, p. 76, pl. 1.
Stromatocerium lamottense chazianum Seely. R. V. S. G., IV, p. 148.
Lingula brainerdi Raymond. R. V. S. G., V, p. 183, pl. 41. R. V. S. G., VII, pl. 51. R. V. S. G., X, p. 216.
Chazy.
Ampyx halli (Billings). R. V. S. G., VII, p. 216.
Camarotoechia plena (Hall). B. U. S. N. M., 92, p. 178.
Camerella breviplicata Billings. R. V. S. G., VII, p. 48. R. V. S. G., X, p. 216.
Girvanella atrata (Seely). R. V. S. G., III, p. 157, pl. 57, fig. 1; pl. 58, fig. 9.
Monticulipora insularis Seely. R. V. S. G., V, p. 185, pl. 43, 44.
Dalmanella testudinaria (Dalman). R. V. S. G., VII, p. 49.
Eospongia varians Billings. R. V. S. G., VII, p. 48.
Girvanella ocellata (Seely). R. V. S. G., IX, pl. 50. R. V. S. G., X, p. 216.
Lingula perryi Billings. R. V. S. G., VII, p. 48.
Orthis costalis Hall. R. V. S. G., VII, p. 48.
Prasopora hero Seely. R. V. S. G., V, p. 187, pl. 45.
Protarea patella Seely. R. V. S. G., VII, p. 48.
Solenopora compacta (Billings). R. V. S. G., VII, p. 48.
Stromatocerium lamottense Seely. R. V. S. G., IV, p. 147.
Strophomena aurora (Billings). R. V. S. G., VII, p. 48.

SOUTH HERO.
Chazy.
Zygospira acutirostris Hall. R. V. S. G., VII, p. 48.
Black River.
Columnaria alveolata Goldfuss. R. V. S. G., VII, p. 49.
Maclurea logani (Salter). R. V. S. G., VII, p. 49.
Strephochetus atrata (Seely). R. V. S. G., VII, p. 49.
Stromatocerium rugosum Hall. R. V. S. G., VII, p. 49.
Tetradium fibratum Safford. R. V. S. G., VII, p. 49.

SOUTH HERO, McBride's Bay to Barnes Bay.
Trenton.
Calymene senaria Conrad. R. V. S. G., X, p. 217.
Cryptolithus tessellatus Green. R. V. S. G., X, p. 217.
Cheirocrinus cf. logani (Billings). R. V. S. G., XII, p. 90.
Endoceras proteiforme Hall. R. V. S. G., XII, p. 91.
Eridotrypa aedilis minor (Ulrich). R. V. S. G., XII, p. 90.
Escharapora sp. R. V. S. G., XII, p. 90.
Orthoceras amplicameratum Hall. R. V. S. G., VII, p. 49.
Orthoceras junceum Hall. R. V. S. G., VII, p. 49.
Orthoceras olorus (Hall). R. V. S. G., VII, p. 49.
Orthoceras strigatum Hall. R. V. S. G., VII, p. 49.

Platystrophia biforata (Schlotheim). R. V. S. G., VII, p. 49.
Plectambonites sericeus (Sowerby). R. V. S. G., XII, p. 90.
Prasopora simulatrix orientalis Ulrich. R. V. S. G., XIII, p. 153.
Rhynchotrema. R. V. S. G., VII, p. 49.
Schizocrinus nodosus Hall. R. V. S. G., XII, p. 90.
Zygospira recurvirostris (Hall). R. V. S. G., VII, p. 49.

SOUTH HERO.

Trenton.

Ambonychia orbicularis (Emmons). R. V. S. G., XII, p. 90.
Ambonychia cf. orbicularis (Emmons). R. V. S. G., XIV, p. 70.
Buthotrephis cf. succulens Hall. R. V. S. G., XII, p. 90.
Bucania punctifrons (Emmons). R. V. S. G., XII, p. 91.
Bythocypris cylindrica (Hall). R. V. S. G., XII, p. 91.
Calymene scnaria Conrad. R. V. S. G., XII, p. 91. R. V. S. G., XIV, p. 70.
Ceraurus pleurexanthemus Green. R. V. S. G., XII, p. 91. R. V. S. G., XIV, p. 70.
Cheirocrinus cf. anatiformis (Hall). R. V. S. G., XIV, p. 69.
Clidophorus foerstei Ruedemann. R. V. S. G., XII, p. 90.
Conularia trentonensis Hall. R. V. S. G., XII, p. 91.
Cryptolithus tessellatus Green. R. V. S. G., XII, p. 91. R. V. S. G., XIV, p. 70.
Ctenodonta levata (Hall). R. V. S. G., XII, p. 90. R. V. S. G., XIV, p. 70. Geol. Vt., I, 1861, p. 295.
Dalmanella rogata (Sardeson). R. V. S. G., XII, p. 91.
Dinorthis pectinella (Emmons). R. V. S. G., XII, p. 91.
Eridotrypa aedilis (Eichwald). R. V. S. G., XIV, p. 69.
Geisonoceras tenuitextum (Hall). R. V. S. G., XII, p. 91.
Hallopora sp. R. V. S. G., XII, p. 91.
Holopea sp. R. V. S. G., XII, p. 91.
Hormotoma gracilis (Hall). R. V. S. G., XII, p. 91.
Illaenurus cf. americanus (Billings). R. V. S. G., XII, p. 91.
Isotelus gigas deKay. R. V. S. G., XII, p. 91.
Lepidocoleus jamesi (Hall and Whitfield). R. V. S. G., XII, p. 91.
Lingula obtusa Hall. R. V. S. G., XII, p. 90. Geol. Vt., I, 1861, p. 292, fig. 195.
Lophospira bicincta (Hall). R. V. S. G., XII, p. 91.
Modiolopsis sp. R. V. S. G., XII, p. 90.
Orthodesma cf. nasutum (Conrad). R. V. S. G., XII, p. 90.
Pachydictya acuta (Hall). R. V. S. G., XII, p. 90.
Palaeoglossa trentonensis (Conrad). R. V. S. G., XII, p. 91.
Parastrophia hemiplicata Hall. R. V. S. G., XII, p. 91.
Prasopora simulatrix orientalis Ulrich. R. V. S. G., XIV, p. 69.
Pterygometopus eboraceus Clarke. R. V. S. G., XII, p. 91.
Rafinesquina alternata (Emmons). R. V. S. G., XIV, p. 70. R. V. S. G., XII, pp. 90, 91.
Sinuites cancellatus (Hall). R. V. S. G., XII, p. 91.
Spyroceras bilineatum (Hall). R. V. S. G., XII, p. 91.
Tetradella subquadrans radiomarginata Ruedemann. R. V. S. G., XII, p. 91.
Trematis terminalis (Emmons). R. V. S. G., XII, pp. 90, 91.
Trocholites ammonius Conrad. R. V. S. G., XII, p. 91. Geol. Vt., I, p. 297, fig. 207.
Vanuxemia sp. R. V. S. G., XIV, p. 70.
Zygospira exigua (Hall). R. V. S. G., XI, pp. 90, 91.

Canajoharie.

Calymene senaria Conrad. R. V. S. G., XII, p. 92.
Climacograptus typicalis Hall. R. V. S. G., XII, p. 91.
Diplograptus amplexicaulis Hall. R. V. S. G., XII, p. 91.
Lingula curta Conrad. R. V. S. G., XIV, p. 69.
Schizocrania filosa Hall. R. V. S. G., XII, p. 92.
Serpulites sp. R. V. S. G., XII, p. 92.

STARKSBORO, near Rockville, at house of Mr. Hill.

Cambrian.

Lingula sp. A. J. S., (3), 1873, VI, p. 277.

Lower Cambrian.

Nothozoe vermontana Whitfield. R. V. S. G., V, p. 117.

SUNDERLAND, Roaring Branch, 1 mi. up ravine.

Cambrian, erratics.

Hyolithes sp. R. V. S. G., V, p. 124.

SUNDERLAND, Roaring Branch.

Cambrian.

Scolithus sp. R. V. S. G., V, p. 124.

SWANTON, J. P. Kelley, old Cushman farm.

Cambrian.

Agnostus interstrictus White. R. V. S. G., VI, p. 216. R. V. S. G., X, p. 218.

SWANTON, East of.

Cambrian.

Camerella antiquata Billings. 10 Ann. R. U. S. G. S., p. 573.
Camerella antiquata Billings. R. V. S. G., V, p. 118.
Dactyloides asteroides Fitch. R. V. S. G., VI, p. 216. R. V. S. G., X, p. 218.

SWANTON, N. of 2 ls. masses 30 rods W. of sh. N. of Kelley farm. Close to Winooski marble.

Cambrian.

Hyolithes sp. R. V. S. G., VI, p. 217.

SWANTON, E. NE. of Barney quarries.

Cambrian.

Iphidia labradorica; = I. swantonensis Walcott. R. V. S. G., VI, p. 205.
Iphidia labradorica. R. V. S. G., VI, p. 217. R. V. S. G., X, p. 218.
Kutorgina cingulata (Billings). R. V. S. G., VI, pp. 201, 205.
Kutorgina labradorica var. swantonensis Walcott. 10 Ann. R. U. S. G. S., p. 573.
Lingulepis acuminata (Conrad). R. V. S. G., VI, p. 214.
Microdiscus parkeri Walcott. R. V. S. G., X, pp. 216, 218.
Micromitra labradorica swantonensis (Walcott). A. M. N. H.
Nisusia festinata Billings. R. V. S. G., VI, p. 217.
Olenellus thompsoni Hall. R. V. S. G., VI, p. 215.
Olenoides marcoui Whitfield. R. V. S. G., V, p. 216. R. V. S. G., X, p. 218.
Orthisina festinata Billings. R. V. S. G., V, p. 118. R. V. S. G., VI, p. 201.
Planolites congregatus Hall. R. V. S. G., VI, p. 216.
Planolites virgatus Hall. R. V. S. G., VI, p. 216.

Protypus senectus Billings. 10 Ann. R. U. S. G. S., p. 575.
Ptychoparia adamsi Billings. 10 Ann. R. U. S. G. S., p. 575. R. V. S. G., VI, p. 215.
Ptychoparia teucer Billings. R. V. S. G., V, p. 119.
Rustella edsoni Walcott. R. V. S. G., VI, p. 216.
Salterella pulchella Billings. R. V. S. G., VI, p. 226.

SWANTON, S. of village.
Chazy.
Girvanella ocellata (Seely). R. V. S. G., XIII, p. 194.
Maclurites magnus (Lesueur). R. V. S. G., XIII, p. 194.

SWANTON, bed of river.
Trenton.
Diplograptus foliaceous (Murchison). R. V. S. G., V, p. 212.

SWANTON FALLS.
Trenton, Canajoharie.
Glossograptus quadrimucronatus (Hall). R. V. S. G., XIII, p. 191.

VERGENNES, W. of playgrounds, Industrial School.
Chazy B.
Girvanella ocellata (Seely). R. V. S. G., XIII, p. 236.

VERGENNES, 3½ mi. S. of.
Chazy B.
Maclurites magnus (Lesueur). R. V. S. G., X, p. 242. R. V. S. G., XIII, p. 236.

VERGENNES, 2 mi. NE.
Trenton.
Calymene senaria Conrad. R. V. S. G., XIII, p. 236.
Cryptolithus tessellatus Green. R. V. S. G., XIII, p. 236.
Diplograptus amplexicaulis Hall. A. M. N. H., Cat. No. $\frac{1040}{8}$.

VERGENNES, Industrial School grounds near boat landing.
Trenton, Canajoharie.
Glossograptus quadrimucronatus (Hall). R. V. S. G., XIII, p. 236.

WALTHAM, 1½ mi. S. of Vergennes.
Chazy.
Girvanella ocellata (Seely). R. V. S. G., XIII, p. 244.
Maclurites magnus (Lesueur). R. V. S. G., XIII, pp. 244, 245.

WILLISTON.
Chazy.
Stromatopora. A. J. S. (3), VI, p. 276, 1873.

THE CLAY DEPOSITS AND CLAY INDUSTRIES OF VERMONT

ELBRIDGE CHURCHILL JACOBS.

CONTENTS.

INTRODUCTION.

At the request of the State Geologist the writer has made a survey of the clay resources and clay industries of the State. He has found that the deposits of Quaternary (glacial) clays are enormous and that the resources of the State in china clay are much greater than is generally supposed. At the present time Vermont has only a small clay industry, but there are good reasons for believing that in the near future this will be greatly enlarged by the development of her china clay deposits.

In a region of many streams and glacial lakes and in one everywhere covered with glacial drift, Quaternary clay deposits naturally occur in many places, and numbers of old brick houses in many parts of the State testify to their abundance and former extensive use.

It has been one object of the present investigation to locate and to describe those considerable deposits of clay which are not being worked but are available and commercially accessible for the various purposes to which they are suited.

Since the report is written chiefly for the general reader it is presented in perhaps greater detail than would be the case if it were intended wholly for the technical student.

Professor Ries,[1] who is the authority on the subject, defines clay as "the term applied to those earthy materials, occurring in nature, whose most prominent property is that of plasticity when wet." "On this account," he continues, "they can be moulded

[1] Clays, Occurrence, Properties, and Uses, Heinrich Ries.

into almost any desired shape, which is retained when dry. Furthermore, if heated to redness or higher, the material becomes hard and rock-like."

Merrill[1] points out that "clays although alike in their general physical and even ultimate nature, have widely diverse origins, being indefinite admixtures of more or less hydrated aluminum silicates, free silica, iron oxides, carbonate of lime, and various silicate minerals which, in more or less decomposed and fragmental condition, have survived the destructive agencies to which they have been subjected." In other words, clay is composed of certain residual products of rock disintegration.

Lindgren[2] notes that sedimentary clay is a rock rather than a mineral and, this being so, that kaolin or china clay is to be distinguished from kaolinite, which is a mineral having a definite chemical composition with the formula, $H_4Al_2Si_2O_9$, calling for 46.5 percent SiO_2, 39.5 percent $Al_2\ O_3$, and 14 percent water.

Of late years much attention has been paid to so-called colloids and to the colloidal state of matter. Popular definitions are difficult to give, but it may be stated that the colloidal state results generally from an exceedingly fine subdivision of many different substances. Opposed to the colloidal state is the crystalline condition, in which the mineral molecules are organized, forming planes and faces often definitely related to one another. Egg albumen, glue, jellies, etc., are well-known examples of substances in the colloidal state, while Bancroft[3] points out that so many substances in our every day experiences—cement, bricks, pottery, porcelain, glass, rubber, soaps, etc.—exist in this state, that "colloid chemistry is the chemistry of every day life"; that it is a common and not an unusual condition of matter.

Ashley[4] has studied the colloidal state as it exists in clay and, defining clays as mixtures of various silicate minerals, among which kaolinite is the most characteristic, he points out that these mineral grains which exhibit both crystal faces and irregular shapes, are enveloped by colloidal coatings. These coatings are chiefly of silicate constitution, but also consist of organic colloids, iron, manganese and aluminum hydroxides, and of hydrated silicic acid.

In clays the proportion of crystalline and colloidal matter is such that, when moistened, plasticity results. If the colloidal matter is in excess the clay is considered very plastic, "fat," or sticky; while if the crystalline material is in excess, the clay is sandy, weak, or non-plastic.

[1] Rocks, Rock-weathering and Soils, G. P. Merrill.
[2] Mineral Deposits, Waldemar Lindgren.
[3] Applied Colloidal Chemistry, W. D. Bancroft.
[4] The Colloid Matter of Clay, and its Measurement, H. E. Ashley, Bull. U. S. G. S., No. 388.

USES OF CLAYS.

The uses of clay are many and varied. The following partial list, taken from Ries,[1] will give some of the more common, local ones:

Domestic.—Porcelain, stoneware, yellow ware, Rockingham ware for table service and cooking. Fire-kindlers.

Structural.—Brick, common, pressed, faced, paving, glazed; terra-cotta; roofing-tile; drain-tile; door-knobs.

Refractories.—Fire-brick, saggers, stove and furnace-brick (furnace cement).

Engineering.—Portland cement; electrical conduits; road-metal.

Decorative.—Ornamental pottery (Parian ware).

Minor uses.—Food adulterants, paint fillers, paper fillers, electric insulators, scouring-soap, chemical apparatus, smoking-pipes, filter-tubes, plaster, alum, etc.

Vermont clays have been used in the past, are being used at present, or will probably be used in the future for making porcelain, white ware, stoneware, yellow ware, Rockingham ware, Parian ware, bricks (common and faced), drain-tile, saggers, stove- and furnace-lining, ornamental pottery, paints, fillers, paper-filling, electrical insulators, etc. It is, furthermore, proposed to use some of the best grades as a basis for the production of alums.

CLASSIFICATION OF VERMONT CLAYS.

The origin of clays is so varied and their properties and uses are so diverse that their classification is a matter of considerable difficulty.

As regards origin, Vermont clays may be listed as follows:

RESIDUAL CLAYS.

Under this heading are included those clays which are found in contact with the rock from which they were derived by the process called kaolinization. This parent rock may contain feldspar (a family of anhydrous silicates of aluminum, potassium, sodium, calcium, or isomorphous mixtures of these) or any other mineral which, on weathering, produces more or less of the mineral kaolinite, together with other aluminum silicates. Common parent rocks are pegmatite, granite, feldspathic quartzite, etc.

The clays derived from these residual deposits give us the kaolins, which Ries defines as "White-burning clays of residual character, which are composed mostly of silica, alumina, and

[1] *Loc. cit.*

chemically-combined water, and have very low percentages of fluxing impurities, especially iron."

This class of clays occurs in Vermont along the western border of the Green Mountains.

TRANSPORTED CLAYS.

Here are included those clay sediments which bear no direct relation to the underlying rocks, but have been transported, mixed, and deposited by the agency of running water. They may include white-burning, plastic clays, derived from residual deposits, or colored clays, having oftentimes remote and complex origins. Transported clays include:

ESTUARINE CLAYS.

These, as Ries states, "Represent bodies of clays laid down in shallow arms of the sea." The Champlain Clays belong to this class of deposits, since Lake Champlain at the close of the Glacial Epoch formed a part of the ~~Hudson~~-Champlain-St. Lawrence arm of the Atlantic Ocean which separated New England and southeastern Canada from the rest of the continent.

LAKE AND POND CLAYS.

Vermont is a region of many lakes and ponds, probably all of which are of glacial origin. These formed settling basins into which the clay and other material, brought down by streams from the melting ice on the retreat of the ice-cap, were deposited and settled out, more or less interstratified with other rock débris, especially sand.

FLOOD-PLAIN AND TERRACE CLAYS.

Ries[1] states that: "Many rivers, especially in broad valleys, are bordered by a terrace or plain, there being sometimes two or more, extending like a series of shelves or steps up the valley sides. The lowest of these is often covered by the river during periods of high water, and is consequently termed a flood-plain. In such times much clayey sediment is added to the surface of this flood-terrace, and thus a flood-plain clay deposit may be built up."

In Vermont the Missisquoi, Lamoille, Winooski, and Otter Rivers, as well as the Connecticut, are bordered by flights of terraces, which represent old flood-plains through which the rivers have cut their courses, owing to the rise of the land. On these terraces are found deposits of sedimentary clays, some of which have been used for brick-making, while many more would afford material for this or other clay industries for many years to come.

[1] *Loc. cit.*

DRIFT OR BOWLDER CLAY.

During the last glacial epoch, the so-called Pleistocene, the ice-sheet which came down from the North, burying a large part of the continent to a depth of thousands of feet, brought with it an enormous amount of bowlders, rock-débris, sand, clay, etc. This material is called "till" or "glacial drift" and it is found everywhere in Vermont, filling old depressions and leaving transported bowlders or "erratics" in the fields and even on the mountain tops. The clay and associated rock waste, formed by the grinding action of the englaciated material, is known as "bowlder-clay" or "hardpan." Splendid examples of hardpan may be seen at Clarendon Springs and elsewhere in the State. Clays derived from this class of deposits are generally too impure for commercial use.

SEASONAL OR VARVE CLAYS.

As the Great Ice Age came to a close and the ice-cap retreated northward, owing to the coming of a more moderate climate, many temporary streams were formed in and on the borders of the ice. These streams, working over the englaciated rock marial, sorted it according to its size and specific gravity and formed it into eskers and outwash-plains. When the glacial streams discharged into standing water, the coarser, heavier sand was deposited near shore, while the lighter, clay material was carried farther out, gradually to sink in the still water. Even here there was a sorting action going on, owing to the extremely fine, colloidal state of division of which clay particles are susceptible. In the warmer seasons, with their vigorous stream-flow, coarser clay particles and correspondingly finer particles of sand, having the same "settling power," to use a term employed in ore-dressing, settled together; while in the colder parts of the year, when streams no longer issued from the ice and standing bodies of water were frozen over, the finer clay particles, and associated with them, fine shreds of organic matter, gradually sank to the bottom and formed a stratum quite distinct from the sand-clay layer. Evidently these two strata were the result of one season's deposition, and the number of pairs of strata found in a given clay deposit is a measure of the number of years needed for its formation. Such deposits are called "seasonal clays" and the annual layers are called "varves."

In Europe De Geer, and in this country Ernst Antevs, have made use of such varve clays to establish a glacial chronology. It will be seen that many Vermont clays belong to this class of deposits.

Plate XXI, printed by permission of the Harvard Museum of Comparative Zoology, shows a large deposit of varve clay, on the Vermont side of the Connecticut River, near Hanover, N. H.

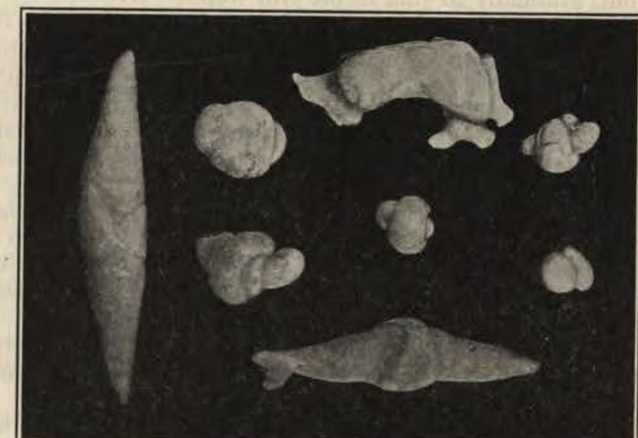
CLAY CONCRETIONS.

Besides the stones and bowlders which are associated with glacial clay banks, there are found deep within the clay itself (derived from it, in distinction from the stones and bowlders)

PLATE XX.

A varve-clay deposit.

PLATE XXI.



Clay concretions.

various mineral substances, such as limonite, siderits, pyrite, and carbonate of calcium. The calcium carbonate manifests itself in curious shapes and forms, as shown in Plate XXII. These do not appear to have formed around nuclei—or if they have,

the nuclei are too microscopic to be discovered in the broken concretions. The concretions are found only in clays which have a considerable lime content and appear to have been formed by a gathering together of the lime carbonate molecules. In this respect they resemble the crystallized pyrite which one finds in the chlorite schist around Chester. By the brick-maker they are called "clay-dogs."

PROPERTIES OF CLAYS.

The commercial value of a clay will depend upon its chemical and mineral composition and upon such physical properties as its color, plasticity, shrinkage, porosity, fusibility, absorbtion, etc. Clays are therefore tested chemically, microscopically, and physically and on the following pages the results of such tests, made on various clay deposits, are tabulated. It will, therefore, be illuminating to consider these properties and tests in some detail.

CHEMICAL ANALYSIS.

The chemical analysis shows the ultimate composition of the material. For convenience the elements present are expressed as oxides and acid-radicals and these should (but never do) aggregate exactly 100 percent. The analysis will reveal the identity and amount of both desirable and undesirable ingredients in the sample. If we may take kaolinite as the essential clay substance, we may regard it as having the formula: Al_2O_3, 2 SiO_2, 2 H_2O, which corresponds to the composition: SiO_2, 46.50 percent; Al_2O_3, 39.57 percent; water (H_2O), 13.93 percent. Other constituents of a clay, such as oxides of iron, the alkalies and alkaline earths, etc., will have their effect on its color, fusibility, etc.

The chemical analysis may be "recast" to show the percentages of *mineral* constituents present, as kaolinite, feldspar, free quartz (sand), etc. This gives the "rational analysis." Or a special chemical procedure may be carried on, which will serve to give the same thing. (See the analyses of Bennington clays, p. 206).

PLASTICITY.

Ries defines plasticity as "The property which many bodies possess of changing form under pressure, without rupturing, which form they retain when the pressure ceases." He states that plasticity is not restricted to clays, but is more highly developed in them than in some other substances.

For the purpose of obtaining reliable results from physical tests made upon clays, The American Ceramic Society has adopted standard procedures and standard sizes for the test pieces used. These test pieces are made from the clay under examination and are approximately 1⅛ x 1⅛ x 1⅞ inches. With such pieces the following tests are made:

WATER OF PLASTICITY.

This shows the percent of water present in the sample of plastic clay in question. It is based on the weight of the dry clay test-piece and is calculated from the equation:

$$T = \frac{W_p - W_d}{W_d} \times 100$$

in which T is the percentage water of plasticity,
W_p is the weight of the plastic test-piece,
W_d is the weight of the dry test-piece.

LINEAR DRYING SHRINKAGE.

This test shows the extent to which a clay will contract in linear dimension on drying under uniform conditions. It will depend on the fatness of the clay and on the fineness of its grain. It is based on a test piece of plastic clay of definite length and is expressed in percent as above.

SOFTENING POINT.

The softening points of clays are determined by forming them into small cones or pyramids of standard dimensions, properly dried, and comparing their behaviors with those of standard cones (Seger or Orton) or pyramids of known softening points, when exposed to the same temperatures, under standard conditions.

The standard cones are made of various refractory materials, or of mixtures of these materials. These standard cones have softening points of pretty definite temperatures, varying with their composition. Thermo-electric pyrometers, set into the furnace, serve to relate the softening points of the cones to the Centigrade scale. The standard cones are distinguished by numbers: 1, 2, 4, 7, 10, 13, etc.

PERCENT BURNED SHRINKAGE.

This is the percent diminuation in length of a dry test-piece, when exposed to a definite temperature, under standard conditions. It shows the clay manufacturer to what extent his clay will shrink under the conditions of firing which are required for the ware he is making. From this he will judge how to modify his clay mixture to obtain the desired results.

PERCENT ABSORBTION.

This is obtained by allowing test-pieces, exposed to different temperatures, to absorb their maximum amount of water, and then determining the amount of the water absorbed, by drying the pieces under standard conditions.

Various other tests can of course be made, but the above are the ones used by various testing laboratories. Tests on clays are made by the Bureau of Standards, Washington, D. C.; the Mellon Institute, of Pittsburg, Pa.; Ellis Lovejoy, of Columbus, Ohio, etc.

THE PRESENT CLAY INDUSTRIES IN VERMONT.

Today there are being worked in the State:

1. Quarternary or Glacial Clays, for the manufacture of bricks.
2. Kaolin Deposits, for paper-filling, electrical-porcelain manufacture, stove and furnace linings, and other purposes.

BRICK MANUFACTURE.

The producers of bricks are:

The Drury Brick and Tile Company.

The Bennington Brick Company, now owned by the Green Mountain Kaolin Corporation.

The Wells River Brickyard.

THE DRURY BRICK AND TILE COMPANY.

This company was incorporated in 1897, but dates back to 1867, when it was known as J. K. Drury and Son.

The plant and clay deposits are situated in Essex Junction, near the highway leading to Jericho and Cambridge. A spur-track connects the works with the Central Vermont Railroad.

The corporation has for many years worked the clay on a tract of land some twenty-eight acres in extent. Recently it has purchased the adjoining Place farm of one hundred acres and it is now estimated that the supply of clay is sufficient to last for at least fifty years. The clay lies near the foot-hills of the Green Mountains, whose outcrops of sericite schist appear a few hundred yards to the north.

The clay was probably deposited in an old glacial pond. It is underlain by glacial till and contains considerable quantities of transported glacial débris: Black Isle La Motte limestone, Champlain "marbles," as well as clay concretions, or "clay dogs." The maximum thickness exposed is about thirty feet and it is covered with a sandy loam.

The material is a varve or seasonal clay, varying in color from blue to red.

An analysis of the blue clay, made in the laboratories of the University, shows:

	Percent
SiO_2	53.69
Al_2O_3	21.24
Fe_2O_3	8.65
$TioO_2$	.41
MnO	.02
CaO	2.84
MgO	1.03
Na_2O	1.78
K_2O	3.94
H_2O	5.36
Moisture	.79
	99.75

CO_2 and SO_2 present, but not determined.

Unfortunately, fusibility tests have not been made.

METHOD OF WORKING AND MANUFACTURE OF BRICK.

The clay is dug with a Thew Automatic Electric Shovel and a Schofield & Burkett Excavator, which deliver the material to cars. These are hauled by a gasoline locomotive over narrow-

PLATE XXII.

Thew automatic electric shovel.

gauge tracks to the moulding department. Here the clay is mixed with the proper amount of sand, slack coal and hydrated lime, the amounts depending upon the character of the clay and its water content. This mixture passes through a disintegrator and then, by means of a belt conveyor, is delivered to the pug-mill, the knives of which, set into a horizontal, revolving shaft, cut up the lumps and thoroughly mix the mass. This then passes to a Martin Automatic Brick Machine, which forms the bricks, sands them, and delivers them to pallets, which are carried by cable conveyors either to open-air drying sheds or to steam dryers. The bricks remain in the open-air dryers generally ten days; in the steam dryers, over night—in either case till they are sufficiently strong to be built into kilns. The burning takes place in scove-

type, up-draught kilns, fired with oil during the greater part of the time, but finished with wood-firing, in order to give the desired color. About 680,000 bricks are burned at a time. The building of the kiln requires three weeks, the firing four or five days, and the cooling about five days more.

The standard brick is 2¼ by 3¾ by 8 inches. It weighs approximately four pounds.

The Drury Company shipped 6,076,074 bricks in 1925. The base price is $18 a thousand. The bricks are sold in Vermont, New Hampshire, and eastern New York. The new Ira Allen Chapel, being built for the University of Vermont, and the new Burlington City Hall are being constructed of Drury bricks.

BENNINGTON.

In 1924 the Bennington Brick Company was formed for the purpose of working a deposit of clay on the Fred Foster farm, in the southeastern part of the village. Bricks had been made from this clay over a period of at least seventy years, and used locally with good results.

The deposit is a blue varve-clay and is remarkably free from inclusions and concretions of foreign material. The face exposed to date is about eleven feet in depth and the clay is overlain by three or four feet of glacial débris.

The material is a blue, coarse-grained, fairly homogeneous clay, having a softening-point of about 1,190 degrees Centigrade and a linear drying shrinkage equal to 7.6 percent of the plastic length. Other tests made on the clay showed the following results:

Cone	Percent burned shrinkage	Percent absorbtion	Color
08	10.6	18.7	buff
06	12.6	7.8	salmon
04	16.8	3.6	lt. red
02	18.2	.6	red
1	8.0 (overfired)	1.7	chocolate

The bricks produced are colonial red in color. Several local structures, built of them, have developed no excresences whatever.

The company made about half a million bricks in 1925, while up to September 1, 1926, it had burned about a million more.

In 1925 the Green Mountain Kaolin Corporation was formed (see under Kaolin), and took over the Bennington Brick Co.

THE WELLS RIVER BRICKYARD.

This yard is located in the northeast part of the town of Newbury, on the Wells River, about two miles from its confluence with the Connecticut. The industry was established seven years ago by D. S. Stone. Two years ago, when the writer visited the

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THE WELLS RIVER BRICKYARD.

This yard is located in the northeast part of the town of Newbury, on the Wells River, about two miles from its confluence with the Connecticut. The industry was established seven years ago by D. S. Stone. Two years ago, when the writer visited the plant, it was making about 360,000 bricks a year. The selling price varied from $15 to $20 a thousand.

The deposit from which the bricks are made consists of a slate-colored, fat, varve-clay, some twenty feet in visible thickness, overlain by fifteen or twenty feet of fine sand.

KAOLIN DEPOSITS.

Along the western side of the State there is a broken chain of kaolin deposits, extending from Monkton to Pownal and including outcrops at Monkton, Brandon (Forestdale), Rutland, South Wallingford, Tinmouth, North Dorset, Shaftsbury, and Bennington. It is quite possible that future discoveries will fill in some of the breaks in this chain.

These deposits are more or less associated with iron ore and manganese minerals. Some of them were worked, years ago, for iron and manganese. It is probably safe to say that kaolin has been mined to some extent for over a century. In the last few years there has been increased activity in kaolin mining and at the present time the prospects are extremely good for the establishment of an important kaolin industry in the State.

PRESENT STATUS OF THE INDUSTRY.

At the present time kaolin is being produced, or will probably soon be produced, by the folllowing organizations:

The Vermont Kaolin Corporation, at East Bennington.

Frank E. Bushy and Sons, at East Monkton.

The Green Mountain Kaolin Corporation, at Bennington.

In addition, the Rutland Fire Clay Company is producing a series of fire-resisting substances, which depend more or less on kaolin for their manufacture.

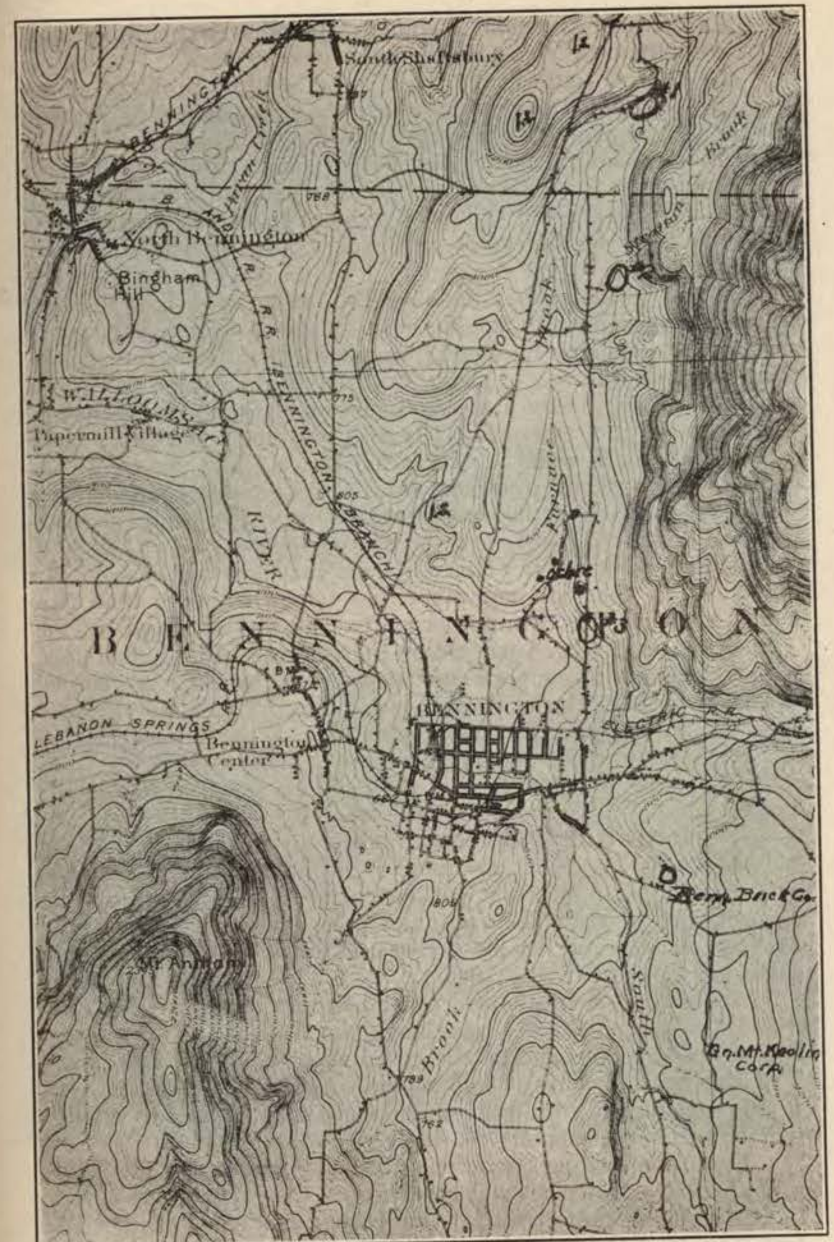
THE VERMONT KAOLIN CORPORATION.

Shaftsbury and Bennington.

In the southeastern part of Shaftsbury and the northeastern part of Bennington, lying somewhat east of Furnace Brook (Plate XXIV), there is a chain of kaolin deposits, which strikes approximately north and south and extends for a distance of about three miles. In three places on this chain kaolin has been mined at intervals for many years.

In East Shaftsbury (location No. 1 on the map) the clay was worked by Booth and Lyons before 1865. Later it was operated by H. N. Elwell, and then by Lafayette Lyons till 1889. In that year the property passed into the hands of S. C. Lyons and Brothers, who mined the clay till 1915, after which time operations were suspended for several years.

PLATE XXIII.



Map of Bennington area.

In 1923 the Vermont Kaolin Corporation was formed and took over the property, which it holds in reserve.

Lying next south in the chain is the Stratton property (location No. 2, on the map), on which clay was mined by Homer Lyons in the eighteen-seventies. Two or three thousand tons were removed and hauled to Furnace Brook, one mile west, where the clay was washed. During 1917 Messrs. Horn and Crockett prospected the deposit, drilling five holes to depths of 105 feet. In 1926 the mineral rights were sold to the Vermont Kaolin Corporation.

Recent drilling operations by the corporation have located a very large deposit of kaolin, covering more than twenty acres in area, and ranging in depth from about fifty to more than 150 feet. The overburden of glacial material averages perhaps twenty feet. The clay does not appear to differ markedly from that in the No. 3 location (see map), being prevailingly of white, blue, or buff color. It seems to carry a relatively low percentage of grit and is unusually free from iron. It is possible that this clay may serve as a material for the manufacture of aluminum sulphate.

The third location (No. 3 on the map), which has so far proved to be the most important, lies somewhat more than two miles south of the Stratton property. It was operated by the United States Pottery Company in the eighteen-fifties and sixties. In the seventies and eighties the deposit was worked by Samuel Keyes, who sold the clay for paper-filling. Later the Stevens and Thompson Paper Company, of Hoosic, N. Y., mined the clay for the same purpose for about a year. The property was sold to S. C. Lyons and Brothers in the eighties, and passed into the possession of the Vermont Kaolin Corporation in 1923.

This corporation went energetically to work, reopened the old shaft, sunk by S. C. Lyons and Brothers, erected a modern clay-washing plant, near the workings and sold the washed product for paper-clay, enameled ware, and other purposes. The crude material found a market for sagger and fire-clay. Unfortunately the plant was destroyed by fire.

Negotiations with the Merrimac Chemical Company, of Boston, Mass., are now under way, looking to the lease of the properties owned or controlled by the corporation for a term of years. The Merrimac Chemical Company has in view the use of this clay for the production of aluminum sulphate, as well as for supplying the ordinary demands for high-grade clay.

Extensive drilling operations are being carried on this summer at the No. 3 deposit and have proved the existence of a very large deposit of first-class clay, underlying a tract of land, 1,100 feet long, by 600 feet wide. Drill-holes have reached a depth of 130 feet and are still bottomed in white clay. It is estimated that

PLATE XXIV.

Clay deposits A and B.

at least one and one-half million tons of clay are now "in sight." The overburden of glacial drift varies from one foot to fifty feet, but probably averages thirty feet. It is proposed to strip off this overburden and mine the clay with steam, or other mechanical shovels.

TESTS ON THE CLAY.

Analysis of the clay shows:

	Percent.
Free moisture	.19
Combined moisture	8.31
SiO_2	52.65
Fe_2O_3	.57
Al_2O_3	32.80
CaO	0.00
MgO	.45
K_2O	3.66
	98.63

Na_2O and TiO_2 were not determined, though probably present.

Practically all of the clay is of comparatively low grit content, much lower than the English residual clays or those of the South. By far the greater part of the material at Bennington contains less than 40 percent of sand, while practically all the white clay carries less than 20 percent. It is estimated that, for the whole deposit, the material other than clay will average around 30 percent.

Fusibility tests on several samples gave the following results:
Sample No. 1, a fine, white, homogeneous clay.
Water of plasticity, based on net weight, 20.5 percent.
Linear drying-shrinkage, 4 percent of the plastic length.
Softening-point, equivalent to Orton pyrometric cone No. 26, approximately 1,595 degrees C.
Results of a draw-trial burn:

Cone	Percent burned shrinkage	Percent absorbtion	Color
01	7.2	17.7	white
3	7.6	16.4	white
6	10.1	13.3	white
9	14.4	6.7	

The relatively low refractoriness of this sample was attributed, by the experimenter, to an admixture of fluxing impurities, probably soda, potash, lime, or magnesia—or to all of them.
Sample No. 2, a fine-grained, homogeneous, plastic clay.
Water of plasticity, based on net weight, 27.5 percent.
Linear drying-shrinkage, 7.6 percent of the plastic length.
Softening-point, equivalent to Orton pyrometric cone No. 32, approximately 1,700 degrees C.

Results of a draw-trial burn:

Cone	Percent burned shrinkage	Percent absorbtion	Color
1	12	11	white
4	15.1	6.8	buff
7	17.2	5.4	buff[1]
10	19.4	3.2	yellow
13	20	1.8	yellow

Sample No. 3, best white kaolin.
Water of plasticity, based on net weight, 27.2 percent.
Linear drying-shrinkage, 6.2 percent of the plastic length.
Softening-point, equivalent to Orton pyrometric cone No. 33, approximately 1,720 degrees C.
Results of a draw-trial burn:

Cone	Percent burned shrinkage	Percent absorbtion	Color
1	7.8	31.2	clean white
4	11.4	24.4	clean white
7	15.4	16.5	clean white
10	15.6	14.6	clean white
13	16.8	10.7	very light cream

GEOLOGY OF THE DEPOSIT.

This is undoubtedly a residual deposit of kaolin, derived from feldspathic rocks lying below it.

The Green Mountains, in this part of the State, are made up prevailingly of Cambrian quartzite. Bald Mountain, at the foot of which (see the map, Plate XXIV) the deposit lies, shows on the accessible outcrops no rock from which the kaolin could have been derived. To the west of the valley the ridges show outcrops of shaly limestone (l. s. on the map). On the other hand, feldspar fragments, much kaolinized, and quartz, are associated with the clay—are mined with it and make up the tailings from the washing. One must conclude, therefore, that the feldspathic rocks, whose alteration has resulted in the formation of the kaolin, lie below the clay deposit.

It is noteworthy that, west of the deposit, there exist some beds of limonite (these were worked for iron in the past), associated with more or less manganese. This of course suggests the former presence of ferro-magnesian minerals, associated with the feldspar, and also argues that the clay was formed "in situ."

SUMMARY.

We have here the largest deposit of kaolin thus far discovered in the State. The clay is of high grade, easily mined, adapted to a variety of purposes, and advantageously located with respect to transportation.

[1] Iron-stained.

THE GREEN MOUNTAIN KAOLIN CORPORATION.

Bennington.

This organization was formed in 1925 and, as already noted, has taken over the business of the Bennington Brick Company.

The corporation also has purchased a tract of land, some 150 acres in extent and underlain by kaolin, lying east of Bennington, at the foot of the Green Mountains.

This property has been examined by Prof. W. F. Jones, whose report to the corporation is in part as follows:

"The deposits of kaolin lie about a mile and a half east of Bennington at the base of a high north-south ridge which bounds the valley on the east. The deposit is about a mile and a half long and of variable width, but averages 100 yards. A number of bore holes put down into the clay showed that the material extends from about one foot beneath the surface to a depth of from six to twenty feet, averaging about twelve feet.

"The clay contains a few scattered bowlders, but no gravel. Here and there in the clay are lenticular layers of sand, the result of freshets during the period of deposition.

"The clay contains a surprisingly small amount of grit, or sand, and is exceedingly finely comminuted. All of it, when wet, has a distinctly 'greasy' smooth texture.

"The deposit may be divided into two parts. The northern two-thirds is kaolin of light buff or cream color, which dries in the sun to an almost pure white. The southern third is a light grayish blue and dries to a pure chalk white. This difference in color is dependent on the percentage of iron present (see the analyses).

"All the clay bakes a pure white and all of it may be said to be a fire clay, in that the material fuses at quite a high temperature.

"The entire deposit contains at least a million tons of clay, of which 250,000 tons are of the grayish blue color."

ANALYSES OF THE KAOLIN.

	North End	Middle	South End
	Percent	Percent	Percent
Loss on ignition	8.30	6.08	6.98
SiO_2	60.14	65.59	65.34
Al_2O_3	28.48	24.39	24.59
Fe_2O_3	1.51	.66	.78
CaO	trace	trace	trace
MgO	trace	trace	trace
Alkalies	not determined		

RATIONAL ANALYSIS.

	Percent
Clay substance (kaolin)	88
Silica sand	7
Zircon, tourmaline, garnet	3½
Feldspar	1½
	100

This analysis shows a very large percentage of clay substance and a very small percentage of sand and feldspar.

ORIGIN.

Professor Jones believes that the kaolin is "the result of disintegration by normal processes of rock decay of the granite rocks of which the high ridge above the clay deposits is largely composed." "These products of disintegration consist of silica sand, soluble potash, and clay. The sand and clay are left as residium, the potash being removed in solution. The residium either accumulated *in situ,* or was washed down by surface waters and carried to favorable points of deposition. In the case of this deposit there has been some transportation, not enough to allow the admixture of impurities to any extent with the clay, but sufficient to separate almost entirely the clay and sand, each being deposited in different places."

If this theory of origin is correct, this deposit differs markedly from the other kaolin beds already described. In these the parent rock was shown to be below the clay, at or near the contact of the Cambrian quartzites and limestones forming the country rock of the region. The writer has not been able to find any feldspathic facies in the quartzite which makes up the mountains to the east of the kaolin deposits. He suggests that the clay deposit under discussion is a transported one, whose origin was to the north, perhaps in the deposits of the Vermont Kaolin Corporation.

The Green Mountain Kaolin Corporation is investigating the adaptability of their clay to paper-making and the ceramic arts. Furthermore, experimental face-bricks are being made from varying mixtures of clays with encouraging results. No light colored face-bricks are being manufactured in New England, the sources of this product being Pennsylvania and Ohio. There seems to be reason to expect that in the future the production of face-brick may take its place as an important Vermont industry.

FRANK E. BUSHY AND SON.

Monkton.

On the Middlebury Quadrangle of the United States Geological Survey, in East Monkton, there is shown the location of an ore-bed lying on the west side of a valley in the western ranges of the Green Mountains.

Here iron ore, called hematite but more probably limonite, was mined many years ago by the Boston Iron Company. Some of the ore was sent to the smelter at Port Henry, across the lake.

North of the ore-pit kaolin is found, extending for at least a mile. This clay has been prospected and worked, on and off, for many years. Early in this century, according to the Report of the Vermont State Geologist for 1905-06, six bore-holes were sunk, varying in depth from 41 to 174 feet, revealing kaolin in all of them to the greatest depth reached.

On the south end of the deposit Samuel Goss quarried clay at one time. O. N. Williams formed the American Paper Clay Company and was working the north end when the 1921-22 Report was written. Later the mill burned down. This property is now owned by the Continental Clay Company, which is controlled by the R. T. Vanderbilt Company of New York City. It is not being operated at present.

Immediately south of the Continental Clay Company's holdings, Frank E. Bushy and Son have been working a clay-pit for the past three years, producing about a thousand tons annually. The material mined is a white kaolin of good quality. It is being air-dried and shipped to the Rutland Fire Clay Company for use in its products.

The clay of the Monkton district lies under a quartzite capping, contains fragments of feldspar, and is probably residual.

THE RUTLAND FIRE CLAY COMPANY.

This company does a large business in the manufacture and sale of certain specialties, which includes: plastic stove lining, boiler-covering cement, patching plaster, furnace cement, waterproof cement, etc.

The output in 1923 reached $700,000 and was sold widely over the country as far west as Kansas and Nebraska.

The works are located on Curtis Avenue, South Rutland, while the pits are in South Rutland and Mendon.

The material mined by the company at present is a fine-grained, mica schist. The company buys kaolin of F. E. Bushy and Son, at East Monkton, and of the Vermont Kaolin Corporation, at Bennington; and also asbestos, for use in the manufacture of its products.

Evidently the material is not, properly speaking, a fire clay, but it fulfills some of the requirements of such a clay, while its usefulness is attested by the large business done, easily the largest of its kind in the State.

OTHER KAOLIN DEPOSITS.

RUTLAND.

In the southern part of Rutland township, in the hills on the west side of the Otter Creek valley, there is a considerable deposit of kaolin on the farm of D. W. Cutting. The deposit has not been opened up to any considerable extent, but surface outcrops of red and brown clay, which soon merge into white kaolin, as is shown in a small test pit three feet deep, seem to indicate a considerable deposit of china clay. Feldspar outcroppings nearby suggest the residual nature of the deposit.

This prospect is worthy of the attention of those interested in clays.

NORTH CLARENDON.

There is said to be a deposit of white kaolin in this place, near Cold River, a tributary of the Otter. The writer was informed that a shaft had been sunk to a depth of about eighty feet and that mining operations extended over a period of two years. Nothing could be found out about the present status of this enterprise.

SOUTH WALLINGFORD.

In South Wallingford, about a mile from the railroad station, there is a large deposit of clay, manganese ore, and limonite which has been worked for its manganese content, but not, as far the writer has been able to learn, for its kaolin.

To quote from E. C. Harder[1]: "The ores are found in a clay layer at the contact of the Cambrian quartzite and limestone. This layer has a general north-south direction and a nearly vertical dip. The deposit consists of associated iron and manganese ores, occurring in pockets and nests, in yellow, red, gray, or white clay. The ores of iron and manganese may be in separate pockets or may occur together in the same pocket, mixed in all proportions. The clay bed has a probable average thickness of several hundred feet, and ore is scattered through this at intervals. The deposit is overlain by ten to sixty feet of glacial drift. The iron ore is limonite; the manganese ore consists of massive psilomelane, crystalline pyrolusite, and probably some manganite."

The writer was informed that manganese was first discovered here over a century ago. The deposit was worked for this metal by Carnegie interests from 1888 to 1890 and it is said that more than 20,000 tons of ore were shipped.

The present owners are Dr. William Bull and Miss Vera Griffith. Their holdings comprise some 155 acres.

The outcrop of the deposit is over 1,000 feet, while its maximum width is about 200 feet. In several adits driven into the

[1] Bull. U. S. G. S., No. 427; 1910.

hill in recent years, kaolin and feldspar have been encountered. The so-called Curtis adit, after being driven through some sixty feet of glacial material, penetrated over 100 feet of kaolin and feldspar, showing the residual nature of the deposit. The kaolin was white and apparently of good quality.

Outcrops of kaolin are reported on farms lying north of this property and owned by Edward Foreman, J. O'Dare, and J. Fish.

All of these deposits should be investigated by those interested in kaolin.

A deposit containing more or less kaolin is also reported from the Gilmore farm, in Tinmouth.

NORTH DORSET.

The Vermont Lime Products Company owns a deposit of clay, situated on the Dacey farm about one mile from the railroad. The material underlies an area 200 by 100 feet and is called a fire clay, but whether or not this is its true nature would have to be determined by analyses and fusibility tests.

BRANDON.

Although the kaolin mine here has been practically worked out, the writer has thought best to describe it on account of the information it adds to our knowledge of the nature of Vermont clay deposits.

The deposit is located in the village of Forestdale, in a small tributary valley of the Otter Creek, and was opened up by the Horn, Crockett Company in 1902. This company operated the mine for twenty years, producing in this time some 80,000 tons of kaolin, which found a market as a paper filler. By April, 1922, the mine had reached a depth of 230 feet, along a strike of 200 feet and a width of 150 feet. The areal extent of the deposit had been accurately demarked by diamond drilling. Unfortunately the mine caved in at this time and was abandoned.

According to Harder's[1] description, the deposit here much resembles that at South Wallingford. Harder says: "The deposit consists of iron ore containing manganese ore in subordinate quantities. The ores occur in a brown and white clay that occupies the bottom of the tributary valley. To the east are ridges of quartzite; to the west, a white, dolomitic limestone. The clay bed overlies their contact, and is in turn overlain by glacial deposits. Fossil plants and fruits of Tertiary (probably Miocene) age have been discovered in lignite in a similar clay bed in the same locality. This makes it probable that the iron and manganese-bearing clay is a Tertiary deposit derived from an underlying clay, similar in position to that containing the South Wallingford ores."

[1] *Ibid.*

According to Messrs. Horn and Crockett the clay deposit never came nearer than fifty feet to the surface and, therefore, its geology is much concealed. The late Prof. J. B. Woodworth,[1] of Harvard University, examined the clay deposit and its associated lignites and came to the conclusion that the kaolin resulted from the decomposition of the underlying bed rock, hence was residual in origin.

Mr. T. Nelson Dale,[2] of the United States Geological Survey, has also made an examination of the Brandon deposit and also agrees that the "kaolin must be regarded as the product of the weathering of feldspathic rocks such as the gneisses and quartzites of the Green Mountain range."

As at Wallingford the fact that the kaolin is associated with iron and manganese minerals would argue its residual nature.

In regard to the lignite and its fossil fruits, the reader is referred to several articles in the Report of the Vermont State Geologist for 1903-04.

It may be noted that the deposit was originally worked for its iron content, the limonite being used in paint manufacture. It is also of much interest to read[3] that the famous English geologist, the late Sir Charles Lyell, examined the deposit and gave it as his opinion that "the clay alone would be found eventually to possess a value exceeding that of the iron," a prediction that was amply fulfilled.

CONSIDERABLE QUATERNARY CLAY DEPOSITS.

Under this heading the writer has located and more or less fully described such deposits of glacial clay as would, by reason of their quality, quantity, and accessibility, probably be suitable for brick-making or other purposes. Undoubtedly many deposits have been overlooked, since funds available for the survey have been limited, but a sufficient number has been tabulated to remove any anxiety concerning a dearth of this material in Vermont.

GRAND ISLE COUNTY.

In his Geology of Grand Isle County,[4] Professor Perkins states that "the greater proportion of South Hero is covered with glacial material, including deposits of clay, which in part are Quaternary and in part have been derived from the decomposition of the underlying Utica shale, of Ordovician age." Professor

[1] Report of the Vermont State Geologist, 1903-04, p. 166.
[2] *Ibid.*
[3] The Geology of Vermont, 1861, Vol. 2, p. 803.
[4] Report of the State Geologist, 1903-04.

Perkins notes a bank of glacial clay, some twenty feet in thickness, around Balls Bay. Presumably other deposits of considerable thickness occur. It is also very probable that some of the shale would make excellent material for the manufacture of drain-pipe, tile, and other lines, calling for a stiffer substance than glacial clay.

FRANKLIN COUNTY.

On the road leading from St. Albans to St. Albans Bay there is an excellent deposit of blue clay, on the farm of M. D. Jarvis. This has been used to some extent by the Foundry Manufacturing Company, of St. Albans, for moulding purposes.

In Fairfield there was formerly a small brick industry, based on a deposit of glacial clay of no present commercial importance. Also at Highgate Falls brick-making from the Missisquoi River clays was once carried on. But there is probably no commercially important clay deposit in the county.

LAMOILLE COUNTY.

Lamoille River clays have been used for brick-making in the past, as shown by the number of brick structures in Cambridge, Johnson, Hyde Park, Morrisville, etc., and there are probably considerable deposits still available.

WASHINGTON COUNTY.

There is a good deal of river-clay along the course of the Winooski, in this county, and some of the deposits have been worked in the past.

In Middlesex there are clay-banks apparently of good quality.

In and around Montpelier there are very large deposits of blue river-clay. One is on Seminary Hill, where the clay is fifty feet thick.

On the road from Montpelier to East Montpelier, at Stevens Turn, there is a bank of fat, blue clay, forty to fifty feet high; while a quarter of a mile nearer Montpelier there are several great ridges of equally promising material.

Nearer the railroad bridge, not far from the above localities, there is a huge bank of fat, blue clay, thirty to thirty-five feet high.

Between Barre and East Barre, along a tributary of the Winooski, there are enormous sandy clay-banks, but they are probably too poor in quality and too inaccessible to be commercial possibilities.

On the high road from Barre to East Montpelier and Hardwick, small banks of clay appear.

At Waterbury the river clays were formerly used for brick-making by the Demerritt Company. The bricks used in the construction of the buildings of the Waterbury Insane Asylum were made at this yard.

CHITTENDEN COUNTY.

In Jericho, on the lands of A. A. Wizzle and Albert Byington, which border the Lee River, there is a bank, fifty feet high, of dark blue varve clay, which extends along the stream for perhaps half a mile. This deposit is enormous and, if the quality of the material proved suitable, would support a clay industry for many years.

Essex Junction. See the Drury Brick & Tile Co. (p. 200).

LOWER WINOOSKI RIVER CLAYS.

Along the lower course of the Winooski River there is a series of estuarine clay deposits, found in the river terraces for which this stream is remarkable.

In the terrace on which the Lower Road from Burlington to Winooski is built, a river-clay deposit was worked for brick-making purposes not many years ago.

In Richmond township, on the terrace back of C. S. Perkins' house, there is a large deposit of solid blue clay, which extends eastward to H. Stockwell's farm. The clay is twenty to twenty-five feet thick and is overlain by sand.

In the brook, just north of Stockwell's, there is a deposit of varve clay, which was quarried for paint-clay some fifteen years ago. The brook has probably cut down through an old glacial pond, in which the varves were laid down.

ADDISON COUNTY.

As already noted, the western tier of townships in Addison County (as well as those in Chittenden and Franklin) are built on old lake-bottoms, and there is much lacustrine clay. However, no sizable deposits were found.

RUTLAND COUNTY.

In North Poultney, on the property of the New York Consolidated Slate Company, two and one-half miles north of Poultney village, there is a great deposit of seasonal clay, with varves an inch wide, which accumulated in an old glacial basin. The slate quarry adjoins this deposit. A slip, some years ago, carried some thirty thousand yards of clay into the workings, entailing much expense for its removal. The clay is dark brown in color and may be of value in the industries.

There is also a clay deposit, associated with the slate at Pawlet, but this the writer has not visited.

BENNINGTON COUNTY.

Brick clay of good quality occurs near the road from South Shaftsbury to North Bennington, and also on A. G. Dewey's land, west of Bennington.

The clay deposit in the southeastern part of Bennington village, on which is located the Bennington Brick Company's plant, has already been described.

A search across the State, from Bennington to Brattleboro, failed to locate any considerable clay deposits.

ORLEANS COUNTY.

Around Lake Memphremagog there are naturally deposits of lacustrine clay. At Newport Center, along the road from the city farm to the lake, a great deal of plastic brown clay was seen. This might prove to be fit for brick-making or other purpose.

In Craftsbury, on the Young farm, there is brick-clay of good quality. Bricks were made here thirty years ago. In the same town, near the Albany line, there are considerable deposits of good blue clay. These are along the course of the Black River.

CALEDONIA COUNTY.

The History of St. Johnsbury recounts that Asa Lee established the first brickyard in that town in 1791. It continued in operation for many years, for in 1891 it furnished bricks for the new chimney of the Fairbanks Scale Works.

The Bagley Brick Works was founded by a Mr. Bagley, who came from Weare, N. H. The business was continued by his son throughout his lifetime. Many public buildings, including the Court House, Union School and the Athenaeum testify to the importance of the industry. The clay deposits worked were above Paddock village.

The brickyards of Sanford and Lewis Thayer, on the Danville Road, did a brisk business in the thirties.

At the present time there is no brick or other clay industry in this region. Building bricks are obtained chiefly from the New Hampshire yards.

THE CONNECTICUT RIVER CLAY DEPOSITS.

Along the course of the Connecticut River there occur by far the largest deposits of Quaternary clay in the State.

Ernst Antevs[1] has shown that with the retreat of the ice-sheet in New England, at the close of the so-called "Great Ice Age," chains of long, narrow lakes were formed along what is now the Connecticut River. This ponding of the ice water was made possible by the gradual up-tilting of the land towards the north. During the warmer parts of the year glacial rivers deposited in these lakes their mixed sediments of sand and clay; while in the colder months, the streams ceasing to flow, only the fine colloidal suspensions of clay, mixed with vegetable shreds settled out. Thus were formed the varves or seasonal clay deposits, which became exposed to view with the rising of the region and the cutting away of the barriers between the lakes by the rejuvenated Connecticut River. (Plate XX.)

[1] The Recession of the Last Ice Sheet in New England, Am. Geographic Society, Research Series, No. 11.

Antevs has examined the varve clays along the Connecticut as far south as Hartford. The writer, for the purpose at hand, has noted and briefly described those deposits along the Vermont side of the river which, by reason of their quality, quantity, and accessibility, promise best for commercial enterprises.

Going south from St. Johnsbury, one finds by the railroad bridge north of Passumpsic Station a large bank of excellent varve clay. It contains many concretions, but has evidently been found fit for brickmaking and has been worked a good deal. A great deal of clay still remains.

At Inwood (Antev's location No. 88), on the farm of G. A. Richardson, there is a great mass of clay which forms the east bank of Passumpsic River. The material is a very fat, lead-colored varve clay, surmounted by some twenty-five feet of sand. A tremendous tonnage of material, probably suitable for brick-making or kindred purpose awaits development. The river flat offers an excellent site for a brickyard and its proximity to the railroad would be of great advantage. New Jersey interests have tried, without success, to acquire this property for industrial purposes.

At East Ryegate, M. H. Gibson conducted a brickyard for some twenty years, but discontinued it in 1910, on account of the high freight rates. There is still much good brick clay in this vicinity.

It may be noted that the brickyard operated for many years at Woodsville, just across the Connecticut from Wells River, was closed in 1922.

The Wells River Brickyard has already been discussed.

In Newbury, seven miles south of Wells River and one mile north of Conicut Station, there is a clay deposit on the land of A. D. Downing (Antev's location No. 73). In the ravine of a brook good fat clay, not less than twenty feet in thickness appears, overlain by fifteen feet of sand. This is an excellent prospect.

Three-quarters of a mile north of White River Junction, in a ravine just west of the railroad, Antevs located a seasonal clay deposit more than thirty feet thick, covered by four feet of sand (his location No. 66). The writer did not visit this deposit.

In Ascutneyville, south of Windsor, there is a large deposit of apparently good brick-clay. There has been some agitation for the building of a brickyard here, but, as far as the writer could learn, nothing tangible has been done.

In Westminster, about a mile north of the railroad station (Antev's location No. 36), there is a deposit of blue clay in the walls of a ravine. This may have commercial possibilities.

In the same township, about a mile southwest of Grout Station (Antev's location No. 35) there is a bluff of blue varve clay, overlain by sand and gravel. There seems to be a great quantity of clay here.

Three miles south of the above deposit, a brook has cut a great ravine to the southwest of the road. Here is found not less than thirty feet of varve clay, overlain as usual by sand and gravel. Bricks were made here some thirty years ago. The property is owned by G. C. Woodburn.

Near Putney Station the Vermont Brick Company manufactured bricks from about 1900 to 1921, when the industry was given up. The deposit is a silty varve clay (Antev's location No. 31) of which much remains. It is said that this deposit produced excellent building bricks, which sold as far south as Boston. Prices during the war ranged from $30 to $35 per thousand.

At Guilford, on the land of George Houghton, there is a clay bank, northeast of his house, with about twenty feet of clay exposed. Bricks were made here twenty-five years ago and sold in Brattleboro. This neighborhood probably contains a great deal of glacial clay.

SUMMARY.

It is seen from this survey that the most important Quaternary or Glacial clays of the State are found along the rivers, and of these that the deposits along the course of the Connecticut offer probably the best opportunity for industrial enterprises.

PETROGRAPHY OF THE QUATERNARY CLAYS.

The microscopic examination of clay is attended with considerable difficulty, owing to the weathered condition of the component minerals, which show few crystal faces and lack some of the distinguishing characteristics of fresh material. The clays were sifted through a one hundred mesh sieve, immersed in a liquid of known refractive index and then studied with the polarizing microscope. The material was found to be made up predominatingly of flocculent kaolinite, or other hydrous silicate, with lesser amounts of quartz and occasional fragments of orthoclase, plagioclase, tourmaline, rutile, apatite, nephelite, grossularite, and talc. Considerable amounts of iron oxide were present, staining the clay mass. The clays along the Connecticut showed a greater variety of minerals than the Drury deposit and suggested that Canadian talc and Mount Ascutney syenites, as well as the granites along the Connecticut River, had all made contributions to the deposits.

POTTERY.

Although the manufacture of pottery and porcelain in Vermont is now a thing of the past, a report on the clay industries of the State would be incomplete without a brief mention of this fascinating phase of the subject.

INDIAN POTTERY.

The first potters in what is now the State of Vermont were the Algonkian Indians, who were in possession of the region at the coming of the white man. In the old burial mounds, discovered many years ago near East Swanton and along the Missisquoi River, many objects of aboriginal craftsmanship were found and many of these are now to be seen in the various museums of the State and elsewhere.

In the Seventh Report of the Vermont State Geologist, 1909-10, Professor Perkins has an article on Indian Relics in the State Cabinet, illustrated by many cuts. Among these relics he mentions and gives illustrations of three earthenware jars, nearly intact, which are preserved in the University collections; as well as many fragments of pottery and several earthernware pipes. The pottery is for the most part of a reddish-brown color, but also includes drab and black specimens. The illustrations show that the ware was richly ornamented.

BENNINGTON POTTERY.

But it was in Bennington that Vermont pottery achieved its highest expression and fame. In his chapter on The Potters of Bennington, Dyer[1] records that "In 1793 Capt. John Norton and his son, William, moved from Sharon, Connecticut, and settled in Bennington, where they started an earthernware kiln and, in 1800, added the manufacture of stoneware." They also made bricks. Mr. John Spargo, in his recent book[2] traces in detail the history of this enterprise which was carried on by the Norton family for 101 years, till the death of Edward L. Norton in 1894.

The variety of the Norton wares is shown by an advertisement, appearing in the *State Banner* of Bennington, on February 27, 1841. This reads as follows:

[1] Walter A. Dyer, Early American Craftsmen.
[2] The Potters and Potteries of Bennington.

BENNINGTON

STONEWARE FACTORY

JULIUS NORTON

Manufactures and keeps constantly for sale at his factory in Bennington, East Village, Vt., a large assortment of

STONEWARE

Consisting of—

BUTTER, CAKE, PICKLE, PRESERVE, & OYSTER POTS,
JUGS, CHURNS, BEER & BLACKING BOTTLES,
JARS, PLAIN AND FANCY PITCHERS,
INKSTANDS, EARTHEN MILKPANS,
STOVE TUBES, KEGS, MUGS,
FLOWER POTS, &C., &C.

Also PATENT FIRE BRICK,
(the best in the world) at $50 per thousand.

Orders from Merchants faithfully executed, and ware forwarded on the shortest notice.

Bennington E. Village, Feb. 27, 1841.

The United States Pottery Company, founded by Christopher Webber Fenton, perhaps the most famous of the Bennington potters, was incorporated in 1853 and, according to Dyer, began the production of fine ornamental wares: Rockingham, Parian, white granite, etc. The local source of the china clay used by the corporation was the No. 3 deposit of the present Vermont Kaolin Corporation, but the company also used materials from New Jersey and imported clays from England. Tableware, toilet sets, elaborate ornaments, toys, plain crockery, door plates, foot warmers, door knobs and many other articles were made. The corporation was very prosperous in the middle fifties, but after that its fortunes waned and it became insolvent in 1858.

ST. JOHNSBURY.

In the History of the Town of St. Johnsbury, we read the following: "Pottery. An old-time land mark with low red buildings west of the river half a mile south of the Center Village, was the Pottery established in 1808 by Gen. R. W. Fenton, somewhile known as the St. Johnsbury Stone Ware Pottery. Its products were in constant demand until the introduction of tinware. The business was successfully carried on by Gen. Fenton and by his son Leander until the entire establishment went down in flames in 1859. All sorts of domestic ware were turned out on those potters' wheels, from jugs, jars, bowls, bottles, and milk pans, at a dollar a dozen, to fancy flower pots at sixty cents each, and St. Johnsbury pottery gained high repute; occasionally surviving specimens of it may still be seen. The power was supplied by a merry little brook that came tumbling down the hillside."

It is said that this pottery was unsigned, hence little is known of its present whereabouts. The Fairbanks Museum, in St. Johnsbury has possessed for some years two pots of grayish-brown mottled ware, while during the past winter it came into ownership of a marked Fenton and Hancock pottery churn, made at a later date than the unmarked ware. The writer has been unable to learn whether or not Gen. R. W. Fenton was related to Christopher Webber Fenton.

BURLINGTON.

According to Spargo, Capt. John Norton's business passed into the hands of his son, Luman Norton, in 1828. His nephew, Norman L. Judd, worked in the Norton pottery from 1796 to 1806 and then came to Burlington and established a pottery, one of the first if not the first in that town. Its location is quaintly, if indefinitely, described as follows: "On the left as we go down to the wharf, stands a brick building, in the under part of which Mr. Norman Judd of Bennington once carried on a pottery." Whether this described the old red brick building on Pearl Street, just west of Church Street, where E. L. Farrar conducted a pottery from 1830 to 1892 the writer has been unable to learn.

OTHER OLD POTTERIES.

Richard L. Fenton, a brother of Christopher Webber Fenton and once employed in the Norton works, conducted a pottery in Dorset for some years.

Middlebury also had a small pottery at one time in her history.

GEOLOGIC HISTORY OF THE GREEN MOUNTAIN FRONT

Geo. W. Bain.

INTRODUCTION.

The Green Mountain State is divided into two halves by a great wall stretching almost north and south. To the west of it lie the marble valley, the Taconic mountains and the fertile Champlain lowlands. On the east side of it, hills follow hills, to the Connecticut valley; the country is rugged and supports a scattered farming population. Granite quarries and talc mines help augment the resources of the section. This great wall is the Green Mountain front. It was made by nature, not all at one time because at intervals nature looked on and rested; and as if displeased with the results of her work has started in anew to modify the framework of her Vermont home.

THE GATHERING OF THE MATERIALS.

The region of the Champlain lowlands, the Taconic mountains, the marble valley and the Green Mountain front was at one time a great arm of a southern sea or a sound between two mountainous regions. This was during early Cambrian time. The body of water extended southward to the Gulf of Mexico and spread from near the present shore line of the Atlantic Ocean to beyond the Mississippi valley. Eastward lay a continent known as Appalachia, and to the north the great Laurentian shield or region of semi-rugged topography with hills differing but slightly from the present form of the Green and White Mountains. The northern arm of the southern sea lay between the Adirondacks on the west and the continent of Appalachia on the east and extended as far as or even beyond Quebec City. The pebbles, sand and clay out of which the hills of western Vermont are made were washed into this basin by streams flowing from the west, north and east.

THE BENNINGTON QUARTZITE.

The early streams came from a youthful rugged country and consequently were swift flowing, so that they left thick, coarse bouldery deposits on the ancient piedmont plain in the northern part of the State. In central Vermont between Brandon and Rutland the beds are thinner and only in rare instances do constituent grains exceed one-quarter of an inch in diameter. At Bennington the beds are composed of small sand grains. Unweathered feldspar pebbles are common in the deposits between Brandon and Rutland and this indicates rapid erosion and deposition without pronounced rock decay to form clayey minerals. Thick contemporaneous clay deposits are not to be expected neither nearby nor in more distant parts where the velocity of the streams had slackened. Finer textured sand beds are all that may be expected.

THE GEORGIA SLATE.

All the sand and gravel deposited to make the Bennington quartzite must have come from the drainage basins of the streams which brought the material to the intermontane sound. As the valley was filled in the hills at the headwaters of the rivers were lowered, the grade of the streams was decreased and the velocity slackened. Rock fragments were subjected to abrasion and weathering in the water of the streams for a longer period before being buried. Only fine particles could be transported to the estuaries of the streams with the result that clays and sandy clays were the dominant deposits of the period. Sediments of this type attain a thickness of several thousand feet in the northern part of the State, but thin and disappear almost entirely in the south.

The floor of the valley was subsiding just as many of the present day basins have subsided below sea-level. For a short period a shallow sea flooded the region from the Green Mountains to the Adirondacks and fish and crustaceans such as the trilobites moved about. Entombed skeletons of these organisms are found as far north as the Canadian border. This period of subsidence was slight and of short duration because it lasted only during the middle of the early or Lower Cambrian epoch.

THE DOLOMITE BEDS.

Streams continued to flow and deposit their load where the grade decreased and the velocity slackened. The sediment left, however, is dominantly bedded unfossiliferous dolomite, sandy dolomite and quartzite. As in the other rocks of the region, so in these, the effect of southward flowing streams is very marked. North of Burlington rocks made of angular or slightly rounded fragments up to several inches thick, and of the same material as that in which they lie, are very common. These breccias are known as interformational conglomerates and are due to local erosion and redeposition of a recent deposit which has become slightly consolidated. Caving of banks of streams which are rapidly filling their channels is the most common way in which this can take place.

The gorge of the Winooski River and the cliffs near Lone Rock Point on Lake Champlain afford an unusually good section of a portion of the dolomite series of beds or deposits. The lowest or oldest beds are those exposed along the lake and dipping eastward at a gentle angle beneath the city of Burlington. Single beds of buff to reddish dolomite attain a thickness of twenty feet, but usually range from six to ten. The rock is massive and lacks any structures that tell the conditions during this period of Vermont's history.

The red sandrock is the next younger tablet or bed of rock on which history is recorded and this story is one of alternate flood and drought. The sand layers range from a fraction of an inch to two feet in thickness. Occasional beds of white sandstone are interspersed with highly ferruginous zones. Symmetrical ripples such as are formed in large lakes characterize some beds; tongue-shaped markings such as are formed in the lee of little obstructions on the flood plains of rivers are common in layers only a few feet higher or lower. Odd diamond-shaped markings such as storm waves make on a sea beach are not unusual and mud cracks formed due to baking of muds by the heat of the sun, are extremely common. The deposits are typical of those laid down in a rapidly filling estuary.

Siliceous dolomites overlie the red sandrock and an unusual and characteristic feature of them is the presence of cross-bedding of the stream type. Plate XXV. This type of cross-bedding is produced by running water building a series of overlapping deltas with fronts dipping downstream. The calcareous and dolomitic beds are, therefore, lime muds and not limestones made from the shells of marine organisms which is the usual manner in which these rocks are formed. Instead fossils or preserved shells are totally lacking; worm burrows and trails of worms as they moved over the surface of the mud are found instead. These trails and burrows are very common in a bed at the top of the quarry at Willard's Ledge near Burlington. Alternating sandstone and dolomite with good cross-bedding occurs as far as the power house between Winooski and St. Michael's College. Limestone with occasional cross-bedded zones occurs from this point to the Limekiln.

This region, therefore, seems to have been a muddy estuary throughout Middle and Upper or closing Cambrian time. The cross-bedding, or series of delta fronts, shows that the streams came from the north, west and east, but never from the south.

The zone of cross-bedding thins southward and between Dorset and Manchester is only ten feet thick; it lies within one hundred and fifty feet of the top of the dolomite series. Dolomite is the dominant rock in districts south of Rutland, but some sandy dolomites or even sandstone zones are also present.

PLATE XXV.

This photograph shows the dolomite beds at the C. and P. Railroad crossing between the Sutherland Falls Quarry and the machine shop of the Vermont Marble Co. at Proctor. The rock breaks in blocks which, when they are in place, dip at about 60° to the right or east. The planes parallel to which the rock breaks is the bedding plane or plane parallel to which the materials of the rock were deposited. These sediments were laid down in the same way that streams of today deposit material, namely, in horizontal layers or in a series of deltas or cross-beds. The cross-beds or deltas have a steep front at the top which gradually flattens parallel to the bedding at the bottom. In the layer shown in the illustration the bottoms of the cross-beds face upwards, that is, they have been turned up to vertical and 30° beyond. This tilting occurred during the Taconic period of mountain building.

THE MARBLE BEDS.

The marble beds extend from the Canadian border southward into Massachusetts. The rock is almost pure calcium carbonate or calcite and contains here and there the shells of marine animals, such as Maclurites magnus, an organism somewhat similar to the present day snails, but lived in water instead of on land; Turritiforme sp., a gastropod or spirally coiled sea shell; and crinoids or "stone lilies." So that during this period the valley between the Adirondacks and Appalachia must have been beneath the sea. The beds are almost entirely free from clayey partings so that the water must have been free from silt and very clear at the time the beds were laid down. Mechanical erosion of the land must have been slight in comparison to chemical weathering and solution; hills would be extremely low to bring about these conditions of earth destruction.

But towards the close of Chazy time when the upper part of the marble beds was being laid down, argillaceous sediment was deposited along with the limestone in the southeast part of the State. In the north and west clays were not laid down until Middle Trenton so that the source of this sediment must have been in a newly uplifted part of Appalachia rather than in the Adirondacks and Laurentian Shield which yielded the greater portion of the earlier sediments.

THE BERKSHIRE SCHIST.

The clays are not over six hundred feet thick in the northern part of the State where they go under the name of Utica shale, a black, thinly bedded rock, but in the south their thickness is measured in thousands of feet and they are called the Berkshire schist. In places the clays become coarse clayey sandstone, especially near West Rutland and again at Mt. Equinox. These areas of coarser material probably indicate a delta of a river which was bringing sediment from the hills in the east to the sea; coarse sediment would be deposited on top of and along the front of the delta whereas the finer clay would be washed off to the sides and front by waves and shore currents too feeble to move fragments of larger size.

From these materials, namely, the Bennington quartzite, the Georgia slate, the dolomite beds, the marble beds and the Berkshire schist, have been modelled and carved the various forms of the Green Mountain front and regions west of the great wall.

THE MOULDING OF THE MATERIALS.

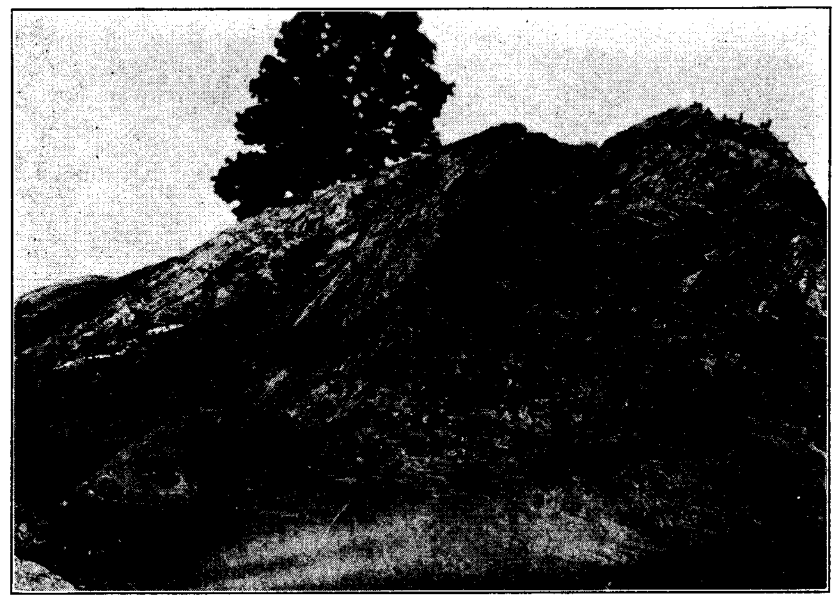
The sediments or structural materials were deposited as horizontal or gently dipping beds. But they no longer maintain this position. The layers are tilted and broken and lack their original

continuity. Movements which moulded the contorted forms found in the marble and the Berkshire schist began at the opening of the Silurian period or immediately following the deposition of the clays and sandy clays or graywackes which make up the the topmost beds.

THE TACONIC DISTURBANCE.

A slow thrust of great magnitude shoved the beds westward from the east, forcing the horizontal layers to crinkle into great folds and the marble to mould like dough, producing the odd designs seen in it. The rocks were thrust from the east faster than the western front of the folds could move on so that the

PLATE XXVI.



This photograph shows the parallel bands of the gneiss crumpled like discarded tissue paper, due to the crushing and twisting forces to which they have been subjected during the period of movement along the thrust plane which lies only ten or fifteen feet below.

layers developed a steep western dip and a more gentle eastern slope. Near Dorset and Manchester the thrust was so great that the rolls were moved over the top of beds that were being folded and the crest of the arch now lies two to three miles west of the bottom of the trough and highly folded sediments lie horizontal, but one bed recurs three times on the side of Mt. Equinox instead of appearing only once. Plate XXXI.

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THE BERKSHIRE SCHIST.

The clays are not over six hundred feet thick in the northern part of the State where they go under the name of Utica shale, a black, thinly bedded rock, but in the south their thickness is measured in thousands of feet and they are called the Berkshire schist. In places the clays become coarse clayey sandstone, especially near West Rutland and again at Mt. Equinox. These areas of coarser material probably indicate a delta of a river which was bringing sediment from the hills in the east to the sea; coarse sediment would be deposited on top of and along the front of the delta whereas the finer clay would be washed off to the sides and front by waves and shore currents too feeble to move fragments of larger size.

From these materials, namely, the Bennington quartzite, the Georgia slate, the dolomite beds, the marble beds and the Berkshire schist, have been modelled and carved the various forms of the Green Mountain front and regions west of the great wall.

THE MOULDING OF THE MATERIALS.

The sediments or structural materials were deposited as horizontal or gently dipping beds. But they no longer maintain this position. The layers are tilted and broken and lack their original

continuity. Movements which moulded the contorted forms found in the marble and the Berkshire schist began at the opening of the Silurian period or immediately following the deposition of the clays and sandy clays or graywackes which make up the the topmost beds.

THE TACONIC DISTURBANCE.

A slow thrust of great magnitude shoved the beds westward from the east, forcing the horizontal layers to crinkle into great folds and the marble to mould like dough, producing the odd designs seen in it. The rocks were thrust from the east faster than the western front of the folds could move on so that the

PLATE XXVI.

This photograph shows the parallel bands of the gneiss crumpled like discarded tissue paper, due to the crushing and twisting forces to which they have been subjected during the period of movement along the thrust plane which lies only ten or fifteen feet below.

layers developed a steep western dip and a more gentle eastern slope. Near Dorset and Manchester the thrust was so great that the rolls were moved over the top of beds that were being folded and the crest of the arch now lies two to three miles west of the bottom of the trough and highly folded sediments lie horizontal, but one bed recurs three times on the side of Mt. Equinox instead of appearing only once. Plate XXXI.

This great overlap is shown unusually well between Sandgate and Beartown in the hollow between Bear Mountain and Equinox Mountain. The sandy clays and graywackes of the Berkshire schist, involved in the great crumple terminating in Mt. Equinox, have been sheared and hardened into schist and slate. Two miles north of Sandgate a trail turns west into Bear Mountain; a small stream parallels the trail and in the bottom rest nearly unmetamorphosed, banded, crumbly sandy shales or consolidated muds. The great crumple has overlapped these beds, but has not appreciably affected them or changed their form.

Two or more major folds are present at nearly all points. The western front of one of these is marked by the beds of Bennington quartzite lying against the face of the great wall at many points such as East Dorset, Danby, Pittsford and Lake Dunmore. The crest line of a second follows the Otter Creek valley from Danby to Rutland and northward to Pittsford Mills, where it passes beneath the great overthrust of the Green Mountain front. South from Danby, this fold turns over and lies almost horizontally above the third crumple or next fold to the west. The axial plane of the third anticline also lies almost horizontal and its crest begins on the west side of Equinox Mountain and follows Tinmouth valley and the Otter Creek valley to Proctor and Brandon. This is the main fold or great crumple described above. A fourth smaller anticline begins between North Rupert and East Rupert and continues north beneath the Berkshire schist to join the West Rutland arch.

The tightest wrinkles are in the east and fade out almost entirely west of the West Rutland anticline. Folding contorted the marble bed at the top of the sedimentary series and produced the odd patterns found in it. The clays and shales were hardened and sheared to make slates and, in some instances, coarse mica flakes formed along the slaty cleavage to produce a rock known as a schist.

At many points, especially one mile northwest of Proctor, pegmatite dikes, or dikes of very coarse granite, follow the cleavage planes in the schist. These dikes are fingers from a much deeper and larger mass of intrusive granite. Solutions and volcanic gases escaping from this intrusive mass, in the same manner in which they escape from a volcanic crater, soaked up along the cleavage planes of the slates and recrystallized the rock to form coarse mica flakes and produce schists. Other schists were formed from the Georgia slates lying east of the marble valley. West of the valley through Lake Bomoseen, the rocks are slaty, but pegmatites are absent and solutions necessary to form the mica flakes did not pass through the rocks. Granite intrusions seem to underlie only the eastern or very highly folded part of the region.

THE MONTEREGIAN PERIOD OF VOLCANIC ACTIVITY.

North of the Canadian border a group of gray and dark colored rocks intrude beds of Devonian age. Similar rocks cut the Cambro-Ordovician sediments throughout Vermont State, but are exceptionally numerous in the vicinity of Burlington. Dike forms are the most common, but one mass occurring in the bed of the Winooski River just above the power house near St. Michael's College, possesses vertical flow structure formed by movement of the volcanic rock as it solidified on its way to the surface. This rock appears to be an old volcanic neck. This rock is green and contains many small white crystals; large black hornblende and pyroxene crystals are common in dikes in the north part of the state, whereas fine textures are characteristic of those in the south. Open cavities or vesicles filled with minute crystals occur in some dikes. This indicates a rock cover so shallow that the volcanic gases in the liquid lava could expand against the pressure of the liquid to make bubbles. Therefore, most of the overlying dolomite, marble and slate must have been worn away after the Taconic disturbance and before the lava of these dikes flowed in between the enclosing walls.

The dikes in the vicinity of Burlington are extremely interesting because they tell something about the foundation upon which the sediments of the lowlands rest and through which the liquid rocks have flowed on their way to the surface. The dikes contain inclusions of "stranger rocks," or as they are called, xenoliths. These strangers have risen from below, carried along in the fluid lava which rose to fill the fissures, and are entirely different from any of the sedimentary series. Granites and banded granitic rocks or gneisses similar to those found in the Adirondacks predominate; fragments of coarsely crystalline limestone are also common; jaspilite or banded red and black jasper, and mica schist are also present. The Cambro-Ordovician beds, therefore, rest upon old metamorphic rocks similar to some found in the Adirondack region and to others which are not known in regions south of Hastings County, Ontario, but which must lie deep below the Champlain lowland.

THE APPALACHIAN REVOLUTION.

A great period of mountain building occurred at the close of the Paleozoic era. The rocks in the region of the Berkshire Hills were folded into great mountain masses by a westward thrust from Appalachia. Volcanic activity, described above, was common and great masses of granite welled up and claimed for themselves vast volumes of roof rocks. This great disturbance was felt throughout the region of the Green Mountain front and the thrust was felt as far west as the Adirondacks.

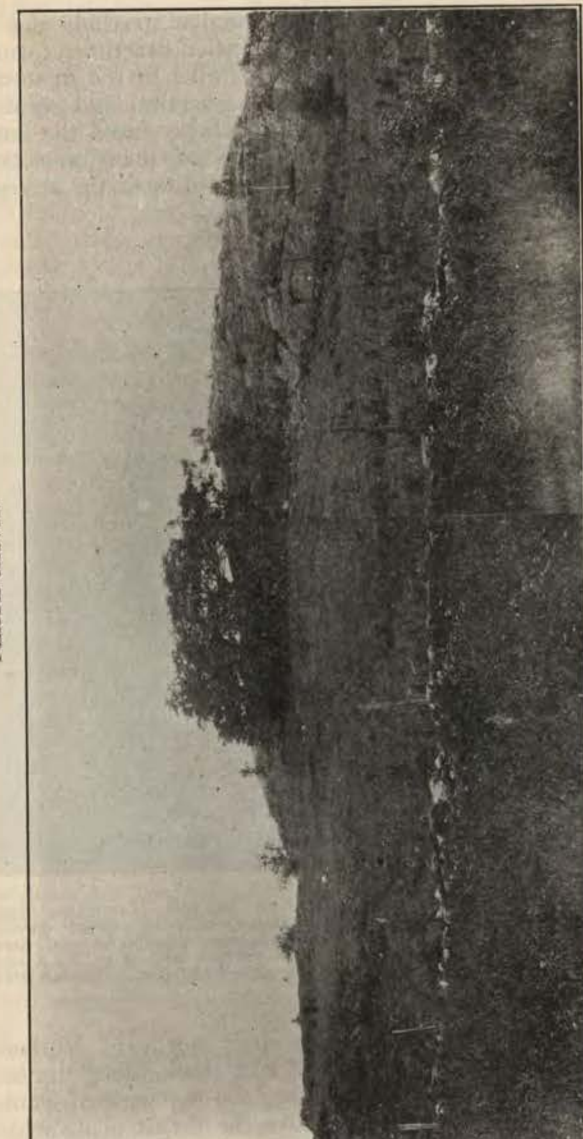
A great thickness of sediments lay in the region of the Berkshires, but the Green Mountain section had been folded into a mountain range during the late Ordovician or early Silurian, and the tops of the range were worn away before the Monteregian period of volcanic activity and Appalachian Revolution began. Much of the material worn away was doubtless used to build up the sedimentary beds of the eastern hills and Catskill plateaus. The result of thinning of the rock cover in Vermont was that instead of folding further the beds sheared over one another along two great long planes dipping at a very flat angle to the east. The westernmost of these begins in Canada and closely follows the eastern shore of Lake Champlain to Burlington, thence just west of Snake Mountain and on southward. The second lies along or slightly in front of the Green Mountain front from beyond Burlington in the north to below Manchester in the south.

The first or Lake Champlain fault dips about 17° east, where it is exposed on Lone Rock Point near Burlington. Dolomite beds found near the base of the Cambro-Ordovician sediments are thrust up upon the Upper Ordovician, which is equivalent in age to part of the Berkshire schist. Scratches were produced upon the moving surfaces during the thrust and are still preserved, but these run in various directions indicating repeated changes in the direction of the movement. The load upon the upper block must have been slight because abrasion produced during one movement was not great enough to wear away all the scratches made during an earlier one. The steep inclination of the fault plane at this point (about 17°) may also be due to the light load upon it when movement began. Total displacement of the beds is at least two or three miles.

The Green Mountain front fault dips at an angle of less than one degree to the east. The fault plane itself is not exposed, But Bennington quartzite and schists equivalent in age to the Georgia slate rest upon Berkshire schist on Stiles Mountain. Plate XXXI. The same quartzite and schist rest upon a syncline of black Berkshire schist south of Webb Mountain and about one mile north of Pittsford. The displacement in this section must be over eight miles and the plane of movement cuts across the tops of three major anticlines.

The flat angle thrust faults or breaks in the earth are produced by great pressure tending to force the rocks together. The period of deformation due to compression was accompanied by invasion of large masses of hot liquid granite in the region of the Green Mountains and eastward; but no intrusives seem to have reached the surface in the region west of the great wall.

PLATE XXVII.



The photograph shows the west side of Flat Rock, a low hill between Rutland and Chippenhook. The rock exposed on the low cliff in the background is Lower Cambrian or pre-Cambrian gneiss. The rock exposed between the fence and the trees is Berkshire schist and should lie several thousand feet above the gneiss instead of in contact with it. The gneiss is a remnant of a much larger mass, now worn away by running water and ice, which was shoved westward and upward over the overlying or younger rocks. Plate XXVI shows the contortions in the gneiss adjacent to the plane of movement.

TRIASSIC FAULTING.

Compression was followed by contraction, possibly due to cooling of the hot intrusive rocks, and tension fractures formed along planes trending north and south parallel to the mountain axis. These contraction faults are almost vertical and seem to be of the same age as the great rifts which produced the basin in which the sediments of red sandstones of the Connecticut valley were deposited. The faults, and deposits in the troughs formed by them, are of Triassic age.

PLATE XXVIII.

Photograph showing Stratton Mountain as seen from Equinox Mountain. Stratton Mountain stands up above a group of rounded hills of equal elevations. These hills are remnants of the dissected Cretaceous peneplane and Stratton Mountain is a hill which surmounts that level surface and is called a monadnock. The peneplane level lies between 2,300 and 2,400 feet, whereas Stratton Mountain has an elevation of 3,859 feet.

One normal fault begins in the drift north of Rutland, follows the foot of Boardman Hill and Flat Rock, along the east side of Clark Mountain and dies out along the west side of Danby Hill. Lower Cambrian beds lying above the thrust plane which comes out along the Green Mountain front, have been lowered on the west side of this normal fault until they abut on the east against sedimentary rock over which they have been shoved. Between Wallingford and Danby, a second fault lies parallel to

this main normal one, but is one and one-half miles east of it. The relative movement is the same.

JURASSIC FAULTING.

A later group of faults or readjustments of the architectural units of the Green Mountain front took place and movement was almost at right angles to the earlier normal faults. The most prominent of these displacements occurs along the north side of Green Hill and crosses the Otter Creek valley. Lower Cambrian quartzite, of Green Hill, lying above the Green Mountain front thrust plane, has been lowered on the south side of the normal fault and lies against the broken ends of the dolomite beds to the north.

Other similar fractures follow the gaps between the Otter Creek valley and the next one to the west, at Chippenhook and at Tinmouth Pond and also along the valley of the Metawee River. The downthrown side of the faults lies south of the plane of movement and the outcrop of the thrust plane is offset, in varying degrees, to the west as each of these faults is passed while going south through the valley. The thrust plane, therefore, has a perplexing irregularity due to these lateral displacements of outcrops brought about by vertical movement of the rocks.

The Triassic lowland of the Connecticut valley lying east of the Green Mountain axis has the north south faults of Triassic age developed to an extraordinary degree. A later set intersect the north-south ones and are of Jurassic age. The last set of faults of the Green Mountain front are believed to belong to this later set.

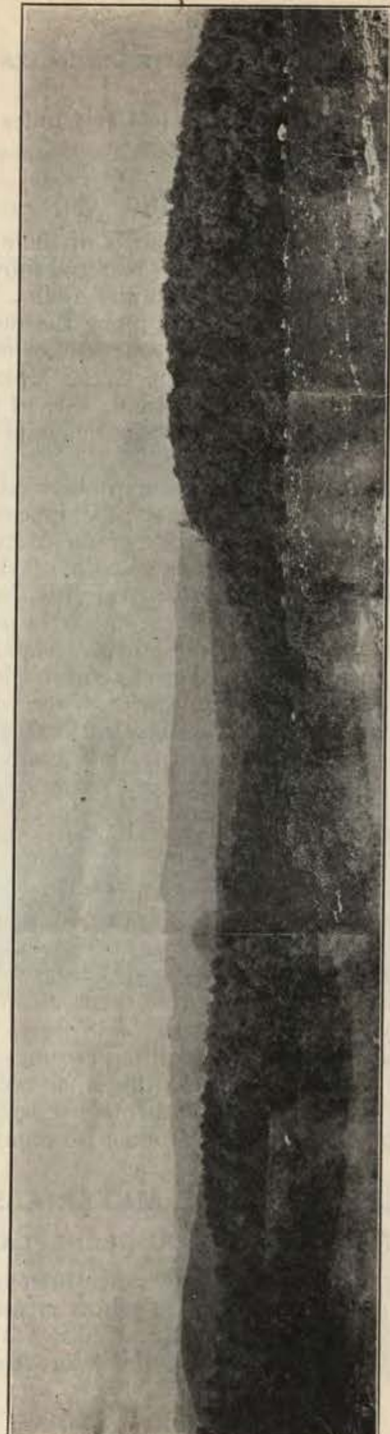
The sediments of the Green Mountain front have, therefore, been consolidated to rock, the rocks squeezed and crumpled, secondary cleavage developed in them and the weakness due to this cleavage somewhat lessened by pegmatitic injection and cementation of the rock. The rocks were then cut up into almost rectangular blocks by these three sets of fault planes intersecting at nearly right angles and produced at different times. The relative positions of the carbonate beds to the other rocks, brought about by the folding and faulting movements, are responsible for most of the topographic forms of the Green Mountain front.

SCULPTURING OF THE MATERIALS.

EROSION TO THE CRETACEOUS PENEPLANE.

The Jurassic period of faulting and readjustment of the rocks was followed by a quiet interval during which streams attacked the scarps produced by displacement and tilting of blocks of rock. The land was worn down most along the stream courses

PLATE XXIX.



This photograph shows the even crestline of the Taconic Mountains between Rutland and Brandon or their northern end. This northern end comes behind the forested hill in the central foreground. Farther to the right is the Champlain lowland with its many hills of hard red sandrock. Many of these have a level top, but at a lower elevation than the even summit level of the Taconics. The elevation of the Taconics is 2,000 to 2,200 feet and is the Cretaceous peneplane surface. The level topped hills of the lowland have an elevation of 900 to 1,000 feet and represent the only remnants of the mid-Tertiary peneplane. The lowland level itself is due to erosion to base level in late Tertiary time.

and the major part of the surface brought to the gradient of the rivers. Larger streams have a lower gradient than small ones, so that along the principal drainage lines the surface slope was flatter than elsewhere; the smaller tributaries have steeper gradients and the steepness of slope increased in the areas between the larger rivers. By the close of the Cretaceous period most of the region of the Green Mountains had been lowered to a low plain, at almost sea-level, by two large rivers, the one occupying the Champlain lowland and the other the Connecticut valley. Areas back from these streams remained as hills and include Mt. Marcy and other high peaks in the Adirondacks to the west, Mt. Mansfield, Camel's Hump, Lincoln Mountain, Breadloaf Mountain, Northfield Mountains, Stratton Mountain, Bromley Mountain, Mt. Greylock, and other high peaks in the central area, and the peaks of the Presidential range, Mt. Monadnock and other very high points east of the Connecticut valley. Plate XXVIII.

Streams rising west of the Northfield Mountains flowed westward between the high hills and joined the main river of the Champlain lowland. A river which occupied the valley of the Winooski between Montpelier and Burlington was the largest of these. The Lamoille valley to the north is another.

THE DOMING OF THE CRETACEOUS PENEPLANE.

The great flat area which was worn almost to a plane level by the streams was slowly bowed upward in the central part of the Green Mountains and sloped downward to sea-level near the Atlantic Ocean. The uplift in the region between Burlington and Montpelier was approximately 750 feet.

THE EARLY TERTIARY PENEPLANE.

Uplift increased the grade of the streams so that they began their work of destruction anew. Main streams must cut their valley before tributaries can deepen their channels so that the rivers in the Champlain and Connecticut lowlands had developed wide open valleys before the streams between Camel's Hump and the Northfield Mountains had begun to deepen their beds. The soft sediments of the lowlands yielded readily to running water and weathering, whereas the hard rocks of the great wall resisted destruction and prevented the ancestral Winooski River from deepening its channel as fast as it would have done had the rocks been uniform throughout the country. As a result the rivers of the lowland had completed their work of destruction and had developed a plane surface by erosion before streams flowing on the hard rocks had deepened their channels and dissected the Cretaceous peneplane to an appreciable degree. Consequently large relatively flat tracts of land were left between the Northfield Mountains and the Green Mountain front and also a few miles back from the Winooski valley in the section around Montpelier and Barre. Other similar flat areas were left around the rim of the Adirondacks, throughout the Green and Taconic Mountains (Plate XXXII), the White Mountains, and the Berkshire and Pelham Hills farther south. But the erosion plane of this last period or Middle Tertiary was developed on the soft rocks of the lowlands only, and lies at a lower level than that in the hill country.

THE LATE TERTIARY PENEPLANE.

Another uplift occurred in late Tertiary time or after the development of the Middle Tertiary peneplane and as before the main streams occupying the Champlain and Connecticut lowlands deepened and widened their channels, especially upon the softer rocks. The harder beds, such as the red sandrock, resisted erosion and left hills such as Mt. Philo, Snake Mountain and those around Monkton. Plate XXX. The flat top of Mt. Philo is one of the few remnants of the Middle Tertiary peneplane in the Champlain lowland. Broad open flats were developed and the country brought to nearly its present form. Erosion lasted only long enough to affect the soft beds so that hard rock outlines produced by folding and faulting during past ages, stand out in strong relief.

PRE-GLACIAL UPLIFT.

During the late Pliocene or at the close of the Tertiary another rise in level occurred and the principal rivers deepened their channels, especially near the ocean. The Hudson River eroded a channel, in the late Tertiary peneplane, which is over 2,000 feet deep and nearly the width of the present channel. The Connecticut River deepened its valley over 500 feet for a width of over 100 feet in the vicinity of Northampton, a point far back from the ocean. The Winooski developed a channel, now filled with sand, much deeper than the level of the peneplane. Uplift must have been two to three thousand feet in order to allow these streams to form narrow, canyonlike valleys of this depth so far from the ocean.

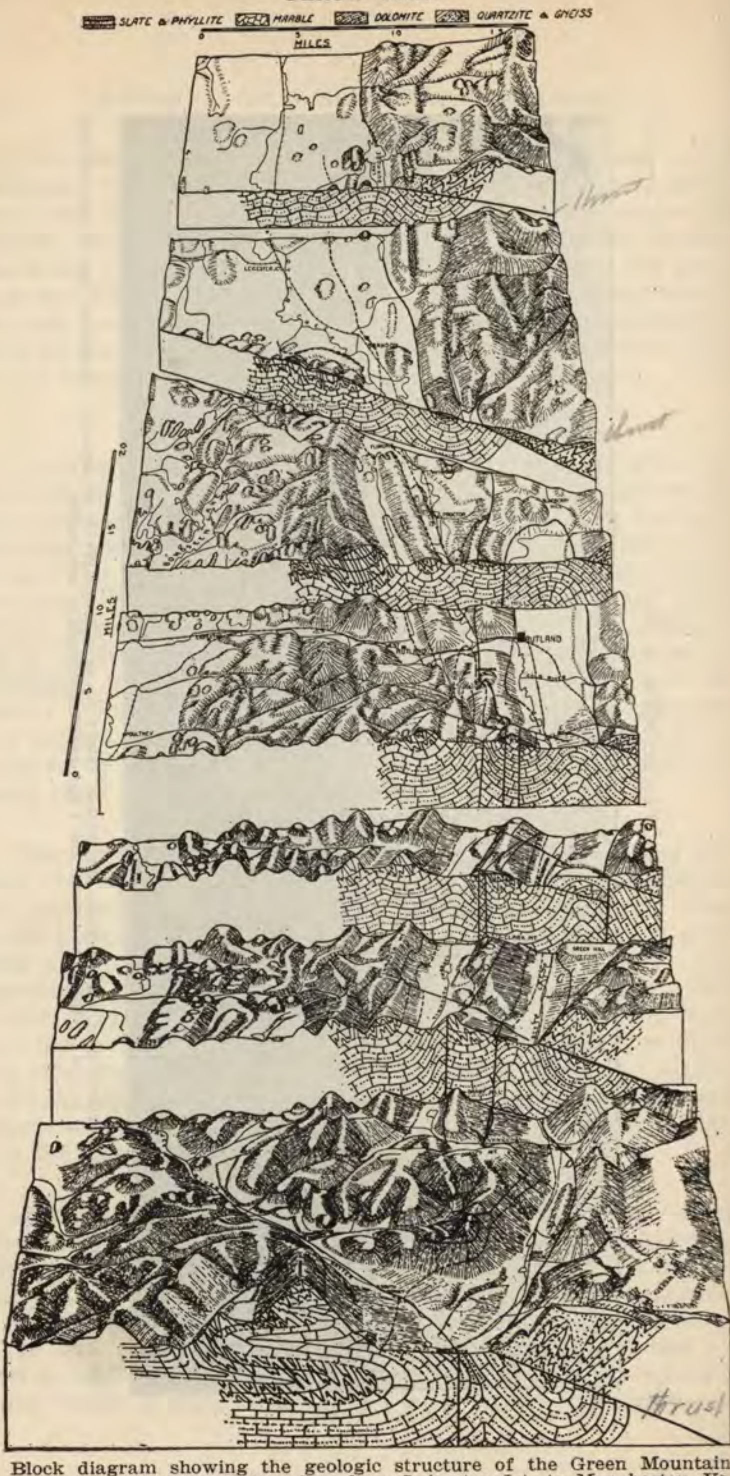
THE GLACIAL PERIOD.

The last uplift of the region on either side of the Green Mountains was the third of a series of increasing magnitude, namely, the doming of the Post-Cretaceous period or first, representing a rise of 750 feet, doming of the Mid-Tertiary peneplane or second, representing a rise of 1,000 to 1,200 feet and doming of the late Tertiary peneplane or third, representing a rise of 2,000 to 3,000 feet. During the period that the land was uplifted to this relatively great elevation and before rivers had an oppor-

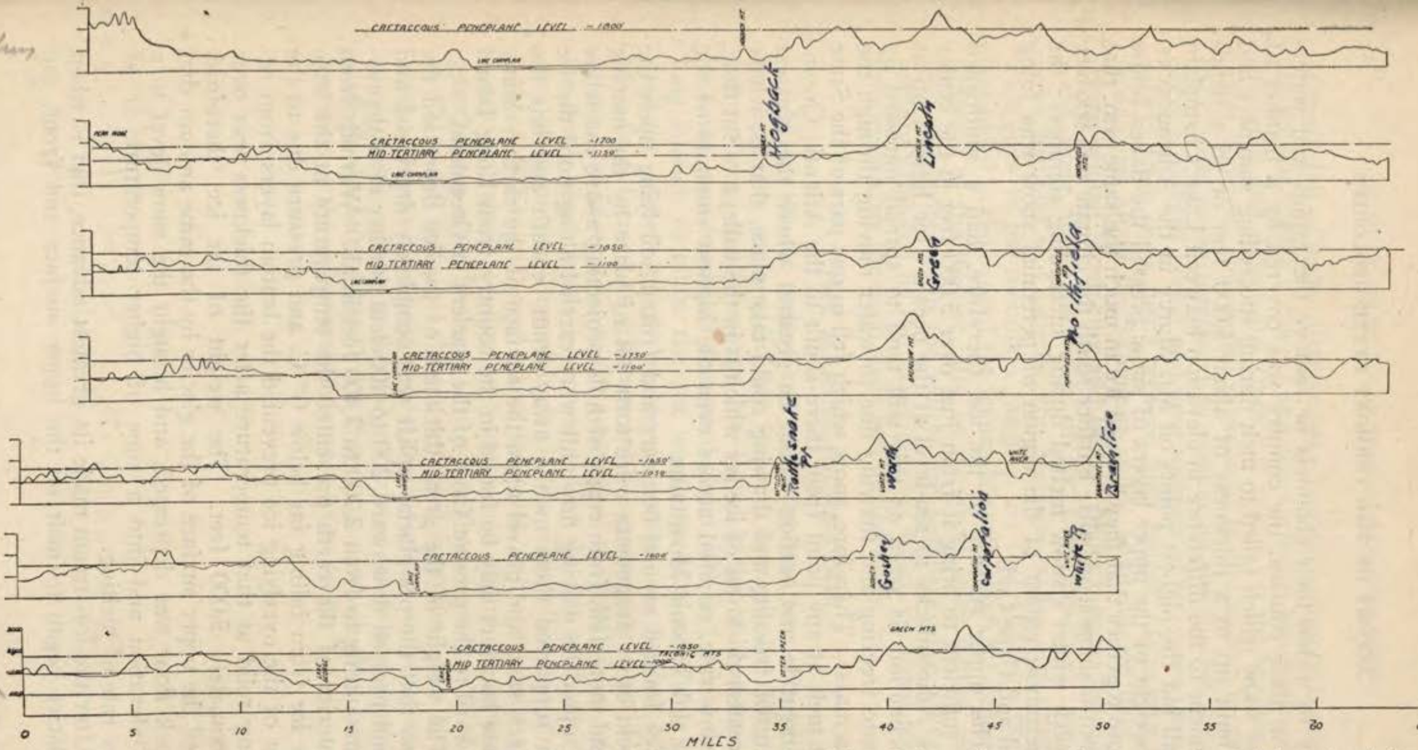
PLATE XXX.

Photograph showing the north end of the Taconic Mountains (left) as seen from Webb Mountain. Brandon lies in the central foreground and the Champlain lowlands to the right.

PLATE XXXI.



Block diagram showing the geologic structure of the Green Mountain front and the marble valley from Leicester Jct. to Manchester, Vt. Dotted lines indicate geologic boundaries. Full heavy lines indicate fault planes.



Series of profiles across the Green Mountains, Champlain lowland and into the Adirondacks. These profiles are made at intervals of five minutes of latitude (about six miles), beginning at Ferrisburg and going as far south as Brandon. The Cretaceous peneplane lies at an elevation of from 1,600 feet to 1,850 feet. The level can scarcely be recognized on the northernmost section because of the great number of valleys cut into it by the Winooski River which lies only a short distance to the north. The mid-Tertiary peneplane lies at an elevation of 1,000 to 1,500 feet. In the lowland it is represented by occasional flat topped hills which happen to lie to one side of the line of section and do not appear on it. The Tertiary peneplane lies beneath the cover of sand and does not show on the profiles. It has an elevation of 100 feet or less.

tunity to widen their channels or remove the rapids and waterfalls in their courses, the country was covered by a blanket of winter snow which failed to melt during succeeding summers and was built up to a thickness of about 5,000 feet or to a depth equivalent to the difference in elevation between Lake Champlain and all but the highest points on Mt. Marcy in the Adirondacks. The weight of the upper layers of snow pressed the flakes below so close together that they formed ice in much the same way that children fashion snowballs. Farther south the climate was warmer and each winter's snow melted during succeeding summers; the southernmost extent of the region of perennial snow was Long Island and Cape Cod.

The upper surface of the ice, therefore, had a southward slope sufficient to bring it from just over 5,000 feet in the center of the Adirondacks to sea-level at the ocean. Ice heaped up at an inclination as steep as this will tend to spread outward by alternate freezing and thawing due to water moving through the frozen mass. Therefore, snow which fell in one part of the State might melt at any point from there south to the Atlantic Ocean. Movement in any section would be greatest where the greatest amount of freezing and thawing could take place, that is, where the greatest thickness of ice lay which is in the valleys. But flow, at a slow rate, occured across even the highest summits of the Green and Taconic Mountains.

Ice formed around boulders and frozen soil lying upon the bedrock, other fragments were torn out of place by the moving ice, and more fell, from crags of hills projecting above the white sheet, upon the moving flow; all were carried along until the ice which supported them melted away from beneath and left the boulders, sand and gravel upon the surface of the earth. Many of these boulders may be found in the country from Long Island northward to the present front of the glaciers in Greenland.

The weight of the great thickness of the ice depressed the land so that the pre-glacial uplift was completely depressed and the land pressed downward 200 to 400 feet further or a depression amounting to from 2,200 to 3,400 feet in all. Warmth from the interior of the earth prevented the temperature at the base of the ice from falling far below 0° C. and pressure due to the weight of the overlying ice prevented the bottom layers from remaining solid at that temperature after the thickness was over approximately 5,000 feet. The weight of the ice, therefore, lowered the upper surface of the glacier by the same amount that the rock floor was depressed, and brought the snow level to a lower elevation and into a zone of higher temperature or of greater rate of melting.

After the ice-stream made its greatest advance, that is when the glacier began to melt on the upper surface and front, the winter's fall of snow disappeared along the southern border during the succeeding summers and the ice began to melt back from the front and downward from low points on the surface where water collected and seeped downward to the valleys in the rock floor. But snow continued to remain on the highest mountains for a prolonged period and long tongues of ice moved out along valleys from snow fields between high ranges. One long tongue flowed out along the Winooski valley from an ice field in the region around Montpelier and Barre. Other tongues flowed westward along along the valley of the Lamoille River, the valley from Rutland to Castleton, the Metawee valley and other east-west gaps in the mountain ranges. So that although the rocks embedded in the base of the ice made north-south scratches on the summits of the highest hills, as the great sheet moved over the land, the striations in the valleys are parallel to the valley walls and are produced by the valley glaciers which persisted for some time even after the main sheet had melted away.

THE MARINE INUNDATION.

When the ice melted away and the load was removed from the land, the surface did not respond instantly by rising to its former level, in fact around Mt. Royal in the St. Lawrence lowland the land remained depressed about 500 feet below sea-level long enough to allow the sea waves to form excellent beaches near the highest points on the mountain. A number of these have been formed at different levels representing a periodic rise of the land in response to the removal of the load of ice. One of the lower beach levels is represented by the flat sand, gravel and clay plain of the Champlain lowland. This plain has an elevation of 300 to 400 feet above sea-level, and from time to time bones and shells of marine animals are found in deposits exposed along river banks. This plain, then, is a record of a rise of 300 to 400 feet since the sea retreated from the Green Mountain State. Rivers have begun anew their work of sculpture and have cut fantastic valleys in the unconsolidated sands and gravels, and through the buried hard rock ridges upon which they have been let down as the softer materials were worn away.

CONTACT METAMORPHISM AND RELATED CHANGES IN COMPOSITION

George W. Bain.

INTRODUCTION.

The Green Mountain section of Vermont is underlain by rocks which have been subjected to extreme metamorphism and, in many cases, have become so changed that their original form is scarcely recognizable. They represent old sedimentary and igneous types which have been subjected to mountain folding and pegmatitic injection in a most intimate manner. Contact metamorphism around surface and subjacent igneous masses is responsible for most of the changes which they have undergone. A knowledge of the changes which have produced similar rocks elsewhere, but in regions where the change has not continued to completion at all points is essential before any detailed study of the schists and gneisses of the mountains can be carried out satisfactorily. Comparison of chemical and mineralogical composition, rock texture and structure with types of known origin is one of the many aids to any geologist working in the region. The following paper is intended to represent a compilation of studies of diverse rock types in various stages of metamorphism. Tables of analyses showing the variation in chemical composition are accompanied by photomicrographs showing the mineralogical transitions.

COMPOSITION CHANGES DURING METAMORPHISM.

Various attempts have been made to use complete analyses of metamorphic rocks to determine their original sedimentary or igneous origin. Studies of the contact zones in the Grenville limestone seemed to indicate that changes in composition due to introduced material were so great that composition, as a criterion of origin, was absolutely useless in those cases where metamorphism was associated with igneous contacts or even with subjacent batholithic masses. Further, if Professor Barrell's[1] conclusion that regional metamorphism in almost all instances is

[1] Barrell, J., Relations of Subjacent Igneous Invasion to Regional Metamorphism, Amer. Jour. Sci., Ser. 5, Vol. I, pp. 1-19. 1921.

associated with subjacent batholithic masses is correct, then chemical composition as a criterion of the ultimate origin of a metamorphic rock would seem to be almost useless in the only cases where it is desirable to use it. If extreme induration and weathering are excluded from metamorphism, Barrell's conclusion can be accepted as essentially correct. The progression of change in chemical composition and the magnitude of the change are, therefore, two very desirable pieces of information to have at hand. A preliminary account of the studies on a contact zone in the Grenville limestone was published by the author[1] and has since been checked up by examination of a great variety of intrusive contacts. Study was also extended to include rocks which had undergone simple shear in the absence of circulating magmatic waters. The behavior of water in rocks during metamorphism was also included in the study and an attempt was made to determine whether the water held in the rocks was capable of effecting their recrystallization as postulated by Professor Van Hise.[2]

Examinations were made on the following types of contacts:

1. Diabase on limestone.
2. Diabase on greywacke.
3. Granite on diabase.
4. Granite on limestone.
5. Granite on mica chlorite schists.
6. Granite on quartzite.

The chemical studies were supplemented by petrographic studies on a much wider range of material and by analyses of some of the prominent minerals undergoing alteration.

Estimation of the change in composition due to simple shear will be taken up before passing to the more complex alteration accompanying shear and recrystallization in the presence of magmas and magmatic solutions.

SIMPLE SHEAR METAMORPHISM.

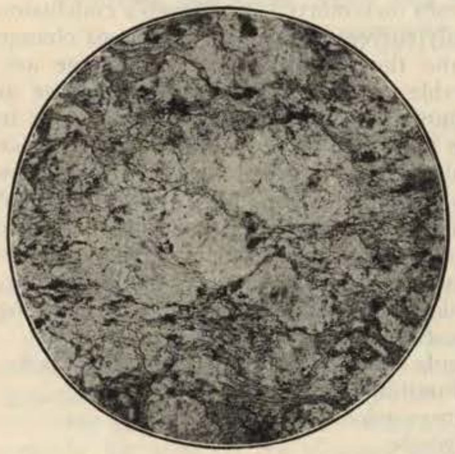
Two types of rocks were studied to determine the degree of change due to simple shearing. The first of these was an unusual specimen of Killarney granite from a broad shear zone and the second a specimen of sheared diabase porphyrite.

Changes in Killarney Granite.—The sheared granite occurs in a fault zone about 200 feet wide, "sympathetic" with the Lake Charles fault or one of the major fracture zones of the western part of the Sudbury district, in Ontario. The specimen of sheared granite used was taken from a heavily glaciated outcrop near the northwest corner of McLander Lake in Dunlop

[1] Bain, Geo. W., Almandite and Its Significance in the Contact Zones of the Grenville Limestone, Jour. of Geol., Vol. XXXI, pp. 650-668.
[2] Van Hise, C. R., Earth Movements, Trans. Wisc. Acad. Sci., Vol. 11, pp. 465-516, 1896-97.

township, Ontario. The rock is nearly white and extremely crumbly. Flat slabs have a bright shiny surface due to the abundance of sericite along the rock cleavage.

PLATE XXXIII.



Photomicrograph of sheared granite. Ordinary light. Magnification about 30 diameters. The lithic fragments (clear) remain as subspherical and augen-shaped pieces separated by sericite shreds.

Microscopic examination of a thin section showed rounded or augen-shaped fragments of granite in a matrix of parallel sericite flakes and of rock flour (Plate XXXIII). Occasional magnetite grains are scattered through this matrix. The round form of some of the fragments seems to be due to a rational movement combined with shearing; in fact conclusive proof of the rotation of fragments in the West Spanish River fault, two miles north of this occurrence, was obtained.

Analyses of massive and sheared granite are given below:

	1	2	3
SiO_2	73.89	73.82	0.07
Al_2O_3	13.75	15.82	2.07
Fe_2O_3	0.61	0.76	0.15
FeO	1.52	0.55	—0.97
CaO	0.63	0.19	—0.44
MgO	0.62	0.62	0.00
K_2O	3.32	3.16	—0.16
Na_2O	4.00	3.59	—0.41
H_2O	0.47	1.14	+0.67
H_2O—	0.00	0.04	+0.04
TiO_2	0.15	Tr.	—0.15
CO_2	0.40	...	...
Total	99.36	99.69	...

1. Massive Killarney granite from Bigelow township. Analyst G. W. Bain.
2. Sheared Killarney granite from Dunlop township. Analyst G. W. Bain.
3. Difference in composition.

The sheared granite shows a slight increase in water and alumina occurring in sericite. The increase in water may indicate introduction of outside material. If such is the case, the amount of material introduced is very slight and confined to the matrix of the fragments. Rather it would seem that the granite varied slightly in composition and that a high alumina portion had been encountered by the shear zone. The high water content is probably due to meteoric solutions moving along the fault zone and facilitating recrystallization of the rock flour. On the other hand the water may have come from the parent magma of a series of olivine diabase dykes which are younger than the faults.

Changes in Sheared Diabase Porphyrite.—The diabase porphyrites of the Huronian region show a great variation in the composition of the ferromagnesian mineral present. Therefore, although the amount of Fe_2O_3, FeO, CaO, and MgO remains approximately constant, the relative amount of each varies considerably and only the change in the total amount present can be used in determining change in composition due to shear.

The sheared diabase used for analysis was taken from the margin of a sheared dyke adjacent to the West Spanish River fault in the southwest corner of Bigelow township, Ontario. Movement parallel to the walls of the dyke had developed a series of sigmoid cleavage planes along the edge of the diabase. The rock is very soft and readily crumbles to a greenish clay.

PLATE XXXIV.

Photomicrograph showing rhombohedral shear lines in diabase porphyrite or huronite. Magnification about 30 diameters. Ordinary light.

Examination of a thin section under the microscope showed that the primary minerals had altered to dark green uralite and chlorite with subordinate areas of saussurite. The minerals are oriented parallel to a series of rhombohedral forms (Plate XXXIV), whose faces are parallel to the larger sigmoid cleavage fragments. Uralization of the pyroxenes and saussuritization of the feldspars is a characteristic alteration of all the diabase porphyrites. The only important change, therefore, is the orientation of the crystals in parallel groups and the development of the rhombohedral shear planes.

Analyses of massive and sheared diabase porphyrites are given below:

	1		2		3	
SiO_2	51.15		51.50		—1.65	
Al_2O_3	12.74		10.22		—2.31	
Fe_2O_3	2.46		0.00		—2.46	
FeO	13.20	28.68	7.94	30.91	—5.26	+2.23
CaO	9.20		6.97		—2.23	
MgO	3.82		16.00		+12.18	
K_2O	0.69		0.77		+0.08	
Na_2O	1.33		2.16		+0.83	
H_2O	0.85		4.26		+3.41	
H_2O—	0.08		0.09		+0.01	
TiO_2	2.03		0.24		—1.79	
CO_2	0.57		0.00		—0.57	
Total	100.12		99.91			

1. Margin of massive diabase dyke in Bigelow township. Analyst G. W. Bain.
2. Sheared margin of another diabase dyke in Bigelow township. Analyst G. W. Bain.
3. Difference in composition.

All the differences in composition except the water content are within the expectable primary variation in the diabases. This water is probably of meteoric origin which entered capillary openings developed in the sheared rocks and was trapped there. On the other hand, the water may have come from the parent magma of the olivine diabase dykes. The presence of specular hematite veins in the West Spanish River fault may indicate that water is magmatic.

Conclusions.—Simple shearing in granites and diabases may produce a marked mineralogical change, but does not seem to have affected the chemical composition appreciably.

Increase in the water content is characteristic. It is not known whether this water is of meteoric or magmatic origin, but it is foreign to the rock.

CONTACT METAMORPHISM.

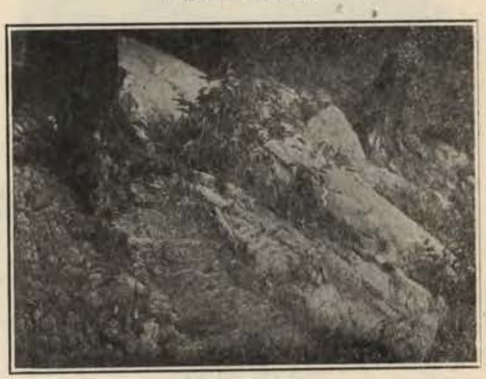
The statement has previously been made that the change in composition is in the direction of equilibrium with the intrusive rock.[1] It has also been shown that, in the case of the series of petrographically different contact zones in the Grenville limestone, "each succeeding zone was enriched in those constituents in which the preceding one was impoverished, and that there was no indication of a reverse reaction. The changes after the formation of a zone are due to the extension of the contact effects farther into

[1] Bain, G. W., Almandite and Its Significance in the Contact Zones of Grenville Limestones, Jour. of Geol., Vol. XXXI, p. 657.

the limestone and a burial of the old zone in a new one."[1] The evidence presented in the following pages and based upon a wider range of material, bears out this conclusion.

Contact Zone of Diabase on Limestone.—Bruce limestone of Lower Huronian age is intruded by a large quartz diabase dyke in Vernon township. The contact zone which is only about thirty-five feet wide is well exposed on the side of a hill near Crazy Creek. The Bruce limestone consists of alternate thin siliceous layers and thicker dolomitic layers. These siliceous bands enable one to follow the same bed comparatively readily. Four specimens were collected from a two-inch bed at right angles to the strike of the diabase dyke (Plate XXXV). The first specimen was a piece of diabase from the dyke, the second a specimen of silicated limestone three to six inches from the dyke, the third a specimen of silicated limestone three feet from the diabase, and the fourth a specimen of limestone about 40 feet from the intrusive. The bed maintains a constant thickness throughout so that the volume change is negligible.

PLATE XXXV.



Photograph showing the contact between a diabase dyke (smooth) and limestone (ribbed). The specimens used for analysis were taken along this zone.

The silicated limestone in contact with the diabase is dark green in color due to the presence of many actinolite needles about half a centimeter in length. Small angular masses of residual carbonate remain scattered throughout the rock. Chlorite occurs as radiating groups between well-formed actinolite prisms. Biotite is common while epidote, apatite and magnetite occur as scattered grains.

The silicated limestone taken three feet from the diabase intrusive is very much coarser than that in contact with it. The actinolite needles (Plate XXXVI) reach a centimeter or more in length and apatite, chlorite and magnetite are much less common. Occasional grains of introduced quartz are present.

The limestone itself is dense and fine grained small actinolite and tremolite needles about three millimeters in length occur throughout the rock.

[1] Bain, G. W., Almandite and Its Significance in the Contact Zones of Grenville Limestone, Jour. of Geology, Vol. XXXI, p. 668.

Analyses of each of the four specimens are given in the following table:

	1	2	3	4
SiO_2	49.90	49.86	46.20	16.60
Al_2O_3	15.35	1.69	0.37	1.93
Fe_2O_3	1.01	0.83	0.00	0.08
FeO	9.65	6.89	8.33	1.79
CaO	12.44	17.01	18.37	19.45
MgO	8.30	13.69	15.20	24.30
K_2O	0.56	0.35	0.20	0.18
Na_2O	2.08	0.52	0.40	0.10
H_2O	0.85	1.57	1.20	1.10
H_2O-	0.09	0.15	0.05	0.18
TiO_2	0.96	0.20	0.14	Tr.
CO_2	Tr.	6.64	9.95	33.27
Total	101.26	99.65	100.68	98.98

1. Diabase intrusive into the Bruce limestone at Crazy Creek, Vernon township, Ontario. Analyst G. W. Bain.
2. Silicated limestone three inches from the intrusive contact. Analyst G. W. Bain.
3. Silicated limestone three feet from the intrusive contact. Analyst G. W. Bain.
4. Bruce limestone 40 feet from intrusive contact. Analyst. G. W. Bain.

PLATE XXXVI.

Photomicrograph of contact limestone at Crazy Creek. Magnification 30 diameters. Crossed nicols. The microphotograph shows actinolite characterized by the cross cleavage at 126° or by long needles, quartz (clear white) and carbonates (turbid).

The analyses when plotted on a curve show the limestone to be approaching the diabase in composition as the distance between the part of the bed examined and the diabase decreases. The rate of approach of composition increases rapidly as the distance from the diabase decreases. Magnesia appears to have been displaced by iron oxides from the zones adjacent to the intrusive and to have migrated to the extreme outer zone. A similar behavior of magnesia in contact zones was noted in the case of the Grenville limestone—Laurentian granite contact zone previously described by the writer.[1] Also more soda has been added and has migrated farther from the intrusive than potash.

A more advanced stage of replacement occurs about a quarter of a mile south of the above occurrence. At this locality the limestone lies below a diabase sheet and is replaced by a rock composed of diopside, actinolite, magnetite and accessory garnet and quartz (Plate XXXVII). Study of a large number of thin sections showed that the diopside was replacing the actinolite and that the magnetite was the last mineral introduced. The magnetite, however, replaced part of the diabase and seems to have been brought in by solutions rising along the gently-dipping footwall of the sheet. The presence of the garnet in appreciable amounts raises the alumina of the rock nearer to the amount found in a diabase.

PLATE XXXVII.

Photomicrograph of rock from the contact between the Bruce limstone and a quartz diabase sheet. Ordinary light. Magnification about 30 diameters. The photomicrograph shows garnet and diopside (light) and hornblende (dark) being replaced by magnetite (black).

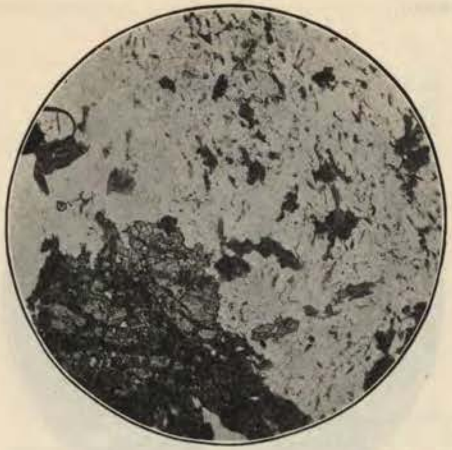
A similar contact zone was observed at another locality near the Spanish River in Shakespeare township, Ontario. A steeply-dipping sheet of diabase several hundred feet thick lay in contact with the banded Bruce limestone. A wide garnet diopside contact zone was developed, but no large quantity of magnetite was present. The carbonate beds were completely replaced by garnet and diopside, but the quartzose bands in between beds only an inch thick remained unaltered. Small veinlets of diopside cut both the silicate and quartzose zones. It appears that the development of the silicates is due to introduction of material rather than due to material already present.

CONTACT OF DIABASE ON GREYWACKE.

The Wanapitei quartzite or greywacke found in Nairn, Dunlop, Hyman and Baldwin townships, Ontario, is heavily injected by offshoots from a large subjacent diabase sheet. Magmatic

[1] Bain, G. W., Op. Cit., pp. 659-664.

PLATE XXXVIII.



Photomicrograph showing Wanapitei greywacke adjacent to the garnet hornblende rim. Ordinary light, magnification about 30 diameters. The microphotograph shows the hornblende (black) as small stringers through the garnet (dark). The greywacke (white) carries many small shreds of biotite and occasional hornblende crystals.

PLATE XXXIX.

Photomicrograph showing garnet (high relief, clear) altering to hornblende (dark) along fractures. Ordinary light. Magnification about 30 diameters.

solutions and diabase magma have worked their way upward along joint planes and corroded the intervening blocks into spheroidal masses resembling pillow lavas. The greywacke adjacent to the diabase occupying the former fractures consists of about 42 percent bluish green hornblende, 20 percent almandite garnet, 20 percent quartz, 5 percent alkali feldspar (Ab_4An_1), 10 percent biotite, and 3 percent magnetite.

Nearer the center of the blocks, garnet, biotite and quartz become more abundant, while hornblende and magnetite decrease in amount (Plate XXXVIII). As the hornblende makes up a smaller portion of the rock, it occurs as smaller and better formed crystals. The central portion of the larger blocks is composed almost entirely of quartz, alkali, feldspar biotite.

The hornblende is dominantly an alteration product of garnet (Plate XXXIX) although some of the latest euhedral crystals seem to have been precipitated for the first time from magmatic solutions soaking into the block. The earlier

generation of feathery and sheaf-like amphiboles are alteration products of almandite and characteristically occupy fractures in it. The garnets on the outside of the blocks have almost completely altered to hornblende, which in some cases preserves the outward form of the earlier mineral. Zonal alteration succeeds zonal deposition and equilibrium with the invading magma is established through the removal of the excess components to the interior of the blocks and outer parts of the contact zones by mineralizers.

Analyses of the diabase supplying the mineralizing solutions effecting the alteration, the garnet hornblende zone near the diabase, and of the intermediate garnet zone were made to determine the composition changes during metamorphism. The analyses are given in the following table:

	1	2	3	4	5
SiO_2	53.34	48.60	56.16	37.41	40.54
Al_2O_3	15.44	16.13	15.18	20.14	16.34
Fe_2O_3	1.44	3.27	4.99	0.05	3.08
FeO	11.69	16.67	6.46	35.60	22.20
CaO	7.84	9.23	14.65	5.58	10.24
MgO	5.50	2.17	0.36	1.20	3.25
K_2O	0.64	0.70	0.34	....	0.45
Na_2O	1.90	1.70	0.70	....	1.31
H_2O	1.21	0.58	0.57	....	1.43
$H_2O—$	0.05	0.02	0.05	....	0.12
TiO_2	1.05	1.59	2.08	0.20	0.75
CO_2	0.53	Tr.	Tr.	....	....
Total...	100.63	100.49	101.57	100.17	99.71

1. Diabase from sheet in Hyman township, Ontario. Analyst G. W. Bain.
2. Greywacke of garnet hornblende zone three inches from diabase. Analyst G. W. Bain.
3. Garnetiferous greywacke about eight inches from the diabase. Analyst G. W. Bain.
4. Garnet from the contact zone. Analyst G. W. Bain.
5. Hornblende formed by alteration of the garnet. Analyst G. W. Bain.

The analyses show an approach of the greywacke to the diabase in composition as the distance between the diabase and the point under consideration decreases. Soda has been added in greater amounts than potash. The presence of abundant garnet and hornblende of the above composition renders the contact rocks low in SiO_2 and high in Al_2O_3 and FeO. Because of the intense injection the greywacke has suffered, unaltered rock could not be obtained to determine the original composition.

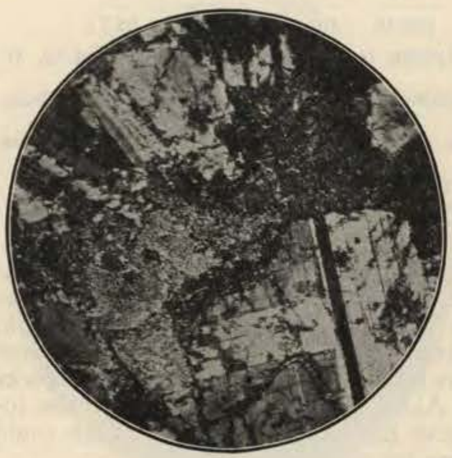
CONTACT EFFECT OF GRANITE ON DIABASE.

Two contrasted effects depending upon different conditions have been observed.

PLATE XL.

Photomicrograph of quartz diabase near the contact with intrusive granite. Ordinary light. Magnification about 30 diameters. The microphotograph shows a light saussuritized area, formerly feldspar at one side of the field. The remainder is a fine hairlike aggregate of uralite and chlorite.

PLATE XLI.



Photomicrograph showing a further stage in the granitization of a diabase. Crossed nicols. Magnification about 30 diameters. The photomicrograph shows the growth of large twinned feldspars in the turbid matrix of chlorite and uralite.

1. Alteration of the diabase to a schistose uralite, chlorite complex followed by granitization.

2. Alteration of the diabase to a carbonate rock.

The first type of alteration is characteristic of diabases coming in contact with the main intrusive mass of granite. The second type of alteration, although found to a minor degree along with the first, becomes characteristic of diabase dykes cutting the sediments near intrusive cupolas of granite which have acted as inverted funnels arranged to collect the escaping mineralizers.

The chlorite-uralite type of alteration begins by complete uralitization and chloritization of the femic and salic minerals. At the same time a weak schistose structure is developed in the rock. Areas of a pale green chlorite surrounded by darker green uralite and chlorite show the outlines of former feldspar crystals (Plate XL), but all other primary structures within the rock are destroyed.

The zone immediately adjacent to the intrusive shows strong granitization effects. The uralite and chlorite have

been largely replaced by a sericitic aggregate. Feldspar metacrysts (Plate XLI) have grown in the slightly schistose rock just as in the case of the soaked Keewatin volcanics described later. Large lacunoid areas of sericitized diabase remain in the feldspars as well as along zones cutting through them.

Chemical analysis of the granitized diabase was made for the purpose of comparison with the composition of the normal diabase dykes and with the Killarney granite. Analyses of the four characteristic rocks are given in the following table:

	1	2	3	4
SiO_2	73.89	60.92	53.34	49.90
Al_2O_3	13.75	21.25	15.44	15.35
Fe_2O_3	0.61	1.15	1.44	1.01
FeO	1.52	2.07	11.69	9.65
CaO	0.63	0.85	7.84	12.44
MgO	0.62	0.79	5.50	8.30
K_2O	3.32	5.96	0.64	0.56
Na_2O	4.00	5.22	1.90	2.08
H_2O+	0.47	1.24	1.21	0.85
H_2O-	0.00	0.10	0.05	0.09
TiO_2	0.15	0.16	1.05	0.96
CO_2	0.40	not. det.	0.53	Tr.
Total	99.36	99.55	100.63	101.26

1. Killarney granite, Bigelow township. Analyst G. W. Bain.
2. Granitized quartz diabase, Hyman township. Analyst G. W. Bain.
3. Quartz diabase, Hyman township. Analyst G. W. Bain.
4. Quartz diabase, Vernon township. Analyst G. W. Bain.

The analyses show the continuous increase in silica toward the granite and the continuous decrease in ferric and ferrous iron, lime, magnesia and titanium. The alumina and alkalies have increased in the granitized diabase due to the large amount of introduced feldspar, so that the rock approaches a syenite or diorite in composition. This behavior may indicate that, although the general underlying principle is that the rocks approach one another in composition, the detailed reactions may be such as to bring the diabase through the same changes in the components that the acid differentiate would have undergone had it passed from diabase to granite without crystallizing. This is the principle recently advocated by Bowen[1] as the controlling process in syntexis.

The carbonate type of alteration occurs chiefly in dykes cutting sediments immediately underlain by granite and not protected by the thick main sheet of the Sudbury norite. In the vicinity of the western end of the Sudbury Basin important concentration of mineralizers has occurred in the cupolas of granite which penetrate the thick femic injective underlying the Huronian sediments. The mineralizers, escaping along the weak zones adjacent

[1] Bowen, N. L., Reaction Principle in Petrogenesis, Jour. of Geology, Vol. III, 1922.

to the contact between the dykes and the sediments have greatly altered the diabases. As a general rule, the ferromagnesian minerals are most altered and were the first to be destroyed. The uralitized pyroxenes have been converted to biotite. Shearing broke up the plagioclase crystals and gave the biotite an imperfect schistose structure. Carbonate was developed as a pneumatolitic product even at this early age, but some seems to have been introduced. Leucoxene in great abundance was formed from ilmenite. Pyrite, chalcopyrite, pyrrhotite and pentlandite are usually associated with the carbonates.

In the final stage of alteration the biotite and feldspars break down and the diabase dykes pass over into carbonate with some granular quartz and chlorite flakes. The parallelism of the quartz and carbonate zones indicates that the dykes have undergone very intense shearing before complete carbonatization.

CONTACT BETWEEN LIMESTONE AND GRANITE.

Contact phenomena between granite and limestone have received more attention than any other because of the mineral deposits associated with the garnet zones. Professor Lindgren[1] and Professor Kemp[2] and others have conducted important researches upon the zones found immediately adjacent to the intrusive. In none of the cases described had metamorphism progressed beyond the garnet stage. A garnet zone in the Grenville limestone of the type area showed a further stage of alteration and was studied in detail by the writer under the guidance of Professor Kemp and Professor Berkey of Columbia University. The results of this study have been published[3] and only extracts and the analyses given below need be repeated here.

	1	2	3	4
SiO_2	16.05	53.10	55.91	59.89
Al_2O_3	0.14	24.38	18.44	17.70
Fe_2O_3	1.54	2.86	2.37	1.95
FeO		11.21	7.42	2.71
CaO	46.65	1.16	3.50	2.53
MgO	5.25	2.40	3.61	1.56
K_2O	....	1.49	1.13	5.83
Na_2O	....	2.94	2.08	5.74
H_2O+	....	0.60	4.74	0.29
H_2O-	....	....		0.39
TiO_2	....	....	....	0.96
CO_2	30.80	....	....	0.17
Total	100.43	100.14	99.20	99.72

[1] Lindgren, W., The Ore Deposits of New Mexico, U. S. G. S. Prof. Paper 68, 1910.

[2] Kemp, James F., Notes on Garnet Zones on the Contact of Intrusive Rocks and Limestones, Trans. Cana. Mining Institute, Vol. XV, pp. 171-186, 1912.

[3] Bain, George W., Almandite and Its Significance in the Contact Zones of the Grenville Limestone, Jour. of Geol., Vol. XXXI, pp. 650-668.

1. Grenville limestone from West River, Chatham township, Quebec. Analyst G. W. Bain.
2. Skarn Rock from Dalesville, Chatham township, Quebec. Analyst G. W. Bain.
3. Biotite gneiss from Dalesville, Chatham township, Quebec. Analyst G. W. Bain.
4. Laurentian granite gneiss from near Lachute, Quebec. Analyst Dr. Dittrich.

The composition of the rocks, from the garnet zone toward the intrusive, show a constant approach to the granite in composition. The change from limestone to skarn rock is rather abrupt, but this is due to zonal alteration and discharge of everything, in excess of the amount required to maintain equilibrium, into a band lying between the unaltered limestone and the garnet rock. The behavior of zonal alteration and discharge of material into limestone farther removed from the intrusive granite is given in the paper previously referred to. As in the case of the diabase limestone contact zone in Vernon township, the magnesia has migrated farther than any other constituent and has become an important part of the limestone. (Unaltered limestones from this locality analyze less than 1 percent MgO.) Also the Na_2O has migrated to a slightly greater degree in both amount and distance than the K_2O.

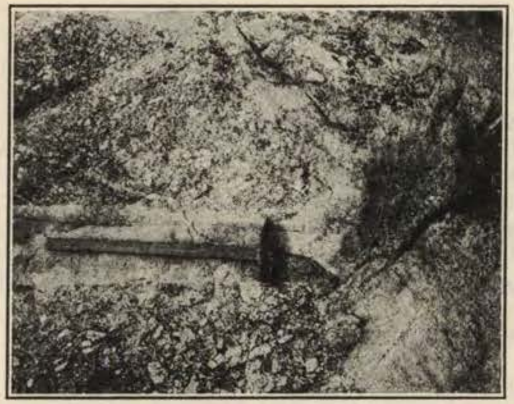
GRANITIZATION OF THE SCHISTS.

PLATE XLII.

Photograph showing a granitized schist resembling granite. The metacrysts reach three inches in length.

East of the road between Webbwood and the West Spanish River in Bigelow township, Ontario, the Killarney granite is characterized by pseudophenocrysts or metacrysts. (Plate XLII.) Feldspar crystals three inches in length occur scattered irregularly through a coarsely granitoid groundmass. Locally dykes granite cut the pseudoporphyritic granitoid rock. (Plate XLIII.) Close examination of the intruded rock discloses the presence of mica, chlorite and epidote arranged in parallel streaks. The streaks are seldom over one-quarter of an inch thick and are spaced far apart. Even in the streaks the femic minerals form only one to five percent of the rock. The large feldspar crystals appear to be very pure, but if examined critically, they show, in many cases, the femic streaks of the rock continuing through themselves. The feldspars, therefore, are later than the streaks of femic minerals and are really metacrysts replacing a chlorite-mica schist. Not only are the metacrysts replacement products, but likewise the entire granitoid rock characterized by the slightly streaked appearance and cut by the intrusive granite dykes, is a chlorite-mica schist which has suffered almost complete granitization by reason of the subjacent granite magma which surrounded these roof pendants on all sides.

PLATE XLIII.



Photograph showing a granitized schist cut by fine grained granite dyke from the subjacent magma. Note the contrast in weather resisting properties of the granitized rock and the dykes.

Granitoid rocks of this character have been mapped as granites because of the difficulty of distinguishing them in many cases and because of their isolated character. Occasionally granitization has been more complete and the schistose residuals have completely disappeared. In other cases soaking has not been nearly so complete and at one occurrence in Bigelow township the femic constituents form a major portion of the rock and the metacrysts have just developed to a slight extent. Such rocks are not true granites; they have never been simultaneously in solution throughout and been able to crystallize from this homogeneous solution. Only portions of them have been in solution at any one time and the solid phase has controlled to some degree the shape of the crystals coming out of solution and the form of the mass itself.

Replacement has come about by addition of material brought in by mineralizers from the Killarney granite magma which lay only a few feet below. As in other cases the occurrence illustrates approach of the composition of the intruded rock to that of the intrusive and the change in composition occurs within the intruded rock only.

GRANITIZATION OF THE MISSISSAGI QUARTZITE.

Contact zones in the Mississagi quartzite of Lower Huronian age, with the Killarney granite are very narrow, seldom exceeding thirty feet. The granite maintains all of its characters to a short distance from the contact where swarms of undissolved xenoliths become evident. Microscopically, the xenoliths appear to have practically the same chemical and mineralogical composition as the granite matrix. The main distinctive difference lies in the character of the quartz grains. The quartz in the granite is clear, and subangular, while that in the xenoliths is turbid and frequently has smooth outlines. On weathered surfaces this character is so distinctive that it is quite easy to distinguish the xenoliths from the intrustive granite.

Sericitization of the quartzite characterized the first stage in granitization (Plate XLIV). Flakes of sericite in more or less parallel orientation were introduced all through the quartz. In the second stage of alteration alkali feldspars formed so that their elongation lies parallel to the dominant direc-

PLATE XLIV.

Photomicrograph showing sericitized Mississagi quartzite from the interior of a xenolith in the Killarney granite. The quartz (white) is almost completely altered to sericite. Crossed nicols. Magnification about 30 diameters.

PLATE XLV.

Photomicrograph of quartzite inclusion in granite showing small elongate areas of feldspar in the sericite aggregate. The feldspars are all approximately parallel as indicated by the cleavage and twinning planes. Crossed nicols. Magnification about 30 diameters.

tion of the sericite flakes (Plate XLV). Instead of the feldspars growing as a single crystal, they start from a nucleus and enlarge in all directions; growth parallel to their elongation takes place at various rates along different sericitic zones, so that prismatic fingers of variable length extend from the primary nucleus.

The feldspar of the final stage has a more or less idiomorphic outline, but contains within itself prismatic or ellipsoidal patches of quartz and sericite or lacunoid areas which the crystals have grown around instead of replacing (Plate XLVI). Some quartz and sericite are retained between the grains, but the amount in the final stage is almost the same as that in the granite.

Biotite is entirely lacking, but the sericite is slightly ferruginous and some magnetite is also present. (The absence of the components, to make biotite, in the mineralizers escaping from the granite strongly supports petrographical evidence, showing that the mica of the Killarney granite is syntectic and not an original component of the magma. The pegmaties cutting the Killarney granite in Concession II of Shakespeare township carry muscovite, containing a slight amount of iron, rather than a typical biotite mica. The biotite of the Killarney granite therefore seems to be present as incompletely distributed inclusions rather than as a primary component of the magma solution.)

PLATE XLVI.

Photomicrograph of quartzite immediately adjacent to the granite showing many of the small feldspars joined up to make a larger one and surrounding lacunoid, turbid, areas of sericite. The rock closely resembles a granite in texture, structure, mineral and chemical composition. Crossed nicols. Magnification about 30 diameters.

Analyses show that most of the iron in the contact zones of the Killarney granite is carried through from the original quartzite. The chief additions are alumina and alkalies to make the feldspar and sericite. These additions are made at the expense of silica which has been transported farther back into the sedimentary series. Redeposition of the silica in openings has given the Mississagi quartzite a hard glassy appearance for some considerable distance back from the intrusive contact. The amount of secondary silica deposited in this zone will account for more

than has been removed from the granitized contact now remaining. The excess may be due to silica driven away from granitized blocks which have been stoped away since or dissolved in place. As before, all the evidence points to continual discharge of material by the magma and no return of material from the intruded rock except in the form of included blocks. Mutual exchange so often described as a process occurring along intrusive contacts does not seem to have occurred along the margins of the Killarney magma.

Samples representative of the various stages of granitization were analyzed and are given in the following table:

	1	2	3	4
SiO_2	73.89	77.90	77.87	89.42
Al_2O_3	13.75	12.21	12.41	5.65
Fe_2O_3	0.61	0.99	0.92	0.30
FeO	1.52	1.45	1.38	0.97
CaO	0.63	0.18	0.20	0.15
MgO	0.62	0.58	0.84	0.46
K_2O	3.32	3.20	3.08	1.82
Na_2O	4.00	2.52	2.20	0.76
H_2O+	0.47	0.91	1.04	0.41
H_2O-	0.00	0.10	0.05	0.04
TiO_2	0.15	0.14	0.18	0.17
CO_2	0.40	0.00	0.00	0.00
Total	99.36	100.18	100.17	100.15

1. Analysis of Killarney granite. Analyst G. W. Bain.
2. Analysis of granitized quartzite; feldspar phase 6 inches from contact. Analyst G. W. Bain.
3. Analysis of sericitized quartzite with incipient feldspar growths, 2 feet from intrusive contact. Analyst G. W. Bain.
4. Analysis of slightly sericitized Mississagi quartzite showing no contact effects. Analyst G. W. Bain.

The analyses when plotted on a curve show the increase in alumina and alkalies next the granite and corresponding decrease in silica already referred to. Soda has been added in slight excess of potash.

The argillite member at the base of the Lorrain quartzite is in contact with the Killarney granite at several points. The contact zone is so narrow as to be almost negligible. A specimen taken one foot from the contact consisted of well rounded and practically undeformed quartz and feldspar grains about 0.02 mms. in diameter in a slightly schistose sericitic matrix. The feldspar grains have a composition of about $Ab_9 An_1$.

A specimen of the same bed taken 6 inches from the contact showed the grains badly deformed and the incipient schistosity completely destroyed. Heavy jointing healed by quartz characterizes the rock. Pyrite and magnetite have been introduced and the micas have been extensively chloritized.

The granite from the contact consists of fragments of crystals and of sediments held in a very fine grained matrix. All the fragments are very angular and show that very rigid conditions existed toward the end. The swarms of sedimentary inclusions show that microscopic as well as large size xenoliths are being stoped off the roof continually by intrusive magmas of batholithic or sub-batholithic dimensions.

The argillite had practically the same composition as the granite and no change in composition is noticeable. The changes which might be expected to be found in a quartzite wall rock may occur in the Lorrain quartzite some distance above.

BEHAVIOR OF PRIMARY WATER IN IGNEOUS ROCKS DURING METAMORPHISM.

Analyses of the various intrusives from the Sudbury Region show low percentages of uncombined water except for the highly titaniferous and totally unaltered olivine diabases. When thin sections from a fresh olivine diabase from Dunlop township are examined under the high power of the microscope, small globules of included water can be seen in the feldspars. This water will escape when the finely powdered rock is heated to 110° C. The combined water is retained above this temperature. The fact that free water exists in appreciable amounts only in the unmetamorphosed diabases and the combined water of these same diabases is much less than in metamorphosed rocks of equivalent composition, suggests that the free water has entered into chemical combination. If the water, primary to the rock, enters into chemical combination, it cannot facilitate the formation of schists by recrystallization. Recrystallization must, therefore, be due to water introduced from outside sources.

A table showing the relative amounts of combined and free water is given below:

	Combined	Free	Relative proportion
1	1.28	0.11	11.65
2	1.23	0.16	7.70
3	1.54	0.10	15.40
4	0.69	0.12	5.75*
5	4.43	0.00	....
6	1.74	0.25	6.95*
7	0.85	0.09	9.44
8	1.21	0.05	24.20
9	1.01	0.11	9.17
10	0.85	0.08	10.62
11	1.75	0.11	15.90
12	2.34	0.06	39.00
13	4.26	0.09	47.33
14	0.96	0.66	1.45
15	1.36	0.23	5.90

*Feldspathic rocks. Note observations on quartzose and feldspathic rocks in the following paragraphs.

ROCKS SUBJECTED TO A PERIOD OF DEFORMATION.

1. Diabase from chilled margin of Norite Sheet. T. B. 118.
2. Diabase 200 feet from base of chilled margin of Norite Sheet. T. B. 118.
3. Dark portion of orbicular norite.
4. Light portion of orbicular norite.
5. Dark bands in norite.
6. Light bands in norite.
7. Diabase at Crazy Creek, Vernon township.
8. Diabase sheet in Hyman township.
9. Matrix of diabase breccia, Bigelow township.
10. Margin of diabase porphyrite, Bigelow township.
11. Intermediate portion of diabase porphyrite, Bigelow township.
12. Central portion of diabase porphyrite, Bigelow township.
13. Sheared diabase, Bigelow township.

ROCKS NOT SUBJECTED TO DEFORMATION.

14. Olivine diabase, Dunlop township.
15. Titaniferous olivine diabase, Vernon township.

The light portion of the orbicular norite and the white bands of the banded norites are the only metamorphosed femic rocks carrying a ratio of free to combined water of less than one to seven. In both cases the rocks are high in feldspar and in no case has feldspar altered nearly so readily as the ferromagnesian minerals. High ratios are encountered in the ferromagnesian rocks and on this basis it has been concluded that the water has entered into chemical combination with pyroxene to give uralite.

The low ratios 1.45 and 5.90 are in the fresh unaltered olivine diabases and the uncombined water is present as primary liquid inclusions which can be recognized when thin sections are examined under the high power of the microscope. No inclusions of water have been recognized in the deformed diabases.

The above figures seem to show that the water present in the rocks before deformation enters into chemical composition with the components of the surrounding rock and is not free to be used over and over again as a catalytic agent to facilitate recrystallization. In rare cases as, for example, the quartz rocks or the feldspar rocks, the original water may not enter into chemical combination, but it is a fact that the water in these same rocks is usually so low that it is used up by the small amount of impurities present in them. It, therefore, seems necessary to look to some outside source to find enough water to effect the recrystallization in metamorphic rocks.

SOURCE OF WATER EFFECTING RECRYSTALLIZATION OF ROCKS.

The granite and pegmatites have the lowest percentage (0.06 to 0.47) of water of any of the rocks and this lack compared to what is to be expected is attributed to the escape of water as a main constituent of magmatic emanations. The loss of water by the granite phase of the magma must have been enormous even if we consider that all that inherent to the chilled diabases remained behind, although some probably escaped. The chilled quartz diabases of the Sudbury district carry 1.20 percent to 1.40 percent total water, whereas the granite carries only 0.47 percent, representing a loss of 0.91 percent. This amount may have been decreased somewhat by the assimilation of quartzites carrying about 0.41 percent H_2O as compared with 0.47 percent in the Killarney granite, but even this amount would not appreciably change the figures.

CONCLUSIONS.

The analyses and petrographic studies of a very wide range of contact rocks seem to show:

1. That the intruded rock approaches the intrusive in composition.
2. Composition changes in the intrusive other than those caused by differentiation are due to solution of included blocks, rather than interchange along the contacts.
3. Contact rocks show a tendency to pass through the reaction series described by Bowen rather than to change their composition along a smooth curve with no reverse slopes.
4. Magnesia and alkalies, notably soda are the most mobile components.
5. Simple shearing does not affect the composition and water is essential to produce recrystallization of the gouge.
6. Water primary to the rocks enters into chemical composition when the rocks are deformed, and cannot be used over and over again. Water to effect recrystallization must come from an outside source and the most logical source is a subjacent magma. This magma is usually of granitic composition.
7. Barrell's hypothesis that metamorphism other than induration and certain forms of weathering is due to subjacent igneous invasion, seems to be borne out by the evidence that water primary to a rock enters into chemical combination on deformation and is not free to facilitate recrystallization.
8. The changes in composition during contact metamorphism are greater than the changes in the major form of a rock. Where metamorphism has progressed to such a degree that the origin of a rock cannot be de-

termined from the outward form, then neither can the ultimate origin be determined from the chemical composition.
9. Comparison of mineral composition and structure with known types of rocks may furnish important clues to metamorphic processes and the primary type of rock which is being studied in its present changed condition.

MINERAL RESOURCES, 1926-1927

G. H. PERKINS.

As most Vermonters know, Vermont is not a mining state and though within the past hundred years a considerable number of iron and copper mines, and a few gold mines, have been opened and to a greater or less extent worked, not one in the long run paid back to the owners anything like what had been expended in working it and by far the great majority proved a total loss. The story of most of these has been told in former Reports and need not be repeated here. The trouble with all these mines was the same as is recorded in mines all over the United States: that the quantity of the metal obtained, if any was obtained, was far too little to pay the cost of working. So far as the writer knows, the only mines in Vermont which have not been failures are the few talc mines. As will be shown later, several of these talc mines have been successfully work and are still in active operation. Consequently, nothing further need be said about Vermont mines except these.

Vermont does indeed possess mineral wealth of great importance, though it is not in mines, but in quarries. It is probably true that now Vermont, small as is its area, produces more marble and granite than any other State in the Union and than any other country in the world. Though following at some distance behind Pennsylvania in the production of slate, Vermont produces more than any other State with that exception.

STONE.

As far as I have been able to collect facts the stone business in this State has not changed to any great extent during the past few years. Exact figures cannot be given for several reasons, some of which will be considered later, but as nearly as I can ascertain, the value of stone of all kinds sold at present in Vermont is not less than $15,000,000 and if every producing company had reported some addition should be made to this amount.

GRANITE.

Nearly all the granite found in Vermont, and all that is quarried is gray. There is a small amount of red granite in the State, but none has as yet been taken out of the ledge. All imaginable shades of gray are found from that which when cut is

practically white, as the Bethel granite, to that which is nearly black, as some of the stone quarried by the "Rock of Ages Corporation."

While, as the following list shows, the number of worked quarries is not large, being not over thirty-five in the whole State, there are over two hundred "cutting sheds," most of them in Barre and Montpelier. Many of the "cutting sheds" (the local name for the manufacturing establishment which take the stone as it comes from the quarry and finish it) are very large and equipped with the best obtainable machinery. Because of the relationship between the quarries and the "cutting sheds" it has proved very difficult to reach a positively accurate statement as to the amount and, therefore, value of the granite sold in Vermont.

It is not very difficult to ascertain the value of granite sold to dealers outside of the State in the rough, nor the value of cut stone, but most of the stone sold in finished form has already been bought from the Vermont quarries and then again sold when finished. It is, therefore, not easy to separate stone that has been sold once from that which has been sold twice, though both have been obtained within the State.

Geologically it is interesting to note that no granite is quarried west of the Green Mountain range. Also that no marble or slate is quarried east of the range, though some slate does occur east of the mountains.

Granite is found in areas of large or small extent throughout the length of the State, from Beebe Plain south to Dummerston, while slate is more restricted in its distribution and marble still more so.

The following list of granite producers will be found useful by anyone who may be interested in the subject. In compiling this list the writer has been greatly assisted by Mr. R. E. Mitchell, Secretary of the Barre Manufacturers' Association, the Woodbury Granite Company, and Mr. R. Farquharson of Ryegate. The list is made out alphabetically by towns.

As the origin, structure and details of quarries, manufacture, etc., have been quite fully presented in previous Reports, it is sufficient here to refer those who are especially interested in granite to articles in the Seventh Report of the Vermont State Geologist, pages 77-198, and Twelfth Report, pages 314-325. Also to the the second paper in this volume. The author of this paper, Dr. Robert Balk, has applied new methods of investigation recently used by some German geologists, in his study of the granite areas of Bethel, Barre and Woodbury. Although this paper is quite technical rather than popular, much of it will be found of value to those interested in Vermont granite, as well as to geologists generally, since this is the first area in America that has been studied in the manner indicated in the paper.

LIST OF GRANITE COMPANIES IN VERMONT, 1927.

ADAMANT.

Adamant Quarry Co., Q.
Hughes Granite & Quarry Co., Q.
Orzella & Massi.
Steele Granite Co.
Waldron Sields.

BARRE.

Alonzo & Aja.
Abbiati & Fontana.
Anderson-Friburg Co., Q.
Anderson & Johnson.
Barclay Brothers, Q.
Bardossi Granite Co.
Barre Memorial Co.
Batchelder, E. J. & Co.
Beck & Beck.
Bettini & Ratazzi.
Bianchi & Sons.
Bilodeau & Co.
Bond, Geo. E. & Co.
Brusa Brothers.
Burke Brothers.
Buzzi Granite Co.
Canales & Gomez.
Canton Brothers, Q.
Carley & Cummings.
Caroll Brothers.
Carswell-Wetmore Co.
Caslani Brothers.
Cedrone Granite Co.
Celente & Bianchi.
Cenchi & Bardessi.
Chioldi Granite Co.
Cole & Son, William.
Cook & Watkins Manufacturing Co.
Comolli & Co.
Corkskie & Co.
Crescent Granite Co.
Debitto & Cacvavo.
Deessureau & Co.
DeRegidus Granite Co.
Dunghi & Groppelli.
Eagle Granite Co.
Fontana, E.
Gelpi Granite Co.
George Granite Co.
Gerard & Barclay.
Glysson & Co.
Gomez Brothers.
Grearson & Lane Co.
Guidici Brothers & Co.
Harrison Granite Co.
Hastings Granite Co.
Hebert & Ladrie.
Hedwall & Stewart.
Hinman Co.
Hoyt & Milne.
Imperial Granite Co.
Industrial Granite Co.
Johnson & Gustafson.
Jones Brothers Co., Q.
Kent & Russell.
Lawson, Alex.
Lawless Granite Co.
LeClair & McNulty.
Liberty Granite Co.
Lion Granite Co.
Littlejohn, Odgers & Milne, Q.
Lorenzini, C.
McColl & Abaire.
McDonnel & Sons, Q.
McGovern Granite Co.
Marr & Gordon, Q.
Marrion & O'Leary.
Martinson Estate Co.
Milne Granite Co., William.
Milne Granite Co., Alex.
Milne Aja & Co.
Modern Granite Co.
Native Granite Co.
Newcombe, Thomas.
Nicora Granite Co.
Novelli & Galcagni.
Novelli & Co.
Oliver Granite Co.
Olson & Johnson.
Parnigoni Brothers.
Parry & Jones Co.
Peerless Granite Co.
Pirie Estate, Q.
Provost Granite Co.
Puente Granite Co.
Redmond & Hartigan.
Rabaoli & Rossi.
Ravilla Granite Co.
Rex Granite Co.
Rizzi & Son.
Robertson, J. C.
Robbins Brothers.
Rock of Ages Corp., Q.
Rossi Granite Co.
Ross & Ralph.
Roux Granite Co.
Royal Granite Co.
Russell & Brand.
Saldi & Co.
Sanguinetti Brothers, Q.
Saporti & Co.
Sartelli & Gierson.
Sierra Granite Co.

Sheridan & Poole.
Shield & Co.
Simonella & Fontana.
Smith, E. L. & Co., Q.
South Barre Granite Co.
Standard Granite Co.
Steele Granite Co.
Straiton, George, Q.
Tosi & Co.
Twentieth Century Granite Co.
Union Granite Co.
United Granite Co.
Usle and Parajo.
Usle & Revilla.
Valz Granite Co.
Valdiviso & Estran.
Vanetti Granite Co.
Venetian Granite Co.
Verde Mountain Granite Co.
Vermont Manufacturing & Quarry Co.
Victory Granite Co.
Webster Granite Co.
Wells & Lamson Quarry Co., Q.
Wetmore & Morse Granite Co., Q.
Williamstown Granite Co.
World Granite Co.
Young Brothers.
Zampieri & Buttura.
Zorsi & Co.

BARTON.

Barton Granite Co., Q.
Crystal Lake Granite Co., Q.
Lewis, L. R.
Roy Monumental Works.

BEEBE PLAIN.

Haselton, C. S.
Sims, W.
Stanstead Quarries Co., Q.
Viznau, C.

CHELSEA.

Brocklebank Granite Co., Q.

CONCORD.

Lillicrap, E. & Co.
Lillicrap, J. & Co.
Moose River Granite Co.
Smith, L. E., Granite Co.

GROTON.

Barre Quarry Co., Q.
Groton Quarry Co., Q.
Hendry, G. H.
Hosmer Brothers.
Main, James.

HARDWICK AND WOODBURY.

Ambrosini & Co., Q.
American Granite Co.
Amick, H. A.
Calderwood, F.
Couhig, M. J.
Eureka Granite Co.
Fletcher, E. R., Q.
George & Somes.
Good, P.
Guaraldi & Co.
Hay, John.
Hardwick Polishing Co.
James Granite Co., Q.
Murch, E. R.
Nunn & Fordyce.
Ralph & Co.
Robie, L. S.
Thomas & Co.
Vermont Quarries Co., Q.
Woodbury Granite Co.

KIRBY.

Burke Granite Co., Q.
Kirby Granite Co., Q.

MONTPELIER.

Aja Granite Co.
American Granite Co.
Arioli & Co.
Belluchi Granite Co.
Bonazzi & Bonazzi, Q.
Capitol Granite Co., Q.
Columbian Artistic Granite Co.
Desilette Granite Co.
Doucette Brothers.
Doyle Granite Co.
Eastern Granite Co.
Eureka Granite Co.
Everlasting Granite Co.
Excelsior Granite Co.
Gill, C. P. & Co.
Green Mountain Granite Co.
Higuera Granite Co.
Johnson Granite Co.
Jose Ortez Granite Co.
Jurras Granite Co.
Lawrence Granite Co.
LeClerc, R. A.
Liberty Granite Co.
Lillie Granite Co.
Lucie Granite Co.
Menard & Erno.

Mills & Co.
Montpelier Granite Works.
National Granite Co.
New Star Granite Co.
Ortis Granite Co.
Pellon Granite Co.
St. Onge & Son Granite Co.
Sheridan & Poole Granite Co.

MORRISVILLE.

Mould, F. W.
Union Granite Co.

NEWPORT.

Lacasse, L. J., Q.

NORTH DERBY.

Barry, Charles.
Culman & Johannson.
Parmenter, Walter.
Wilkinson, Frank, Q

NORTHFIELD.

Chase Granite Co.
Cross Brothers Co.
Dog River Granite Co.
Howe, F. L. & Co.
Northfield Granite Co.
Pando Granite Co.
Pelaggi & Co.
Phillips & Slack Granite Co.

Politi Granite Co.

RIVERTON.

Davis Brothers.
Provost Granite Co.

SOUTH RYEGATE.

Beaton Granite Co.
Beaton, J. F.
Craigie, James.
Charidia, E.
Farquharson, R.
Gibson, C. E., Q.
Gandin, Louis.
Heartz, J. L.
McKinnon, J.
McDonald Co., M. F.
Rosa Brothers.
Rosa, C.
Star Granite Co.
Samuelson, H. & Son.
Zambon, Peter, Brother & Son.

WATERBURY.

O'Clair, C. L.
Perry Granite Corp.
Union Granite Co.

WILLIAMSTOWN.

Jones Brothers Co., Q.
Williamstown Quarry Co., Q.
Williamstown Granite Co.

SLATE.

As has been already noticed, slate is found in various parts of Vermont, on both sides of the Green Mountains, but the main slate belt is almost wholly in Rutland County, on the extreme western border, and from this area comes all the slate that is at present quarried. Here slate of many shades of color are found, purple, green, gray, mottled green and purple, but no clear black nor red, though just across the New York line near Granville, plenty of red slate is quarried. Still, red slate is much less abundant than green or purple.

Those especially interested in slate are referred to a thorough study of the *Slate Belt of Western Vermont,* by T. N. Dale, which is published in the Annual Report of the U. S. Geological Survey, Vol. 19, 1891. Also in Bulletin 275, U. S. Geological Survey, Mr. Dale gives some account of *Slate Deposits and Slate Industry of the U. S.* In the Fifth Report of the Vermont State Geologist, page 8, one may find a brief account of the slate industry of Vermont, also in each of the Biennial Reports of the Vermont Geologist.

As the list of slate companies shows, there are fewer than in the granite industry, but still a considerable number. I am indebted to Messrs. Auld and Conger for revision of the following list:

LIST OF SLATE COMPANIES.

CASTLETON.

P. F. Hinchey & 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.
Stoss Milling Company. Ground slate. Office, Poultney.

FAIR HAVEN.

C. R. Beach Slate Company. Purple.
Clark & Flanagan Slate Company. Quarries. Mill stock and roofing. Unfading green, purple, mottle, gray.
Durick, Keenan & 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 mottle purple.
Old English Slate Company. Quarry. Roofing. Mottle 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 State Company. Mill stock only.

POULTNEY.

Auld & Conger Company. Quarries in Vermont and Pennsylvania. Roofing. Weathering green, unfading green, sea green, purple, mottled.
Cambrian Slate Company. Purple, sea green. Office, Granville, N. Y.
Donelly & Pincus Slate Company. Quarries. Roofing. Unfading green, purple, mottled.
General Slate Company. Quarries. Roofing. Sea 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.
Staso Milling Company. Ground slate only.
United Slate Co. Roofing. Mottled.
Vendor Slate Company. Quarries. Roofing. Sea green, mottled, purple, gray and unfading.

WEST PAWLET.

Rising & Nelson Slate Company. Roofing. Sea green.

WELLS.

O'Brien Brothers Slate Company. Quarries. Roofing. Purple and sea green.
Burdette & 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 & 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.
O. W. Thomas. 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. Purple, red, green.

MARBLE.

The area from which nearly all the commercial marble of Vermont is obtained lies not far from that furnishing the slate, in the eastern part of Rutland County. As has been shown in former Reports, within this limited area many varieties of marble are found. A small amount of marble is found south of Rutland County and a small amount north, but by far the larger quantity is quarried here.

Mr. T. N. Dale has written two Bulletins of the U. S. Geological Survey, *The Commercial Marbles of Western Vermont*, No. 521, and *The Marbles and Limestone of Eastern Vermont*, No. 589. By the courtesy of the Director of the U. S. Survey, these Bulletins are reproduced with all the original maps and illustrations in the Ninth Report of the Vermont Geologist, 1913-1914. In the same volume may be found much additional information as to the marble industry in Vermont and those wishing further information upon this subject are referred to the above works.

As the following list of marble companies shows, the number of such companies is very small compared with those producing granite or slate. There is no marble company in either this country or Europe as large as the Vermont Marble Company, which has its main offices in Proctor. I am indebted to Mr. N. C. Peterson for revising the list of marble companies.

LIST OF MARBLE COMPANIES, 1926-1927.

Clarendon Marble Company, Clarendon.
Eastman Marble Company, West Rutland.
Manchester Marble Company, East Dorset.
The Venetian Marble Company, Pittsford.
The Vermont Marble Company, Proctor, Rutland, West Rutland, Middlebury, Florence, Swanton, in all of which towns the Company has large mills; quarries at Proctor, Brandon, Danby, Dorset, Isle La Motte, Manchester, Pittsford, Rochester, Roxbury, Swanton.

TALC AND SOAPSTONES.

As those who have read the Geological Reports immediately preceding this have noticed there has been considerable fluctuation in the amount of talc sold in Vermont during different years. Of late this has increased.

The companies producing this material in Vermont are as below:

LIST OF COMPANIES PRODUCING TALC.

American Mineral Company, Johnson.
Magnesia Talc Company, Waterbury.
Eastern Talc Company, Main Office, International Trust Co. Building, Boston, Mass. Mines, East Granville, Rochester.
Vermont Talc Company, Chester Depot.
American Soapstone Finish Company, Chester Depot.

LIME AND LIMESTONE.

Very little limestone to be used in building is sold in Vermont. Most of what is quarried is burned to quicklime. The value of such lime sold in the State amounts to not less than $500,000.

A list of Vermont companies that are now, or have recently produced lime are as follows:

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.

NOTES ON THE GEOLOGY OF THE TOWNSHIPS OF BRISTOL, LINCOLN AND WARREN

CLARENCE E. GORDON.

INTRODUCTION.

The studies presented in this paper are distinctly preliminary in their nature. They deal with a region that is so complex that it is difficult to reach conclusions. The hard rocks, as they may be called in order to distinguish the bed-rock formations from the surface mantle, are all more or less crystalline and usually thoroughly metamorphosed. In most cases they give but a faint suggestion of their original nature. The relations among them are obscure. They form a part of a broad belt of greatly altered rocks which extends lengthwise through Vermont, and joins with similar rocks in Massachusetts at the south and in Quebec at the north. In Vermont they belong to what may be called the Green Mountain province.

The Green Mountain plateau is bordered on the west by a lowland region, which in its northern portion is known as the Champlain valley, or Champlain lowland, and in its southern part as the Rutland valley. The latter is frequently referred to as the "Valley of Vermont." The plateau stands in contrast to the lowland, (1) in the types of rocks, and (2) in respect to the degree of alteration and disturbance which the rocks have suffered. In the upland the prevailing rocks forming the present surface are schists and gneisses of various kinds, some of which are altered igneous rocks. In our area calcareous or dolomitic rocks are rarely present in the upland. In the lowland, not only in the part within our area, but practically throughout its eastern portion, the surface rocks are dolomite and quartzite, with some marble. As will be discussed more fully later in this paper, and as has been explained in other papers of the writer, the quartzite is often associated with schist which seems to be a normal member of the quartzite formation; but gneisses are absent in the lowland and igneous rocks are present only as basic dikes which are comparatively recent in origin.

In common with other portions of the western border of the plateau our area shows a pronounced physiographic break between the plateau and the lowland; but a transition is found, both physiographically and geologically, in the front range of hills, which

are flanked on the west by more or less massive quartzite. Similar quartzite, or an associated dolomite, forms the adjacent eastern portion of the lowland.

Elsewhere the writer has offered evidence in favor of the idea that the Champlain lowland and the Rutland valley are really structural in their genesis; that they are, in fact, the results of displacement due to differential movement on a large scale whereby the formations which make up the present lowland, together with the rocks which erosion has removed from it, were, in effect, downfaulted with respect to the rocks which form the bounding upland. The present physiographic contrast is not due, however, to this displacement, but to a more extensive erosion in the region that now forms the lowland. This idea of displacement has supplied the basis for the interpretation of field relations which have been observed along the western margin of the plateau and in adjacent portions of the lowland at many places and for a recognition among them of a common type of deformation.

Out of studies made in the lowland and along the plateau margin there very naturally grew an interest in the question of the extent to which the lowland types of rocks might be traced into the plateau. In approaching this problem it was not apparent that one area offered any advantages over another and the one chosen and discussed in this paper was selected largely as a matter of convenience. As the field work progressed it became apparent that the lowland rocks could not be followed distinctly very far eastward and the problem developed into one of trying to determine the relations of the various rocks which were found to the lowland types in the front range and to each other. The results were not eminently successful; but certain things were noted which it seems worth while to set down.

It has not been thought practicable to present a map of the area under discussion. While definite types of rock may be recognized the boundaries among them are always very indistinct. Over large areas the surface material conceals the bed rock. Explanation of the distribution of the rocks will be, therefore, wholly verbal.

It may be well to advise the reader, who is not familiar with the general region, that neither the word upland nor the expression lowland is to be construed to mean a region of uniform elevation; the upland is deeply dissected and the lowland surface is irregular and studded with hills. Nevertheless, there is a strong contrast between the two physiographic divisions, which is readily apparent from an examination of topographic maps, but which comes out very strongly when the lowland is viewed from the summit of one of the peaks of the Green Mountain range. From such a vantage point the lowland appears as a huge trench extending for many miles between the plateau on the east and the

Adirondacks on the west. In the distance the minor irregularities are lost to view and the surface assumes the character of a vast plain, above which, however, there rise certain ridges which carry the imagination back of the present time, in which conditions speak of profound erosion, to an earlier one when the surface stood at a higher elevation, and still farther back to a time when other forces were in operation, great compressive forces that folded and ruptured the rocks.

Since the history of the region is concerned not only with the deposition of sedimentary rocks, the intrusion of igneous rocks, metamorphism, and deformation; but also with erosion, and other events, including glaciation, it is proper to consider various aspects of the general physiography of the region and the special topographic features of our area. These will be discussed before the subject of the hard rocks is taken up.

CULTURE.

Much of the country is rough and inhospitable and serves only for forest growth and pasturage; but following the pioneers who broke the wilderness there were gradually developed such industries as the region would support. In the western part of Bristol conditions are good for farming. In the eastern part farms have been developed in the valley of Baldwin Creek; but the hills are covered with a straggling forest cover. A small farming settlement has maintained itself on the hills of the southeastern part, around the head portions of Little Notch Brook.

Bristol village in addition to its function as a business center for a farming community supports a coffin factory which gives employment to many of its residents. The lumber comes from the hills of Lincoln and Ripton.

In Lincoln in spite of the irregular and rocky character of the surface there has been considerable development of agricultural land. The farming industry is still carried on, but the struggle to maintain it at many places is apparent and abandoned properties tell the story that is so common of the hill country of Vermont. Lumbering and lumber manufacturing were at one time important occupations and sources of revenue. Lumbering is not practiced much today by individual landowners, although some of these possess good stands of timber on the mountain sides. A lumbering project has been started within the last two years, with headquarters at South Lincoln village, but even under a thoroughly organized plan of operation, profits are small, largely because of competition from western sources. The lumber supplies local markets and those of the cities of Burlington and Rutland, but is seldom shipped to more distant points.

The development of Warren has followed the same lines as in Lincoln. Farming is the chief industry, but lumber manufacturing is practiced on a small scale.

The main roads of the district are excellent and many of them have been improved to accommodate automobile traffic. Lincoln and Warren are joined by a road through Lincoln Gap, which has an elevation of 2,424 feet.

LOCATION AND PHYSICAL GEOGRAPHY OF OUR DISTRICT.

As a means of explaining somewhat the nature of the problem which the region seemed at first to present, mention was made in the introduction of the general physiographic features. It remains to specify the chief topographic features of our district so that the discussion of it in its several aspects may be more readily followed.

The western part of Bristol township includes a portion of the eastern margin of the Champlain lowland. In this portion the elevation is seldom above 500 feet. The extreme northwestern part of the town includes the southern portion of a ridge that projects into Bristol from the town of Monkton. In this part the surface reaches an elevation of 1,000 feet. The eastern part of the town includes a portion of the front range of hills of the plateau. The topographic break with the lowland is sharp, and marked by steep scarps. A deep gap breaches the range east of Bristol village. New Haven River flows through this gap into the lowland. North of the river the western margin of the plateau has the form of a sharp ridge called "Hogback." South of the river is a broad dome known as "South Mountain." East of Hogback is the valley of Baldwin Creek. Eastward the surface rises to form the hilly land in the northern part of Lincoln township. East of South Mountain the surface slopes to the level of New Haven River in Lincoln which, for the most part, occupies a valley between the front range on the west and a group of higher summits belonging to what is called the main range, or Green Mountains proper. In these latitudes the western slopes of the main range and some of the summits are in Lincoln; the other summits of the main range and the eastern slopes are in Warren township which adjoins Lincoln on the east. The town of Warren for the most part also occupies a valley which lies between the main range on the west and another on the east known as the "Northfield Mountains."

The highest point in Hogback is 1,850 feet above mean sea level; that of South Mountain is 2,307 feet. The average elevation of the surface intervening between the front range and the main range in the township of Lincoln is perhaps about 1,400 feet. In the northern part of Lincoln the surface at a few places rises to 1,800 feet, and at Hillsboro Mountain in Starksboro it reaches 2,500 feet. New Haven River in Lincoln is about 1,000 feet above base level. By these citations the uneven character of the surface of the upland between the western margin and the main range is brought out.

In the main range, within our area, are some of the highest peaks in Vermont. The summit called Mt. Abraham (also known as "Potato Hill" and "Mt. Lincoln") is 4,052 feet high. Eastward in the valley of Warren is another irregular surface of about the same average elevation as that of Lincoln. The summit ridge of the Northfield Mountains is about 2,800 feet.

DRAINAGE AND ITS RELATION TO TOPOGRAPHY.

Thinking now of bed-rock formations and ignoring for the present the material of the surface mantle, it is important to understand that the present topographic features of our district, and the physiography of Vermont in general, are the results of differential erosion by agents which wear down the land. Such a statement implies a rock surface standing above the level of the sea and that this surface was attacked by certain agents which break down rocks and other agents which assist in this process and carry the products of rock destruction away. While the work of ice in the form of a massive, moving continental glacier played its part the dominant factor in shaping the surface of the land was running water. It is largely in terms of this agent that the major topographic outlines of our area are to be interpreted. The relatively great erosive work accomplished by agents of the weather and running water acting over a great interval of time, and the relatively small amount of erosion by moving ice acting over a relatively much shorter time, are facts not appreciated by those who, when contrasting the apparent efficiency of different agents, fail to reckon with the time element. At the stage of development which the upland portion of the district now shows it is not difficult to trace the relation between the topography and the distribution and work of the streams and to discern that all the grand features of the landscape were already present when the ice-sheet invaded the region.

It is necessary to qualify what has been said by explaining that our district, in common with the upland region as a whole, possesses features due to erosion that belong to more than one cycle of uplift and stream rejuvenation; that the picture, in other words, is a composite one. But this statement does not affect the general assertion that the physiography is, broadly speaking, the result of streams wearing their channels into the land. It will be better to consider such records as seem to exist regarding early changes due to uplift and denudation under a separate heading and to speak now only of results effected by the recognizable antecedents of the present streams.

The main range as it crosses our area forms a divide between waters that flow westward through New Haven River and Otter Creek into Lake Champlain and other waters on the east side of the range which feed Mad River and reach Lake Champlain through the Winooski River.

New Haven River, which heads in Ripton, south of Lincoln, on a divide that parts its waters from tributaries of Middlebury River, flows northwesterly across the western part of Lincoln township. In Lincoln it receives many tributaries which drain the northern and eastern slopes of South Mountain and others which drain the eastern slopes of the main range. The main stream and its branches had formed in preglacial times a great amphitheatre among the hills. The still somewhat youthful topography of the valley floor and the adjacent slopes with the rugged summits roundabout give the country much scenic charm. From Lincoln the main stream flows in a narrow valley which cuts through the front range. This valley was carved by the river during the same time that its headwaters were excavating the basin in which the town of Lincoln lies. Both valley and basin, therefore, represent the work of erosion of the New Haven River system as the streams sank their channels into the land. The old surface on which the river began its work has disappeared, of course, but it is still roughly represented by the higher summits that make the front range of hills and by isolated hills lying east of the front range, between it and the main range. These considerations enable one to visualize a former surface of probably more nearly level character than the one that now exists, and to recognize the various summits as remnants of erosion.

New Haven River emerges from the upland at Bristol village. South of the village it takes a southwesterly course across the lowland and joins the Otter in New Haven township. In the southwestern part of Bristol the river receives a tributary which may be called the "Little Notch Brook." This drains the western slope of the front range in the southern part of Bristol.

Small streams from the western slope of Hogback Mountain supply Bristol Pond, which lies in the middle of a swampy tract which occupies a depression at the western foot of Hogback north of Bristol village. The depression referred to is due directly to erosion, but is primarily structural in genesis in the sense that it lies in a zone of faulting along the eastern limb of a downfold in the bed-rock formation of quartzite and overlying dolomite. The dolomite was removed by erosion, leaving a basin which lent itself readily to modification by glacial material and the formation of the pond. The pond is drained by Pond Brook which joins Lewis Creek in Monkton.

East of Hogback ridge is a north-south valley which is somewhat out of proportion to the size of the stream which drains it, and which separates the ridge from the hilly land at the east. This valley lies along the axis of a downfold in the quartzite-dolomite formation and is directly due to the erosion of the magnesian rock, but in the same sense as explained above it is a structural valley in its early genesis. The valley is occupied in part by the lower portion of Baldwin Creek which enters the valley from a gorge in the hilly land lying at the east. At the point where the creek enters the north-south valley it is joined by Beaver Brook, which heads farther north in the valley on a divide that separates its waters from the head stream of Lewis Creek. From the point of junction with its tributary, Baldwin Creek flows southward and joins New Haven River at Ackworth.

The gorge occupied by the head portion of Baldwin Creek has been cut by the stream across the strike of the foliation of crystalline schists and similar rocks. The gorge seems clearly to be a preglacial feature. The narrow character of the gorge in contrast to the wider valley which it joins may be attributed to the generally resistant character of the schists in part and partly to the fact that the stream as its sawed its way through rocks of varying resistance was controlled at all times by the more resistant materials. In the wider valley streams worked in less resistant and more uniform material and were able to work faster and achieve greater results.

East of the main range the waters of Mad River flow northward on their way to join those of the Winooski. Mad River heads in the town of Granville, south of Warren. The main stream is fed by many tributaries which drain the eastern slopes of the main range and the western slopes of the Northfield Mountains. In preglacial times this river system carved out the broad valley of irregular surface which extends from Warren northward through Waitsfield and Moretown to the valley of the Winooski River. Within this valley the bed-rock topography is still in a somewhat youthful stage.

EARLY PHYSIOGRAPHIC HISTORY OF THE GENERAL REGION.

The present physiographic features of Vermont, in their bed-rock outlines, are viewed by some students as the result of erosion by streams and by the agents of the weather of an old surface which in a previous cycle had been produced by the activities of similar agents which reduced the land to a condition of low average relief not very far above sea level. According to

this view this ancient, worn-down surface was elevated by a slow, warping movement of the crust and the streams, rejuvenated by uplift, set to work to reshape the surface. In the course of time they have produced the present physiography. The physiography of today may be regarded as a stage in a cycle that began with the elevation of an old base-leveled region and which would if the land, so to speak, should stand still long enough proceed to a condition of reduction of the surface again to one of the low average relief near sea level.

The considerations which seem to justify the ideas of an old base-leveled region and its subsequent elevation rest upon more than one kind of evidence. To the reader unfamiliar with rock structures of different kinds and the interpretations which geologists put upon them it is desirable to point out what seems to be the significance of certain kinds of structure in respect to the physiographic history of the region. In Vermont the structures shown by the rocks taken with certain surface features give substantial support to the ideas which have just been stated, especially since comparison can be made with other regions which are now reduced to featureless plains at a level which is close to that of the sea and in which the rocks show structures like those found in high mountains. Not all mountains, of course, have the same kind of structure. The mountains spoken of in this connection are those which presumably were produced by folding and fracture of rocks under the action of powerful compressive forces.

The structures of the rocks in Vermont, both in the lowland and the upland, go to show that in the long-distant past mountains probably much higher than those of today existed over what is now Vermont. In other regions where high mountains exist today, structures similar to those which characterize our Vermont rocks are found so that the inference is strong that mountain building is distinguished by elevation and the production of certain kinds of structure. In the cases of definite kinds of structure the belief is justified that they could have been produced only under conditions of considerable depth beneath the surface and under a load of overlying material. For such structures to be exposed now at the surface there presumably must have been a vast amount of erosion. Since the kinds of structure that belong with depth are found on the summits of the present mountains of Vermont it would follow that these mountains, in their present form at least, are not the direct result of the folding of the rocks under powerful compressive stresses; that is, the present mountains of Vermont did not acquire their physiographic relations to other parts of the surrounding surface by the action of the forces which produced their structures. In the interpretation of the history of our region such considerations are vital, because they show that we must reckon with the fact of extensive erosion, not only in those portions of Vermont which now exist as valley or lowland regions, but what is more significant also in the highest mountains of the State. On the basis of the metamorphic character of the rocks that compose the present surfaces of the valleys and the lowlands there remains little doubt but that, if these various hollows were filled again with the rocks which were removed in the course of their formation, the restored surfaces would be made up of rocks similar to those now found within them. By this line of approach the conception is gained that the present cycle of physiographic development in our general region began at a surface composed of rocks that represented the deeper parts of ancient mountain masses, and that the mountains of today are not structural in origin but residual.

What has been said regarding ancient mountain building in Vermont constitutes only a general statement. Doubtless the forces that produce such structures as we find in our rocks have operated more than once in the region and some of the rocks have therefore participated more than once in the formation of mountains; but the structures in the rocks everywhere tell us that, whatever may have been the events of folding and erosion antecedent to the last great episode of mountain building in our region, we need apparently to reckon only with the deformations of the youngest rocks in applying the considerations that have just been outlined. Among some of the rocks, as will be suggested again later, we can hardly hope to differentiate between structural features which are very ancient and others which are probably much more recent. If we could, the problem of the age relations among the rocks would be much more easily solved.

In addition to the evidence which the structure of the rocks gives in support of the idea of destruction of high mountains and extensive wearing down of the land prior to the present cycle, one finds further suggestion in the physiography and the drainage. If one stands upon one of the higher summits of the Green Mountain upland one views a succession of peaks and ridges, some nearby and some remote, whose summits, if joined in imagination across the valleys that intervene, seem to belong to an irregular surface whose major elevations are of the same order of magnitude above a hypothetical plane lying somewhere, but not very far, above or below the general level of the lower summits. The accordance in summit levels, not perfect, to be sure, but approximate, taken in connection with the fact that the summits universally show profound erosion may be conceived to indicate a former surface of rather uniform relief produced by erosion, which according to our present notions is a condition which could have been produced only near base level. Assuming that the present summit levels have the significance just suggested it is necessary to conceive that the hypothetical plane mentioned above was once lower than now, that, in fact, it once corresponded with the extension of mean sea level beneath the surface of the land.

The significance which seems to follow from such accordance of level as the mountain summits show proceeds not only from such agreement in level, but also the fact that the summit surfaces are erosion surfaces on rocks that seem to belong to mountain cores. Erosion truncated mountains through their roots.

With some observers the skyline of the mountains of our region might not possess the significance which, by implication, has been claimed for it in the previous paragraphs. It is necessary to grant some imperfection of form, but in this connection there are other considerations that need to be reviewed. In the first place, the reduction of the land might not have proceeded to a condition in which a fairly regular surface of uniform relief was formed, but instead erosion was interrupted by elevation. In such case the region might be thought of as perhaps very generally eroded to a lowland while some parts, because of greater resistance, or for some other reason, retained a comparatively high altitude when the land began to rise. Such a situation is not only possible, but probable, so that one could consider that the present cycle might have begun with certain irregularities already present. In the second place, erosion after elevation would have been differential as a result of possibly several factors involved so that (1) initial irregularities might have been accentuated, or (2) irregularities would have been introduced, on this account. Moreover, elevation might not have been continuous, or nearly so, but on the contrary might have been interrupted by halts, which might have been of varying duration. Some one or more of these halts might have been long enough to leave a record in the topography. If one of these came early enough and lasted long enough, an intermediate level might have been formed not far below the initial one, which, after subsequent elevation and erosion, would leave new topographic features similar to older ones and not easily distinguished from them as to age. It would seem, therefore, that it is possible in several ways to account for some imperfection of form in our region at the present time of an upraised base-leveled surface.

The drainage of a region often affords some clue to its physiographic history. Certain features of the drainage of Vermont may be discussed for whatever suggestion they may afford in this connection.

Several large streams wind through the plateau for many miles in courses more or less at right angles to the structural axes of the rock formations. These streams, now deeply intrenched in the plateau, apparently have their present paths because they formerly wandered over an old surface which was so much reduced by erosion and modified by it that the streams developed courses more or less independently of the structure of the bed-rock. They sank their channels where they chanced to be flowing when the land was elevated. Intrenched meandering streams are rightly regarded as good evidence of the development of a mature topography and subsequent elevation of the land.

In the southern half of Vermont the streams which cross the plateau to join the Connecticut appear to have sunk valleys on a southeastward-tilting slope as the crust was slowly warped. The slow nature of the tilting movement would seem to be attested by the apparent fact that certain streams which feed the larger rivers and which have courses more or less in line with the structural axes of the rock formations have kept pace with the master streams in their down-cutting, which, even in view of their relations to the structures of the rocks, would not probably have been the case if tilting went on at a relatively rapid rate, because of less erosive power in the tributary streams and because tilting would have affected their slopes in less degree on account of their direction.

In the northern half of Vermont the larger streams which cross the plateau have westerly courses, and at the present time empty into Lake Champlain, but several smaller streams in the easterly portion of this northern part flow in a southeasterly direction to join the Connecticut River in courses roughly parallel to the larger rivers which drain to the Connecticut farther south. And the relations which the easterly-flowing streams of northern Vermont have to the head streams of the rivers that flow to the west offer a suggestion that perhaps some of the drainage that formerly found an outlet to the east has been appropriated by more powerful westerly-flowing streams.

At the present time a distinct but irregular divide may be recognized as extending throughout the length of the State, which parts the drainage that flows eastward to the Connecticut and that which seeks the Hudson River and Lake Champlain, but whether this has always been the case is hard to tell. In the southward continuation of the Green Mountains, in Massachusetts, between Hinsdale and Becket, is a gap which Professor Emerson has described as too deep to have been formed by the streams which now head there. He has explained this "canyon" as part of the valley of an ancient stream that headed "far to the west" and flowed easterly across the plateau. Yet, in northwestern Massachusetts the Green Mountains now form the divide between waters that flow easterly to the Connecticut and others that flow westerly to the Hudson.

In Massachusetts the summit levels of the Green Mountains have a more uniform elevation than in Vermont, and thus present a more evenly-developed plateau character. Wind gaps, representing old stream valleys, might conceivably be more easily recognized in Massachusetts than in Vermont, where the ancient surface that is thought to correspond to the plateau of western Massachusetts was presumably not worn down to such uniformity of level, and presented a more broken skyline from the start.

Proceeding now from the idea that the present erosion cycle began with the uplift of an old worn-down region whose surface had reached a condition of advanced maturity throughout and perhaps in great part or in considerable measure that of a lowland of low relief—which is a conception that in the writer's mind seems to be fairly well supported—it is possible to imagine that, as the land was raised in the region which is now western New England, the surface was warped in such way as to give a bulge along what is now the major ridge and divide of the Green Mountains and that the surface from the first had a slope to the east and another to the west. The suggestion which Professor Emerson made of a divide lying far to the west, argues, so far as it goes, against such a view; on the other hand, the present drainage arrangement seems to stand in favor of it. But in the development of the present drainage west of the plateau in Vermont and, at least to some extent, also in Massachusetts, certain probable factors seem to have much significance and a consideration of what their influence may have been may serve to discount somewhat the suggestion given by certain topographic features of the present day.

The surface of the Champlain lowland is composed of rocks which, for the most part, are relatively much less resistant than the rocks of the plateau. These lowland rocks probably are safely interpreted as remnants of great masses of similar rock that once filled this great trench and whose surface was at one time a part of the general base-level which the higher elevations of the plateau are conceived to represent. The Champlain lowland joins at the south with a narrower trench, known generally as the "Vermont Valley." The surface of this valley is made up of rocks like those of the lowland and the history of both as physiographic features of the present landscape was probably essentially the same.

Now, it is not difficult to imagine that in an early stage of the present cycle some of the streams that flow from the plateau in a general easterly direction headed farther west than now on a surface which is gone, and that as the land was raised and the drainage on the less resistant rocks in what are now the lowland portions of the state was gradually developed the head streams of the rivers that flowed to the Connecticut were appropriated and diverted. If such has been the history the appropriation referred to must have been effected very early, for no discernible evidence of such conditions as have been suggested apparently exists in Vermont.

The present conditions indicate that the Hudson and Champlain waterways have existed from ancient times, that they were doubtless well-established drainage lines at the beginning of the present cycle, and that they have been powerful agents of erosion throughout the period of development of the present physiography. The evidence of their power is found in buried channels whose existence has been discovered by borings in certain parts of the Hudson River valley and by soundings in Lake Champlain. As shown in other parts of New England, notably in parts of the Connecticut River valley and in certain stream valleys of eastern Massachusetts, there was relatively rapid uplift of the region in late preglacial time. Then the master streams made gorges in the rising land and often sank their channels more rapidly than did their tributaries. Later the land sank and the bottoms of these gorges were carried below sea level.

In eastern New York and western Vermont the masterful Hudson and Champlain Rivers early in the present cycle would speedily have impressed their lateral drainage on the territory adjacent to them. As the land rose the erosive work of tributaries would have been accelerated by the rapid down-cutting of the main rivers and by the relatively easily-yielding character of the material in which they had to work in many instances.

The effect of the nature of the rock in the process of erosion comes out in a study of the contrast afforded by the broad Vermont valley and the incisions made in the Taconic upland lying west of it by streams which head in the valley and flow through the upland. The Taconic upland is composed of crystalline rocks similar in their resistance to those which make up the plateau on the east. The valleys which cross it are relatively narrow. That portion of the floor of the Vermont valley which is drained by streams which cross the upland could hardly have been lowered faster than these streams sank their channels in the upland rocks. From such a study one is able to understand that the difference in topographic aspect between upland valleys and the broad lowland of the Vermont valley is not due to longer time of erosion in the lowland, but to a difference in the character of the rocks.

Several lines of reasoning converge upon the idea that certain physiographic features of Vermont were shaped simultaneously and that the different stages of topographic development which one sees are due to differential erosion which depended upon several factors. The gorges of the mountain streams on the east side of the Vermont valley are still in youthful stages of development; but the streams which occupy them presumably began their work as early as did the streams which flow through the valley. Some of these mountain streams at an earlier time may have been the head portions of the rivers that now flow through the Taconic upland to reach the Hudson or Lake Champlain and other streams that traverse the lowland may have been tributary to them. The tributaries that flow through the lowland developed their drainage on belts of yielding rocks and early assumed the principal rôle as feeding streams, and are now, in fact, recognized as forming parts of the main rivers.

The westward drainage, pushing its headwaters rapidly eastward by virtue of the low resistance of the material in which the streams did their work, may have shifted the divide between the Hudson-Champlain and Connecticut River systems.

In a previous paragraph the suggestion was made that in the course of uplift of a region it would not be extraordinary, perhaps, if there were one or more halts which were of sufficient duration to permit the partial development of new base levels. Within the upland portion of our area there seems to be some suggestion of the occurrence of a period of relative still-stand of the land—apparently not very long after uplift began, as one speaks of geological events when the duration of time involved is so vague. The record is faint—if indeed what appears to be a record is such—and largely destroyed. Its recognition within our area may be largely a matter of imagination, and yet observations that have been made elsewhere in Vermont and studies of conditions in southern New England, would lead one to look for vestiges of conditions produced by periodic changes in rate of uplift.

Mt. Pleasant with an elevation of 2,000 feet and a neighboring hill that rises twenty feet higher, in the northern part of Lincoln, correspond in summit level with Prospect Rock and sister hills near South Lincoln village and with other unnamed hills near the southern boundary of the town. To the eye these detached hills look like somewhat reduced elements of a surface whose vestiges appear to be recorded by the summits of the lower, gentler slopes of the main range and by occasional isolated summits in Starksboro and Ripton, which now stand at the elevation of about 2,500 feet. The activities of the tributaries of New Haven River in Lincoln may be regarded as accounting for the somewhat lower summits that encircle the amphitheater in which Lincoln lies. By building up these summits and filling in the valleys there would seem to be restored a surface at about the 2,500 feet level which would embrace most of those higher summits which stand below those which form the main range, and which, by reason of the general accordance in level and maturity of slope of the higher portions, might be considered to mark a partial base-level produced between ridges of higher land after the region had risen perhaps 500 or 1,000 feet at the beginning of the present cycle.

On the east side of the main range, in Warren township and in the townships of Fayston and Granville, what appears to be a corresponding level is marked by outlying portions of the main range and by some detached hills, which are distinguished by mature slopes in their summit portions.

It does not appear to be difficult to account for the present, and after all not very great, difference of altitude of the various summits that appear to represent a partial, intermediate base-level. Most of the isolated hills would seemingly have suffered more reduction than would lower slopes of the higher ridges and the masses which remain more or less attached to them, during the erosion that followed a renewed elevation.

In its highest portion, which is 2,307 feet, South Mountain approximates the hypothetical level just discussed. Elsewhere, except on the steep western scarp, most of the surface of the mountain ranges between 1,800 and 2,000 feet. Hogback is only 1,850 feet in its highest part. These masses, though adjoining the Champlain lowland, have withstood reduction because of protection by a covering of very resistant rock.

If during uplift of the region there occurred such a halt as has been suggested, presumably there would have been developed over what is now the Champlain lowland a surface corresponding to that which is thought to be recorded in the upland; but in the lowland region, on account of the weaker character of the rocks no record is now left. The higher hills which occur in the lowland are remnants of a former surface, without doubt, but more than this it is not possible to state.

Within our area the more youthful expression worn by the lower contours of certain portions of river valleys indicates a time of relatively rapid uplift late in that part of the region's history preceding the coming of the ice. Most of the rock cuts and falls seen along the streams of our area today are probably postglacial; but in spite of the drift which fills the old preglacial channels one may discern, particularly along Mad River, youthful outlines at many places which are in contrast to more mature higher slopes. This evidence of acceleration in rate of uplift in late preglacial time, within our area, falls in line, of course, with the evidence that has previously been cited. The idea is strengthened by features which exist at different places in the upland, as noted by the writer in frequent journeys through it. Narrow valleys or gorges, frequently known as "gulfs," which are apparently largely preglacial and which were made by small streams cutting into divides between larger rivers seem to mark a time of relatively rapid elevation. Mad River heads in one of these in the town of Granville.

GLACIAL HISTORY OF THE REGION.

It is now known that in comparatively recent geological time the northern part of our continent was covered with a thick mantle of ice. The record of the existence of the ice is now found in certain effects produced by it on the bed-rock and in the deposits of one kind or other which it left either during its advance or in its retreat.

Erosive Work of the Ice.—The direct action of the ice is manifest in the rounded, smoothed or scratched surfaces of the bed-rock over which it passed, for in the areas which it covered the ice was a moving mass, and carried in it fragments of rocks which it picked up on its way and which it used to abrade the underlying rock.

Within our area distinct marks on the rocks made by ice-borne tools were not often seen, because of weathering of surfaces from long exposure. Presumably beneath the surface mantle protected ledges still bear the clear evidence of the scratching and gouging which such tools accomplish. The rounded character of the summits of the hills and mountains is probably due in some measure to the work of the ice and this fact must not be ignored, of course, in studying the present character of the summit slopes.

In the eastern part of Warren, scratches or striae occur at two different places and give readings, respectively, N. 10° W. and N. 15° E. (magnetic), indicating a general southerly movement of the ice. But in West Warren, in the valley of Lincoln Brook, marks which appeared to be glacial, occurring on a freshly exposed surface along the Warren-Lincoln road, had practically an E.-W. trend.

Deposits of the Ice.—The material left stranded over the bed-rock surface by the ice as it melted is called the ground moraine. Within the upland the slopes of the ridges and the higher elevations within the valleys are mantled with deposits of the ground moraine, consisting of typical boulder drift, and presumably laid down in greater part by the ice during the time of its retreat. Similar material fills old rock valleys and is frequently exposed in cuts made by streams. The ground moraine differs considerably in thickness at different places. It has undoubtedly modified the outlines of the bed-rock surface on which it lies. In Lincoln and Warren valleys outwash deposits from the melting ice at higher levels and terrace plains of sand and gravel at lower levels often cover and conceal the ground moraine.

Accumulations which could safely be interpreted as definite boulder-filled terminal moraines formed at the ice-front and as marking a notable pause in its retreat, were not noted.

Boulder "drift," belonging to the ground moraine and consisting of unsorted materials, grading from sand and gravel to blocks of rock of different sizes, was noted at numerous places. The boulders, which are to be regarded as stranded masses formerly held in the ice, occupy different levels in the drift, depending on their original position in the ice. The finer material which surrounds them probably was moved somewhat by glacial streams, although probably not very far. Concentration of boulders has occurred by the washing away of finer materials.

Excellent development of boulder drift occurs on "Gove Hill," in Lincoln, west of New Haven River, especially at the northern end; on the wooded eastern slopes of South Mountain; on the higher land near South Lincoln village; and on the western slopes of the main range in the eastern part of the town. The better exhibition of the ground moraine material on the west side of the valley in Lincoln would seem to be correlated with the way in which the ice retreated from the surface of this township. Border drainage and glacial ponding operated to modify the surface of the moraine in the eastern part of Lincoln. On the higher slopes west of New Haven River these factors were absent.

Ground moraine material was noted at different places in Warren, particularly on the wooded east slopes of the main range and on the higher portions of the foothills. It is doubtless frequent in the bottoms of old rock valleys, where it is now sometimes exposed as thick masses by stream cutting.

In the formation of that portion of the ground moraine which was left as a mantle on the surface when the ice retreated, one must think of the water streaming out from the ice as always effecting some modification in deposition. On the higher elevations presumably there would have been but little movement or assortment in the finer material, but in places where water was concentrated there might have been considerable movement and assortment, as is apparently shown in places where the water from the melting ice presumably flowed more or less as a stream between the edge of the main mass of the ice and a high ridge of land, or between the edge of a small tongue of the ice and some hill slope. The ground moraine accordingly has variable character, depending upon the factors involved in its deposition, from purely stranded material it may pass into that which has been more or less modified by running water. Special conditions arise when the water instead of escaping as streams becomes impounded in front of the ice. In Lincoln it would appear that deposition of material contributed directly by the ice to streams going out from it and whose waters found free escape did not go on very long; instead as the ice retreated over Lincoln the water from the ice was early impounded in front of it. The same things seems to have occurred to some extent in the Waitsfield-Warren valley. The most interesting features of the mantle of surface material

are found in the deposits of gravel, sand and clay which were laid down in bodies of standing water. These are found both in the lowland and the upland. The fact of the existence of a standing water body in the lowland is supported by present conditions within our area.

The town of Bristol is situated on a plain that forms a portion of the surface of an old delta which clearly was built out by New Haven River into a body of standing water that submerged this part of the lowland. The delta form is well marked and has been recognized by various observers who have studied the region. Typical delta structure is shown in cuts that have been made for road materials.

With subsidence of the waters the river flowed over its old delta and sank its channel into it so that now one sees it divided into the broad flat extending north and west of the river, on which the main portion of the village stands, and a smaller area on the south side of the stream.

South of Bristol village is a broad plain whose surface is considerably lower than that of the delta and which slopes gently southward. It is known as "Bristol Flats." The river flows along its eastern edge. This plain has been interpreted as a later delta plain built by the river as the waters receded.

General Discussion of Postglacial Flooding of the Lowland.—The occupation of the region by the glacier is believed to have led to a depression of the land. As the glacier waned the land is known to have undergone changes in level. Differences of opinion exist as to the behavior of the land in late glacial and early postglacial times, that is, during the time the ice was retreating and subsequent to its retreat far to the north.

An early view as to the explanation and history of the water body that occupied the Champlain lowland during the time of the retreat of the ice-sheet from northern New England had a strong advocate in the late Professor Woodworth. Woodworth's discussion of the matter has been summarized by Merwin, whose account is here followed.

In the course of the retreat of the ice the southern end of a great ice-tongue that occupied the Champlain valley stood in the vicinity of the present divide between the Hudson and Champlain valleys. A body of fresh water, which has been called "Lake Albany," bordered this ice-tongue and drained southward. At a later time the southern part of Lake Albany drained away, but the waters of the northern portion of the lake were retained at a lower level by a barrier across the basin near Schuylerville, N. Y. This water body, held now between the barrier just mentioned and the ice-front gradually expanded, as the ice-front moved northward, and formed "Lake Vermont," or "Glacial Lake Champlain."

The highest level of Lake Vermont was determined by an outlet just east of Quaker Springs, N. Y. A gradual subsidence of the waters took place until by retreat of the ice an outlet about 100 feet lower was uncovered near Coveville, N. Y. The ice-front is thought to have stood at this time somewhere between Port Kent and Street Road, N. Y. The lake is believed to have held the level of this outlet for some time, until the ice-front as it retreated still further left open an outlet through the valley of Wood Creek, which took the drainage of the lake and lowered the level another 100 feet. This is the lowest outlet known for Lake Vermont. The subsequent lowering of the lake is thought to have been caused by escape of the water around or beneath the ice.

When the ice had withdrawn so that it ceased to form a barrier across the northern end of Lake Champlain the sea came in from the St. Lawrence valley owing to the fact that the land was depressed. The lake thus passed from a glacial water body to a marine gulf. The depression of the land is described as of the nature of a tilting, for the head of Lake Champlain was not then below sea level. The amount of depression at the present foot of Lake Champlain was about 450 feet. The record of the presence of marine waters is found in fossils of the deposits which were formed at this time.

After the sea came into the valley there was uplift at the north so that the shore lines which were developed during the marine stage were tilted southward at the rate of about 3.65 feet per mile. This tilted plain is regarded as the upper marine limit. All the higher shore lines are regarded as having been made during different stages of Lake Vermont. These have been uplifted, too, and now slope southward.

This view that the high level plains and deltas of the lowland region were built into a glacial lake has been disputed. There is no doubt but that part of the lowland has been submerged by the sea since glacial times, but the view has been advanced that the higher terraces and deltas were also formed in marine waters. Professor Fairchild has been the principal exponent of this view. He cites many observations to support his contention that glacial lakes were "incompetent" to produce the high level shore phenomena now to be found in various parts of the Champlain region.[1] His idea is that this region, and other parts of New England as well, were more deeply submerged by the sea in post-glacial times than is generally admitted. He contends that the absence of marine fossils from the high-level shore deposit does not necessarily indicate that they were not deposited in waters in open communication with the sea, and that it is an error to assume

[1] Post Glacial Marine Waters in Vermont, by H. L. Fairchild. Tenth Report of the Geologist, 1915-1916, pp. 1-41.

that all sea-level waters must be saline. The high-level waters of the Champlain region were fresh waters; that is, they were marine waters freshened by the glacial flood. It might be better to call them sea-level waters, rather than marine.

Professor Fairchild would interpret the high-level plains and deltas of the Champlain lowland, of which the Bristol delta is one, as structures built in sea-level waters and as now forming a part of an uplifted marine plane. In his opinion other observers have been misled in many ways; they have mistaken strongly developed inferior levels for summit features; they have overlooked the latter when they are "weak or detached"; they have failed accurately to interpret the nature of the warping of the marine plane during uplift and to note that high water levels exist in places where they are apparently absent and that these high levels may all be correlated with one another in a way that could not be done if they had been formed in glacial lakes.

According to Fairchild's view the Champlain waters were joined to the sea waters off southern New England through the Hudson valley region, and the Connecticut River valley was submerged by the sea a long way into Vermont.

The idea that the Champlain water body was a great glacial lake has lately received indirect support from the researches of Dr. Antevs, on conditions in New England during the deposition of the so-called varve clays.[1] For the deposition of these clays standing bodies of fresh water were necessary. These were supplied by the melting of the ice during the time of its retreat, and were, according to Antevs' view, lakes as distinguished from bays of the sea. This idea of a succession of lakes formed in front of the receding ice edge was hardly original with Antevs, but in support of this view difficulty had been found in providing barriers which would permit large bodies of water to be impounded in front of the ice in valleys which it seemed must have drained to the sea. As we have seen, Fairchild could not agree that in such valleys there could have existed for any great length of time water bodies as large as those which must have been concerned with the ancient shore phenomena which they exhibit.

While Fairchild had recourse to a submergence by sea-level waters it will be recalled that he regarded these as freshened by glacial flooding. He did not try to explain the clays, but recognized that the absence of marine fossils generally in the high-level deposits was best accounted for by assuming fresh water conditions.

From studies of the present occurrences of the varve clays it has been shown that while the great ice sheet was waning, southern New England had a higher position than now. At New

[1] The Recession of the Last Ice Sheet in New England. American Geographical Society, Research Series, No. 11.

Haven, Connecticut, varve clays are found 25 feet below sea level, and at Hackensack more than 15 feet below. These clays have such well-developed varves that the conclusion is inevitable that they were deposited in fresh water.[1] Several considerations lead to the conclusion that in late glacial times Long Island Sound was separated from the sea and held a glacial lake.

The general conclusions reached by Antevs from his studies in the field and of the ideas of others are: (1) That during the presence of the ice sheet in New England the land was depressed by the enormous weight; (2) that as the ice gradually waned and its front moved northward the land which was uncovered first rose and then sank, the movement proceeding like a wave, traveling northward with the retreating ice; (3) that the elevation at the crest was great enough to give a northward inclination to the land and allowed impounding of glacial waters between the land barrier and the ice-front, and the formation of long narrow lakes; (4) that glacial rivers loaded with material discharged into these lakes and that some of the lakes existed long enough to become filled with sediments; (5) that when the ice was gone from New England and the wave had passed the last glacial waters were drained; as warping went on the rivers which flowed over the old lake deposits sank their channels into them.

In the Champlain region the effect would have been to impound a great body of water in front of the ice as an immense glacial lake which presumably endured at high levels for a long time. The general history of the lake would have been much as explained by Woodworth.

Although the views which Antevs advances with regard to the wave-like movement of the land are not without some support from studies in the field they are largely theoretical, though plausible. They enable one to visualize how lakes might have been formed in open valleys and how they might have been drained. As they apply to our region they carry us back to the older views of Woodworth and others and seem to provide the conditions that would permit the formation of a glacial water body which was large enough and which lasted long enough to allow the development of the high-level shore features which by others are attributed to sea-level waters.

Lake Lincoln.—With the ideas in mind that the ice sheet submerged the upland, as well as the lowland, and that as it waned its front receded northward, in order to understand the probable history of the surface deposits in Lincoln it is necessary to recall the outlines of the bed-rock topography.

The valley of Lincoln is a rock-rimmed basin, a sort of amphitheater, hemmed in on the north by the hills of Starksboro,

[1] Varve clays are made up of distinct layers which represent deposits during successive years. They are formed only in fresh water.

on the east by the main range, on the south by the high land in the northern part of Ripton, and on the west by the front range. Inspection of the topographic map (Lincoln Mountain sheet) shows that the present lowest level in the rim that bounds Lincoln basin on the south is at an elevation of 1,430 feet in a col on a divide between Alder Brook, a southward-flowing tributary of the north branch of Middlebury River in Ripton, and a stream that flows north into New Haven River. It would appear that as the ice-front retreated from the high land in the southern part of Lincoln, and the southern part of the basin was uncovered, the waters from the melting ice must have collected between the ice and the northward slopes of the hills and formed a lake whose surface would have been determined by the lowest outlet in the rim of hills. This lake, which we may call Lake Lincoln, expanded as the ice withdrew still farther north, but probably held the level of this southern outlet practically from its beginning and until the waters found a new outlet along their present course and the lake was drained; for there does not appear to be any other pass except the southern outlet through which the waters could have escaped.

Lake Lincoln was probably not of very long duration, yet long enough to leave its impress on the topography of the basin. It would appear that the stream that drained the lake through the Alder Brook pass was never very large; apparently the contributions to the lake of water from the melting ice and from streams were not so heavy, but that a moderate stream sufficed to drain the lake.

From its beginning Lake Lincoln served as a settling basin for the sand and gravel that were carried out from the ice. A somewhat independent basin of water probably occurred at first in the valley south of South Lincoln village which is now occupied by the head portion of New Haven River. A short stand of the ice-front is marked a mile and a half south of the village by kame deposits (1,620 feet). These surmount a sand plain of outwash material which formerly extended across this small valley and which has been much dissected by the river and tributaries coming into it from the east. From the hilly land in the northern part of Ripton a short spur juts northward, west of the river. This probably served to create the separate basin just referred to and to divide the waters in it from those west of the spur which found an outlet through Alder Brook pass. The highest summit levels of the terraced remnants of the plain below the kame described above are 1,480 feet. But as a barrier this spur was short lived; the waters in the small eastern basin probably never reached a level much higher than those recorded by the present summit levels just mentioned, and early joined with those which occupied the basin west of the spur.

An imperfect kame topography is shown by the surface of the outwash near South Lincoln. As the ice-front receded from the site of South Lincoln village the lake expanded northward and its waters laved the rocky and till-covered slopes of the bounding hills, presumably at a level determined by that of the southern outlet. Studies of the present surface, in the field and from the map, indicate that much material was carried out from the ice and spread over the bottom of the lake as an uneven sublacustrine plain. It is not possible to determine whether any ice tongue lay in the deeper portion of the basin while these deposits were making, but it does not seem likely that such conditions were present. Around the eastern, southern and western rims of the basin the high-level deposits of the aggrading flood waters are more or less distinctly preserved at altitudes readily correlated with the southern outlet of the lake, and it does not seem difficult, from remnants which have been preserved, to restore an irregular plain across the valley which has largely been destroyed by stream erosion since the lake was drained. The river was clearly from the first a powerful stream and because of the many rocky surfaces which it apparently must have encountered as it wore down through the plain, and which served as local base levels, it did much lateral cutting. On the west side of the main river, north of the parallel of South Lincoln village, terraces marking different levels of lateral planation are still well shown. In most cases streams and wash have destroyed or obscured higher terrace surfaces and slopes, but some intermediate ones and many lower plains are still well preserved. Old flood plain remnants, apparently as flat and fresh now as when formed, occur northwest of South Lincoln village (1,200 feet plus), and on the north side of the river, east and west of West Lincoln village (900 feet plus).

In the course of its wanderings since the lake was drained the river has probably been gradually shifted into its old preglacial valley, so that in the main it now follows its preglacial course. That the river never strayed very far to the east of its preglacial bed-rock valley seems likely, as the rocky east slope of South Mountain would have prevented the development of big meanders, and it is a fair hazard that when the lake was drained the river was constrained to keep not far from its old course by natural hollows in the plain, which may be thought of as consequences of deposition on an uneven rocky floor, since the duration of the lake was hardly long enough for a level plain to be built.

That the course of the river after the disappearance of the lake waters was conditioned by surface features different from those of the bed-rock surface is seen in the superposition of the stream at different places on ledges of the bed-rock which stood above the preglacial level of the river. These ledges were discovered by the stream as it wore down through the plain. The river is intrenched in rocky gorges near South Lincoln.

About a mile southwest of Lincoln village are knobs of sand and gravel which have somewhat the aspect of kames and which have been cut into on the south by a tributary of New Haven River, and on the west by the river itself. Their summits are at the level of 1,260 feet. An alternative explanation is that they are wholly erosion remnants of the plain.

East of Lincoln village and the Alder Hill school is a beautifully preserved outwash surface at 1,460 feet elevation. If this was built out into the main lake it would appear that the lake level was higher than the present surface of Alder Brook pass. Possibly the ice-front retreated in such way as to allow the formation of a relatively long and narrow lake on the east side of the basin, as far north at least as the plain just mentioned. It seems possible that the southern margin of the plain is primary and secondarily lobed by wet weather streams. Such a view would rest on the assumption that the rate of retreat of the ice-front varied and that a halt occurred at the time this plain was formed. It, however, seems to show no development of kames on its surface.

East of the plain, above the house of Eldon Atkins, is a narrow terrace of coarse, gravelly material. It may represent marginal drainage between the edge of the ice and the rocky slope at the foot of the main range. The old trail to Mt. Abraham crosses the terrace.

It appears that at the time of its greatest expansion the lake extended into the northern part of Lincoln township, in the hollows among the hills, where plains are now present at about the level of Alder Brook pass, or slightly higher.

When the ice-front retreated to or north of the valley that cuts the front range east of Bristol village the lake found an outlet to the west. The whole region was probably lower than now. Over the lowland west of the front range lay a body of standing water. Into this the Bristol delta was built.

It does not seem possible to determine whether the drainage from Lake Lincoln had anything to do with the building of Bristol delta. It seems likely that the water from the lake leaked away around the ice-front. The surface materials of the valley east of Bristol village, and that of Baldwin Creek valley which joins it, were graded to the high-water level of the lowland water body. It seems likely that the Bristol delta was built in part by material swept out from the valley east of Bristol and that of Baldwin Creek by the flood that came from the ice-front down the valley of Baldwin Creek, after the front had moved north of Ackworth and lay across the valley and in part by material carried by the flood from the ice. The process was probably somewhat complex.

Glacial Flooding in the Valley of Mad River.—South of Warren township the high land in the northern part of Granville forms the divide between Mad River, which flows northward, and Alder Meadow Brook, a southward-flowing tributary of White River. The road from Warren to Granville over this divide follows a rocky defile which was worn by stream action and is known as "Granville Gulf." At Granville Notch, the highest point in the road through the gulf, the elevation is about 1,400 feet.

It seems likely that as the ice retreated from the Granville divide some ponding of water would have occurred in front of the ice and that some deposits would have formed, for a time at least. Bench deposits at levels that could be correlated with the level of Granville Notch are not conspicuous, certainly, but may have been imperfectly formed and since largely destroyed.

It seems likely that as the glacier waned and melted away northward a tongue of ice lay for some time in the old preglacial valley of Mad River. In front of this some ponding occurred and the water leaked away around the ice tongue. Mad River flowing north, and its tributaries from the mountain slopes, carried sediment into the lake in front of the tongue and built up a sand and gravel plain, and possibly also benches along the sides of the ice, in some cases, which as the tongue front moved back may have been joined by sediment deposited between. Presumably the benches and plains would have been built at lower and lower levels northward, but the elevation which the land subsequently underwent as the ice load disappeared farther north would have altered any such possible primary differences of plain levels and might, in fact, have reversed conditions. The matter has not been investigated.

In Warren no systematic attempt was made to locate glacial delta plains that might be correlated with the level of Granville Notch; but outwash deposits around East Warren village, with a level surface at an elevation of about 1,400 feet, may have been formed in a water body between the ice and the Granville divide when the ice front stood at a favorable height north of Warren village and an arm of the lake extended eastward along the valley of Freeman Brook; or the plain may have been built in a marginal lake.

The beautiful terraces on each side of Mad River in Warren and in the towns north of it have been made by the river as it wore down through the sand plains that were formed, during the retreat of the ice, in the old rock valley. At places Mad River is off its preglacial course and is flowing through gorges in the bed-rock on which it was superposed as it sank its channel in the plain; but in the main the river flows within the confines of its preglacial valley.

BED-ROCK GEOLOGY OF BRISTOL AND LINCOLN TOWNSHIPS.

General.—It will be convenient to divide the district into two parts for purposes of description: (1) The townships of Bristol and Lincoln lying west of the axis of the main range, and (2) the township of Warren on the east side.

In Bristol and Lincoln townships at least two distinct lithological series may be recognized. One of these comprises two formations, a quartzite and a dolomite, each of which is developed in considerable thickness and within our area holds to a notable homogeneity in lithological character. Although these rocks register the former action of compressive forces and attendant metamorphic effects their primary characters and structural features and relationships to each other are fairly readily interpreted. In marked contrast to the rocks just described the members of the other series are much altered and now appear as schists and gneisses of various kinds, which show diversity of type and a number of minor variations and give little or no evidence of their relationships to one another or to the members of the other series. Among the diverse members of the metamorphic group there are some which seem to be somewhat closely related and to be older than the quartzite-dolomite series; but the age of other members, as will be explained, is problematical. The quartzite and dolomite are confined to the western part of our district, in the lowland portion of Bristol and in the front range of hills. The metamorphic group borders this series on the east, forming a strip in the eastern part of Bristol and the bed-rock surface in Lincoln township.

In the lowland of Bristol, north of the latitude of Bristol village, the rock is chiefly quartzite. This rock forms the southern end of the ridge, which extends into the town from Monkton at the north, and passes beneath the surface material in the hollow occupied by Bristol Pond and Pond Brook to join the quartzite forming the high ridge of Hogback. At the southern end of Monkton ridge and at the northern end of Cedar Swamp, in New Haven township, near the New Haven line, massive dolomite overlies the quartzite and ledges of dolomite occur just north of Bristol village. The bed-rock is mostly concealed in Cedar Swamp, but south of it, on the meridians occupied at the northern end of the swamp by the massively-bedded dolomite mentioned as forming the southern extremity of Monkton ridge, there are alternating, relatively thin beds of quartzite and dolomite, which were not noted elsewhere in Bristol, but which comprise a formation which is well represented in the town of New Haven to the west of Bristol and which has an extensive distribution along the eastern portion of the lowland

and southward through the Vermont valley. These rocks are members of the quartzite-dolomite series, as is shown by the close association which these rocks have at many places. A surface section southward from Monkton ridge into New Haven township, allowing for some interruptions, thus appears to give a succession from quartzite, through massively-bedded dolomite to interbedded quartzite and dolomite and suggests that this is the stratigraphic sequence, in ascending order. The dolomite member outcrops in the hills southwest of Bristol village, west of Bristol Flats, between the interbedded quartzite and dolomite in the eastern part of New Haven township, and beds of the basal quartzite formation outcrop at many places along the foot of South Mountain, east of the Flats, between the Bristol delta plain and the Little Notch road.

The quartzite east of the Flats apparently forms a gentle synclinal fold, for at the foot of the mountain it dips westerly at places and along its western edge it shows prevailingly westerly dip. South of Bristol the surface covering prevents accurate determination of the structure of the quartzite and dolomite at most places.

North of Bristol village the quartzite and dolomite have a basin structure and the valley occupied by Bristol Pond and Pond Brook in Monkton has apparently been excavated in the dolomite of this downfold.

Hogback is a mass of quartzite. The rock is usually strongly sheared, but the bedding remains distinct in many places and has easterly dip along the western face in Bristol. The western slope is precipitous and at present distinguished by many small scarps. While these are doubtless the result of freshening by ice action the western face of Hogback marks an old fault line, or zone of differential movement between the quartzite of the mountain and the rock that formerly filled Pond Brook valley. Ice erosion has restored, as it were, old fault line scarps in the resistant quartzite.

With the interpretation of the western face of Hogback as an old fault line it follows that the valley west of the mountain is either on the upthrow or the downthrow side. The size of the valley is seemingly not in proportion to the dimensions of any antecedent of the stream which now traverses it. The valley has been excavated largely by agents of the weather in relatively weak rock, which it is reasonable to believe was a dolomite like that found in neighboring parts of the lowland. The dolomite appears normally to lie above the quartzite. Reasoning in this way the Pond Brook valley is on the downthrow side. It owes its basin character, in the structural sense, partly to fault displacement.

The topography seems to indicate faulting along the east side of Monkton ridge. With this interpretation Pond Brook valley assumes a graben structure, on a small scale. The whole Champlain lowland is regarded as essentially a graben and the Pond Brook basin as only one of several small structural troughs which have resulted from differential movements within the larger basin. The displacement on the western side of Hogback is of the order of those which define the eastern border of the Champlain lowland, and that of its counterpart, the Vermont valley. The western face of South Mountain lies in the zone of this major displacement. Where the Little Notch road emerges from the upland there is an offset so that in southern Bristol the western edge of the plateau lies two-thirds of a mile farther west.

Hogback forms the western limb of a synclinal fold of the quartzite and overlying dolomite. The eastern limb of the fold is ill-defined. In the trough of the fold the rocks were jammed at some places more than at others. Fairly gentle westerly dips were noted in the quartzite in the bed of New Haven River east of Ackworth, and the dolomite in the Baldwin Creek-Beaver Brook valley two miles north of Ackworth; but farther north in Starksboro township both quartzite and dolomite stand on end. Overturning of the eastern limb was not observed. Presumably it would have been imperfectly developed because of the massive character of the formations involved. Apparently—as will be discussed later—deformation took the form of fracture and shearing along the eastern limb. The valley of Baldwin Creek has been worn out of the dolomite formation.

Succession in the Rocks East of Baldwin Creek and North of New Haven River.—In going east from Baldwin Creek puzzling features of structure and problems of correlation appear at once. The abundant outcrops of quartzite about Ackworth, in the bed of the river and in the fields east of the road with features of bedding and dip well shown, raised the expectation that this rock would be found to extend eastward for some distance with practically the same characters, especially in view of the very general substantial thickness of this formation in its occurrences at the west. It was baffling to find the rock rapidly changing in character east of the meridian of Ackworth and soon passing into schistose types, without any discernible traces of uncomformability or means of making a structural separation.

The succession was studied along the surface from Ackworth northeast to Bald Hill and thence eastward across the South Starksboro road, commonly called the "Quaker Hill" road; and from Ackworth eastward in the bed and banks of New Haven River; and in the east-west gorge of Baldwin Creek along the "Drake's Woods" road, from the valley east of Hogback through South Starksboro to the foot of the main range.

Surface Section in the Hills East of Ackworth.—Just east of the bridge at Ackworth the plainly-bedded quartzite dips easterly and pitches slightly to the north. A few steps eastward, ascending the slope, one finds what appears to be the quartzite now sheared into a quartzitic schist with the bedded character indistinct and practically lost so that one cannot tell what relation the planes of bedding have to those which mark the foliation. Eastward up the hill are many ledges of impure quartzitic rock in which the dominant structure is that of foliation which has easterly dip and which has in most cases completely obscured the bedding. In a few cases, as observed on joint surfaces cutting across the foliation, what seemed to be thin and roughly alternating beds, originally of sand and mud, were seen to be jammed into close folds.

There appears to be some variation in lithology along the strike; quartzitic schist is well developed on the west slope of Bald Hill. Over the summit and down the east slope to a swamp the surface rock is prevailingly a strongly quartzose schist, but east of the swamp is strongly micaceous schist with chloritic variations.

Bed of New Haven River East of Ackworth.—The quartzite, with distinct bedding, extends east of Ackworth in the bed of the river, holding to an easterly dip to the dam. The dip shortly changes to a westerly one. Then, not far to the east the bedding becomes obscure and the rock takes on the same sheared character noted in the surface section over the hills east of Ackworth. Farther east in the stream bed the bed-rock is followed with difficulty because of boulders and gravel. At the bridge at West Lincoln is strongly foliated quartzose schist and similar rock occurs on the hill road, north of West Lincoln hamlet, on practically the same meridian.

Gorge of Baldwin Creek.—In the bed of the stream and in the road bank, about one-fourth of a mile east of the junction of Baldwin Creek and Beaver Brook, is some quartzose schist, and similar rock occurs upstream; but towards South Starksboro the rock is micaceous or chloritic and strongly foliated, and frequently pyritiferous. In some places coarse foliation may be seen cutting across distinct bedding planes which have been folded. In a few places calcareous beds or lenses are feebly developed. There were observed no structural features that would serve to separate rocks from one another. In fact, all the rocks in the gorge show the same degree of foliation and the foliation planes throughout have no significant difference in strike or dip. Near South Starksboro chloritic schist shows gneissoid banding.

East of the South Starksboro Road.—Over the area bounded on the west by the road joining South Starksboro and Lincoln villages, on the east by the main range, and on the south by New Haven River and the road from Lincoln to Warren, it is possible to distinguish several varieties of rock, but definition of one from

another cannot be made on the basis of structural features and formational arrangement and rests wholly on lithological features.

Mica schist, often with prominent octohedra of magnetite, extends into the northwestern part of the area from Starksboro township, but it is not sharply delimited from other schist in which magnetite is not macroscopically developed. Mt. Pleasant is a mass of micaceous schist with some arkosic phases. Much of the rock in the northern portion of the area east of the South Starksboro road has prominent contorted bands of white quartz. These seem to be more abundant near the foot of the main range. South of South Starksboro village, in the road, near a school house, the schist carries calcareous lenses.

North and south of the Alder Hill school road are many ledges in the schist formation which are composed of quartzitic schist and some in which the rock is practically a sheared quartzite.

From the Lincoln-Warren road northward along the lower portion of the western slope of the main range a band of strongly garnetiferous mica schist was traced as far as the trail to Mt. Abraham. This carries occasional calcareous beds. Of these the most conspicuous one seen is in the pasture east of the Henry Davis place, just north of the Lincoln-Warren road.

South of the Road from Bristol Through Lincoln to Lincoln Gap.—The steep western face of South Mountain is made of massive quartzite of the quartzite-dolomite series. On the eastern slope of the mountain, quartzite, often sheared, was traced for a distance through the woods by occasional ledges which lie roughly along a meridian about two miles east of the summit of the western scarp.

From West Lincoln village a road runs southward over what is locally known as "Gove Hill" to join the Little Notch road. West of the Gove Hill road, at the northern end of the hill, the surface is composed of coarse boulder drift, with many large boulders of quartzite whose parent ledges lie to the north. About three miles south of West Lincoln and a half mile west of the road are massive ledges of sheared rock which is a quartzitic schist for the most part. Some of the rock is conspicuously magnetiferous, with octohedra frequently well developed. Pebbles of quartz occur at several places in patches of varying dimensions. All the indications are that the pebbles are integral components in all cases of the sheared quartzitic formation in which they occur and not distinct from it. The wonder is that they themselves have not been sheared very strongly, which does not appear to be the case.

Southeast of these outcrops, along the road, the rock is sometimes conspicuously feldspathic, but usually is a quartzose schist with quasi-quartzite phases. Similar rocks occur east of the road, but their eastward extension is uncertain. Quartzitic schist outcrops south of the road that joins South Lincoln village and the Little Notch road, and east of the road to Ripton.

On the north side of the Little Notch road, where it crosses the crest of the divide, are conspicuous beds of dolomite, dipping to the east and having a general north-south strike. A few rods farther west, north of the road, similar rocks show a series of undulating folds and are sheared across the bedding.

Near South Lincoln village and north of it as far as the covered bridge on the Lincoln-Warren road are exposed along the banks and in the bed of the river rocks quite different from any which were seen elsewhere in Lincoln, but as in the cases of other rocks of the township, distinction from the rocks which surround them can be made only on a lithological basis.

About a mile northwest of South Lincoln village the river has cut a postglacial gorge in the bed rock. On the slope of the hill north of this gorge, to the west of the river, are ledges of a greenish rock which is generally sheared into a schist, but which shows at numerous places a more massive character. Associated with greenish rock is a granitic gneiss which is also prevailingly foliated, but which like its greenish associate is massive at some places. The foliation structure has in both cases about the same strike, N. 25° E. (magnetic). In the western portion of the area in which these rocks were noted there is a rough alternation of one with the other across the strike, but their precise primary relations could not be determined. The more distinctly massive portions of these rocks indicate a primary igneous nature. Their texture indicates that they were intrusive.

Under the microscope in transmitted light the massive phase of the greenish rock shows a distinctly granular texture in the arrangement of green and colorless sections of amphibole. Feldspar is absent from the specimen examined. Masses of fibers of what appears to be serpentine are present in some of the amphiboles. In the hand specimen the rock is streaked with epidote. The massive, amphibolitic phase grades into a dioritic rock in which hornblende and plagioclase feldspar are about equal in amount. A thin section of the dioritic phase shows the hornblende frequently changed to chlorite and the feldspar to calcite and kaolin.

The prominently foliated phase of the granitic gneiss associated with the rocks just described under the microscope shows a sort of porphyritic texture in the disparity of size exhibited by some of the microcline grains, but the rock is as distinctly foliated in thin section as in the hand specimen. Microcline occurs also as small grains in the section. The larger grains of this mineral usually show pronounced strain effects. They are wrapped around by hosts of small grains of quartz and biotite mica which with a little admixture of plagioclase make up most of the section. Quartz predominates, forming conspicuous bands which are separated by stringers of biotite. The quartz and biotite in their present condition appear to be secondary. There is nothing in the section which tells of any antecedent condition of either mineral. The larger crystals of microcline might be interpreted as only slightly modified constituents of a granular igneous rock.

North of the outcrops of the rocks just described, at the covered bridge on the Lincoln-Warren road, green, magnetiferous biotite-epidote schist outcrops in the west bank of the stream, under and south of the bridge. West of the bridge, near the road, is gray granitic gneiss. Under the bridge and north of it, in the river bed, gray gneiss is involved with the biotite schist. The gray gneiss is commonly distinctly foliated, but under the bridge a broad band of this rock is notably massive. Small portions of the biotite schist appear to be caught up in the gneiss. The schist carries vein quartz, but it is not clear that the vein quartz has any genetic relation to the granitic rock.

East of the bridge, in the field, are rocks resembling the biotite schist under the bridge, and others which include a rock that is much like the foliated diorite that occurs farther south.

West of South Lincoln in the bed of the stream tributary to New Haven River micaceous granitic gneiss, somewhat massive epidotic gneiss and dioritic gneiss seem to be companion members in a series of rocks which includes those described as occurring under the covered bridge and east of it, and to the west of the river farther south.

Granitic gneiss may be traced southward into Ripton and the series just mentioned may be represented by certain other rocks northwest of the covered bridge.

The granitic gneiss and its associated presumably igneous rocks have not been found "cutting" the quartzose and other schists that make up so much of the country rock in Lincoln township. The structural relations are not known. It hardly seems likely that the gneiss and its companion rocks are younger. It is thought probable that the gneiss occurs beneath the schistose rocks in the northern part of Lincoln. Systematic search might reveal outcrops of it, but none has been observed by the writer.

East of the covered bridge, along the Warren road, and south of it, quartzose-micaceous schist in frequent ledges marks the southward continuation of the rocks near the Alder Hill School at the north, but these rocks give place eastward near the Henry Davis place to garnetiferous mica schist which has already been described as forming a rather distinct band on the lower portion of the western slope of the main range and in the adjoining foothills, to the north of the road. The garnetiferous schist was followed south of the road to "Prospect Rock," where it is prominent and associated with other schist not so conspicuously garnetiferous, and still farther south to the southern boundary of the town.

Summit Portion of the Main Range.—The rock making up the higher portions of the main range is exposed on its slopes in scattered ledges only; heavy forest growth and a mantle of broken rock and soil make any study of the rock very difficult. Examination was made chiefly of outcrops along the Green Mountain trail and on the Warren road near Lincoln Gap. North and south of the gap, along the trail, the rock seems to have throughout a good deal of similarity in lithological character.

The prevailing rock is a mica schist with strongly-developed lense-like inclusions and contorted bands of white quartz. A typical specimen, collected near Battell Lodge, under the microscope gives a decidedly banded arrangement of the chief minerals which are quartz, muscovite, biotite, zoisite or epidote, chlorite and magnetite. The muscovite appears as aggregates of fibers or plates which the hand specimen indicates to be sections of closely-packed, crumpled films of the mineral. Chlorite has much the same form and distribution as the muscovite, but is not so abundant. Epidote or zoisite occurs as elongated prismatic grains. Irregular grains of magnetite are very abundant. They are usually elongated in the direction of the schistosity and are sprinkled among the other minerals. The few flakes of biotite are somewhat "bleached."

As interpreted from the section the characteristic mica schist of the range is a very much altered rock in which there now appears to be no trace of its original condition. In the section examined no feldspar was noted. Feldspar may now be represented by zoisite and muscovite. The magnetite gives one the impression of having been liberated, so to speak, from some mineral rich in iron. The abundant quartz may, for the most part, represent an excess after profound mineralogical changes.

Certain rocks noted in road cuttings west of Lincoln Gap afford examples of variations among the rocks making up the crest portion of the range. The extent of these rocks as components of the formation of which they seem to be a part could not be determined. They show certain mineralogical features which are worthy of notice.

About 200 yards west of the gap is a porphyritic gneiss of which portions are somewhat massive. The foliations dip westerly. Phenocrysts of feldspar give the weathered surface a spangled appearance. Next east is a black gneiss with no superficial resemblance to the porphyritic rock and in which the foliations dip easterly. This passes eastward into the porphyritic gneiss which grades into or is intermingled with rock that is much like that which forms so much of the surface along the crest of the range. At the gap the excavation for the road is in a much-

weathered, blackish schist or gneiss which has been severely sheared.

Under the microscope a section of the porphyritic rock shows numerous relatively large grains of orthoclase in which Carlsbad twinning is sometimes present. These are in a matrix composed of many small quartz grains and flakes of muscovite. Chlorite is common, apparently secondary after biotite. Magnetite is scattered rather promiscuously among the other minerals and occurs sometimes within the feldspars. The latter usually contain many small inclusions of secondary quartz, but on the whole are remarkably fresh in appearance. Plagioclase was not noted. In the feldspar there are occasionally polygonal sections of a colorless mineral of high relief which may be zoisite. In their present condition the quartz and muscovite are apparently secondary, and the feldspars may be also, as the quartz inclusions would seem to suggest.

The black gneiss under the microscope shows abundant flakes and fibers of light-colored mica arranged in long skeins which are sprinkled profusely with a black dust which in the powdered rock the magnet reveals to be magnetite. There are abundant small grains of quartz which are either scattered or arranged in bands with the mica. Nets of mica and magnetite wrap around the feldspar, probably orthoclase, and this mineral is dusted with magnetite arranged as streaks across the mineral, often at right angles to the foliation. The feldspars also carry abundant, rounded inclusions of quartz. The thin section reveals that the black gneiss, which in structure is really a schist, gets its black color from the extraordinary abundance of the magnetite. Comparison of the black and porphyritic gneiss suggests that they are probably derivatives of rather closely related antecedent rocks. In the black gneiss there was for some reason an unusual enrichment in secondary magnetite.

The rocks of the summit portions of the main range give no clues as to their nature prior to the tremendous alteration which it believed they have suffered. There are no structural features by which to determine their relations to other rocks.

SUMMARY OF THE BED-ROCK GEOLOGY OF BRISTOL AND LINCOLN.

As noted above, the quartzite and dolomite formations in the western part of our area, with certain other rocks which consist of more or less alternating beds of quartzite and dolomite, form a definite series whose members are closely related in age and possess many structural features in common. The original strong development of this series is evidenced by its considerable thickness and by its geographical extent on the eastern margin of the

Champlain lowland and the western border of the Green Mountain plateau, and by the widespread occurrence in the Champlain lowland of other rocks which for several reasons are most reasonably regarded as age equivalents or lithological variations of the rocks that compose the border sequence.

In view of the prominence of this series within our area and elsewhere one is impressed as one goes eastward from the border region by the absence of rocks which could with any degree of certainty be correlated with it, as well as by the lack of a well-defined eastern boundary to the series or any trace of unconformability with other rocks.

Lying east of those outcrops in the valley north of Ackworth which may with certainty be assigned to the quartzite-dolomite series there are on the western slopes of Bald Hill, and the high land adjacent to it on the north and south, other rocks which in all cases have been strongly sheared. In many cases these rocks are so dominantly quartzitic, or similar to variations that are known to occur within the quartzite formation, that in the writer's opinion they may be regarded as part of the quartzite formation. This opinion is in agreement with that of N. C. Dale. At Ackworth, as indicated on a preceding page, there appears indeed to be a gradual transition from plainly-bedded and relatively unsheared quartzite to quartzite that has been strongly sheared. A similar transition occurs in the bed of New Haven River east of Ackworth.

Accepting the structure of Hogback and the valley east of it as synclinal, the eastern limb may be thought of as sheared beyond recognition. The shearing was a differential process amounting to a number of small reverse faults. The effects might have been to elevate older rock at the east and to obliterate traces of unconformability.

Except for occasional exhibitions of closely-compressed minor folds there is nothing now to indicate any pattern of major folding or other form of displacement within the various schists that now form the bed-rock surface east of the zone of sheared quartzite. It may be necessary to recognize a pattern of deformation that would allow, so to speak, the preservation at the present surface of certain quartzitic rocks which occur some distance to the east of the sheared zone of quartzite and not far from the foot of the main range. These rocks seem to be comparable with some of rock of the quartzite formation, but there are no apparent reliable criteria for their correlation.

It is thought that the general structural features of the schists that border the zone of sheared quartzite on the east argue against any idea that these schists are younger than the quartzite-dolomite series.

The characters shown by the rocks of the main range, in the

ledge and in thin section, seem to indicate that these rocks were profoundly altered at depth and bear strongly in favor of the idea that they are very old. Their present mineralogical and microscopic structural features seem to be wholly the result of metamorphism from some previous condition which may have been that of an igneous or a sedimentary rock.

The garnetiferous mica schist which forms the long band on the lower western slope of the main range is a well-defined petrographic type among the schists west of the main range, and as has been noted carries interbedded marble, which stamps it as a metamorphosed sedimentary formation. The garnetiferous schist is thought to be probably younger than the schist of the main range on the basis of what is regarded as its more simple structure, but the difference may be more hypothetical than real. The relation of the garnetiferous schist to the other schists lying west of it is problematical. Segregations of quartz now occurring as interrupted contorted bands in the various schists, including those of the main range, are thought to have no significance regarding kinship among the rocks, but are looked upon as instances of parallel development.

The various quartzose and micaceous schists now forming the surface between the main range and the zone of sheared quartzite make up a series at the present time lithologically distinct from the western sequence, which is thought by the writer to include the sheared quartzite zone, but this is about all that may be said in the matter of their differentiation. In this connection the fact of pronounced lithological resemblance of certain quartzitic members of the schist series to the sheared quartzite should not be overlooked.

The calcareous members of the schist series have no obvious significance for purposes of correlation.

The rocks of South Mountain from its western scarp eastward give a succession which it seems possible to harmonize with the surface section across the same meridians north of New Haven River. They seem to belong to the western sequence.

The granitic gneiss and associated basic rocks along New Haven River in the southwestern part of Lincoln are distinct from the schist series east of the western sequence, but structural relations are difficult to determine. These rocks have not been found cutting the schists. They are thought to have been exposed by erosion of the river which cut through a covering of rocks comparable to those which form the surface over most of Lincoln. They may be part of a mass that "stoped" or otherwise intruded its way into older rocks and acquired their structural features during the process. The rocks may be younger than the schists, but the structures of the two may be contemporaneous.

Any arrangement of the rocks of Lincoln on the basis of relative age and structural relations clearly must be tentative and at most only suggestive, at the present time.

THE BED-ROCK GEOLOGY OF WARREN TOWNSHIP.

General.—The problem of separation from one another of the rocks of Warren is more difficult than in Lincoln. All the rocks of Warren township are clearly in a profoundly altered condition. In a few cases, particularly in certain quartzites, a sedimentary history is indicated, but in most cases all traces of the condition of the rocks antecedent to their present structural and mineralogical characters are gone. Probably most of the rocks have been involved in more than one period of metamorphism.

Western Part of Warren.—The western part of the town includes part of the main range, and the summit portions of it in Warren have the same rocks that occur at these altitudes in Lincoln. From an inspection of the rocks on the eastern slope of the range, along the Lincoln-Warren road, and in the valley of Clay Brook and from outcrops in the valley of Stetson Brook, it is inferred that the formation which was described as making up the crest of the main range is represented to some extent on the eastern slope in Warren. In fact, rock that apparently might be included in this formation outcrops along the Warren-Waitsfield road, north of the village of Warren. It is not meant that there is close similarity among the rocks west of Mad River; schists quite different from that which makes the summit of the range were observed, but nothing was noted that served to separate the rocks into different series. Some rusty mica schists and quartzose types seen between Sugar Loaf Mountain and the main range (and at some places east of Mad River) are very similar to members of the schistose assemblage in Lincoln.

In the bed of Mad River, near the dam at Warren village, the rock carries bands of quartzite which suggest a sedimentary history, but aside from these the rock gives little clue to its original nature.

East of Mad River.—Certain talcose and serpentinous types which were not noted in Warren west of the river occur among the rocks east of the river, but it is not certain that these types serve in any real sense to distinguish the areal group in which they occur in Warren, as similar rocks may have been overlooked at other places. Similar rocks were nowhere seen west of the main range, in Lincoln, however, and it seems to be somewhat significant that they with very similar types are more or less characteristic members of a broad band of schistose rocks which extends lengthwise across the State for a long distance, and farther south into Massachusetts. These talcose and serpentinous members

while not forming large areas in our district are frequent enough to attract attention.

Except for the rocks just mentioned it was not possible to make any structural or important mineralogical distinctions among the schists that form the country rock east of Mad River or between them and the rocks that occur west of the river. Everywhere the rocks are dominated by a foliated structure and the foliations have a general north-south strike from which there are no apparent significant variations. The subordinately developed talcose, serpentinous and actinolitic members have the same foliated structure as the enclosing schists.

In Warren no rock was found comparable to the garnetiferous mica schist so conspicuous in the eastern part of Lincoln. Nothing was seen which could by any stretch of the imagination be considered as representing the quartzite-dolomite series of Bristol and West Lincoln. The rocks in the bed of Freeman Brook at some places show more plainly than is usual in Warren a primary bedded arrangement. Probably it is a sedimentary series that is commonly represented—possibly more than one—and in this are probably present altered igneous rocks.

Talc and Serpentine in Warren.—About two miles south-southwest of East Warren village and one-fourth of a mile west of the road running south from the village to join the Warren-Granville road, a small excavation has been made for talc. The extent of the talc is apparently not great. The talc is here associated with actinolite. Under the microscope the actinolitic rock shows a somewhat foliated, but largely felt-like, groundmass of talc, with apparently a little disseminated serpentine, penetrated in all directions with crystals of the actinolite, which in the hand specimen appear as radiating bundles or sheaf-like masses. Magnetite occurs as infrequent, scattered grains. The origin of the talc is not evident from the specimen examined.

Although ledges of talc were reported as occurring about a mile north of East Warren village, near the Henry Brooks place, these were not investigated.

Talc outcrops on the farm of Howard Joslin in Waitsfield, west of Waitsfield Common, were inspected. These have been worked for talc. The country rock near by is schist, carrying segregations of quartz and bunches of coarser more gneissic rock. The talc rock seems to be an altered basic inclusion of some kind in the schist.

In the outskirts of Warren village, perhaps a fourth of a mile east of the center, partly on the farm of Lee Aldrich and partly on that of Leonard Freeman, is a considerable exposure of serpentine. The serpentine forms a sort of whale-back ridge, north of the road to East Warren, and in subdued form approaches the road and perhaps passes beneath. The ridge ends abruptly on the north just south of a brook. The eastern side is steep and descends to swampy land which separates the ridge from the schist on the east. The top surface slopes southward gradually from the northern end to the level of the road. The outcrop is perhaps 100 to 150 yards long and 20 yards wide. In the bed of Freeman Brook, practically in line with the serpentine outcrop, the schist carries bands of talcose rock. The serpentine is apparently bounded on the east and west by schist which also outcrops along the line of strike of the serpentine north of the gully which cuts off the outcrop at the north. The ridge, therefore, presents the aspect of an elongated mass pinched in the schist formation. Irregular ledges of the serpentine near the road are less clearly drawn out in parallelism with the schist.

Some parts of the ridge are distinctly dolomitic, but the proportion and distribution of dolomite in the mass are not easily determined. At first, when the dolomitic phases were noted, it was thought that the rock might represent a lens or pinched out mass of original dolomite whose history had been one of successive metamorphic changes, but later it was thought necessary to consider the possibility of primary igneous origin.

The thin section of a dolomitic portion of the ridge shows a mixture of dolomite and talc in about equal proportions, with only traces of serpentine and with frequent small grains and some larger ones of a black, opaque mineral which can readily be seen by the naked eye promiscuously dotting the surface of the hand specimen. The powdered rock effervesces freely in boiling acid and the black mineral appears to be magnetite. There appears to be in this section no suggestion of former minerals from which the present ones might have come.

The serpentine is commonly massive in appearance. A few thin seams of chrysotile were noted. Three thin sections of the massive serpentine were examined. In one the entire section is composed of interlacing plates of antigorite with a few grains of a mineral identified as magnetite. The magnetite is often corroded and usually surrounded by a halo of carbonate and serpentine. Carbonate is sparingly distributed in the ground mat of serpentine. Another section resembled the one just described except that well-formed grains of carbonate are abundant and more or less interspersed with antigorite throughout the section. In the third section carbonate is moderately abundant and disseminated shapeless material, identified as talc, occurs among the flakes of serpentine. Magnetite held about the same proportion in all three sections.

None of the sections gave any significant clue as to the nature of the rock from which the present one was derived. The field relations are not definite. If the rock was an igneous intrusive its primary relation to the contiguous country rock is lost. If the rock is an extremely altered siliceous dolomite it seems noteworthy that similiar rock does not occur more frequently not far away to the north and south.

The rock would be known in the stone trade as a verd antique "marble." The ledge was purchased by the Vermont Marble Company, according to information furnished by Mr. Freeman. At present it is probably too remote to be worked profitably.

BRIEF REVIEW OF THE WORK OF OTHER STUDENTS IN PARTS OF THE GREEN MOUNTAIN REGION.

An important paper dealing with the problem of age relations among rocks in the Green Mountain province, which have geographical relations to the lowland that borders the plateau on the west much the same as do the rocks of our area, was published by C. L. Whittle in the *Journal of Geology,* Volume II, 1894, pages 396, et seq. Mr. Whittle's detailed studies were made in the district east and southeast of Rutland, in an area bounded on the east by Plymouth valley and on the west by what he called the Rutland valley, a portion of the "Vermont valley." Whittle was led not only to the recognition of the wide distribution of pre-Cambrian rocks in the Green Mountains, but to a separation of them into two distinct series within his area. His paper will doubtless be a valuable reference for all students of Green Mountain geology for a long time to come.

In the western part of the Rutland area of Whittle is a formation (terrane) of quartzite which he called the Olenellus quartzite on the basis of fossils discovered by Dr. Walcott in similar rock farther south. This quartzite has been studied by the writer in the vicinity of Rutland and is recognized as the time equivalent of the basal quartzite member of the quartzite-dolomite series of our area.

The quartzite flanks a central core of crystalline rocks among which is a conglomerate that is associated with the quartzite and has been regarded by some students as a part of the terrane to which the latter belongs. Whittle disagrees with this view and maintains that "Between the conglomerate and the quartzite there is an extensive series of metamorphic rocks which have been overlooked in the past." Also, "Beneath the conglomerate horizon the gneisses and other rocks, a series of dots instead of the line, to indicate omission in quotation, with their interbedded limestones and quartzites make a second series composed wholly or partly of sedimentary rocks, separated from the first, of which the conglomerate is the base, by an unconformity sufficiently well identified to warrant a subdivision of the Precambrian Algonkian terranes into two series."

The several reasons cited for referring the various rocks east of the quartzite to an older terrane than the quartzite, namely the Algonkian (a term employed by the United States Geological Survey and now commonly called the Proterozoic), proceed from the acceptance by the author of the quartzite as a "near-shore deposit" and as such affording evidence in itself of an approximate subjacent limitation of the Cambrian sediments. To quote the author: "The Lower Cambrian lies directly upon granitoid gneiss twenty-five miles south of Wallingford, where the contact is depositional with no conglomerate whatever." From occurrences such as just stated Whittle holds that it is not necessary to postulate still lower members of the Olenellus horizon on the ground that the base is not delimited by a conglomerate. Further, a reversed dip in the quartzite was not observed on the west side of the range while "in the stratified series just below overturns occur along this line. This may be cited as evidence of discordance at the base of the Olenellus quartzite as it is extremely unlikely that pronounced overturning could have taken place without involving the quartzite in its folds." The author recognizes that under certain circumstances a thick bed of quartzite might not be affected by minor folds. "The series below (below the Olenellus quartzite), however, possesses quartzites still more massive and flinty, rocks which have been involved in close flexures as sharp as those in fissile associated beds."

Attention is then called to the remarkable persistence of the Olenellus quartzite in southern Vermont and in Massachusetts, while "the series immediately beneath is extremely variable in character and thickness, due to original deposition and to the metamorphism that it has suffered."

Careful search through the Green Mountains proper did not result in finding any traces of the quartzite and there appeared to be no evidence that it once mantled over the range. "There are abundant occurrences, however, of the lower series in the heart of the range where many of the highest peaks are capped by one member or other. There is stratigraphical and microscopical evidence that this series has undergone repeated disturbances; the quartzite exhibits but one."

The lower series may be wanting, as at Clarksburg Mountain in Massachusetts, and at other places where the quartzite rests unconformably upon crystalline gneisses. "It should not fail to be stated that in many localities the quartzite lies directly upon fissile mica schist, the upper member of the series below in apparent conformity therewith, and the difficulty of referring the schist to the Lower Cambrian or the Algonkian is apparent." Whittle is disposed to call the schist, on which he states the quartzite "lies," the uppermost member of an upper series of pre-Cambrian rocks and to place at the base of this series the metamorphic conglomerate which serves to delimit the series from another which lies below.

In summing up the considerations which seemed to him to justify the separation from the Cambrian of the various metamorphic rocks which form the surface east of the present eastern margin of the quartzite formation, Whittle stresses the following: (1) Extreme diversity of the metamorphic series, or great lithological difference, as compared with the quartzite horizon. (2) Evidence of profound orographic movements in the latter not observed in the former, the folds often occurring overturned to the west. (3) Occurrence of the quartzite reposing discordantly upon granitoid gneiss not far south of the area under discussion and also nearby in New York. (4) The near-shore character of the quartzite. (5) The fact that the quartzite does not occur in the heart of, or to the east, of the range, whereas the series below has been traced across the mountains.

In his discussion Whittle seems at no time to entertain the idea that the metamorphic series in any part could be younger than the Cambrian, but he does admit, "That a part of the Vermont rocks immediately below the quartzite may be proven in the future to belong with the quartzite." By most of the earlier workers in the Green Mountain region the "central gneiss" was regarded as older than the quartzite. By one early student it was considered "more recent than the Stockbridge limestone."

Following his general statement of the various considerations that led him to a differentiation on the basis of age of the metamorphic rocks from the Cambrian the author gives a somewhat detailed description of the members comprising each of his pre-Cambrian series. The younger of these he calls the "Mendon Series" and the older the "Mt. Holly Series."

To one acquainted with the rocks of our district the description of the Mendon group reads in some ways so much like what one finds in the schist series of Lincoln that it seems necessary to consider the possibility of kinship between them and a similar geological history for both. Resemblances may be stated as follows: (1) Much the same passage at the present surface from bedded quartzite to mica schists; (2) similarity of types of schists and variations within them: muscovitic and chloritic rocks; (3) segregations of secondary quartz in lenses and irregular bunches; (4) inclusion of quartzitic types; (5) frequence of magnetitic phases; (6) presence of arkosic phases.

In the Lincoln area metamorphic conglomerate was not found developed on the scale described by Whittle for the Mendon district; nor is there present such abundance of limestone as in the Mendon series. In structural features the schists of Lincoln have much in common with those of Mendon.

The Mt. Holly series appears to be somewhat more diversified than any group found in our area which could be regarded as in any way distinct from the schist series of Lincoln, and it does not appear possible to draw any close comparisons of rocks found in the main range of our area and to the east of the range, in Warren, with those mentioned by Whittle for his Mt. Holly series. From the description the members of the Mt. Holly series appear to be more "chaotic" in arrangement, as well as more diversified, than the rocks of Warren.

A number of years later Professor Foye[1] working in the Rochester quadrangle, which lies just south of the Lincoln Mountain area and, therefore, between our district and that studied by Whittle, arrived at conclusions which supported in several respects the views advanced by Whittle in regard to the existence of a pre-Cambrian series, such as described for the Mendon group.

In the Rochester area, in the town of Ripton, a conglomerate is present which Mr. T. N. Dale[2] had previously described as basal Cambrian. Mr. Foye recognizes a conglomeratic phase in the basal portion of the quartzite at some places, but this he seems to regard as typically arkosic and different in character from the rock which Dale described as Cambrian. The latter, Foye, considers as probably equivalent to the metamorphic conglomerate of Whittle, and as pre-Cambrian (Proterozoic) in age. As described by Foye the Cambrian sequence of his area is substantially like that of ours, consisting of a dolomite lying on a quartzite which at some places has an arkosic conglomerate at its base. Below this series, like Whittle, Foye distinguishes an older series which is, however, represented differently at different places. It may consist only of a conglomerate overlain by dolomite, in which case it is thought that the lower series is only partially represented due to erosion of higher members consisting of micaceous quartzite and mica schist. From the resemblances in many cases which the rocks of his area seem to have to those described by Whittle as making up his Mendon series, both with respect to the characters of the rocks and their relations, Foye considers that the Mendon group is well represented in the Rochester district. To explain certain relations which he observed between the metamorphic conglomerate, which he regards as pre-Cambrian, and other rocks Foye introduces the idea of overthrust faulting. South of Ripton "the conglomerate was found to overthrust a chlorite schist." At Silver Lake, in Salisbury and outside the Rochester area, a conglomerate like that found in Ripton and regarded as Proterozoic in age is associated with quartzite, but the relations "may best be explained by an overthrust fault which has carried the underlying Mendon conglomerate up and over the Cambrian quartzite."

[1] Report of the State Geologist, Vol. 11, 1917-1918, pp. 76-98.
[2] The Cambrian Conglomerate of Ripton, Vermont. *Amer. Jour. Sci.*, Vol. 30, 1910.

Although Professor Foye is unmistakably disposed throughout his paper to recognize the presence in the Rochester area of equivalents of the members of Whittle's Mendon series, and to accept their pre-Cambrian age, he feels obliged to state that "It remains to be demonstrated that they form a part of the Mendon series, for very similar rocks occur in the Lower Cambrian series outcropping in the front range and in the Champlain valley to the west."

In a paper published in the Eleventh Report of the Vermont Geologist, 1917-1918, pages 194-199, Mr. Nelson C. Dale gives a preliminary account of studies in the Green Mountain region which extended into the western portion of our area. A more detailed statement is given in the next Report of the Geologist, 1919-1920, pages 43-56.

In his first paper Professor Dale writes of the schists lying to the east of the quartzite-dolomite series as possibly Ordovician in age, but in his later discussion he leans towards a pre-Cambrian age for these rocks. The uncertainty which he feels respecting their stratigraphic position is best expressed in his own words (second paper). "The rock types of the so-called pre-Cambrian, though very different as a whole from the Cambrian, may upon further investigaton turn out to be younger than the age assigned them. Though in large part of sedimentary origin . . . . . these pre-Cambrian rocks are not set apart because of any great unconformity or any structural incongruity, but simply on the basis of lithological characteristics. It is quite possible that they may be younger than the Cambrian, because there were no structural inconsistencies near the line of contact." Mr. Dale, however, regards certain highly metamorphic members which "were undoubtedly igneous in origin" as properly included for that reason in the pre-Cambrian. "Some of the schists . . . occurring among the quartzite-dolomite contact in the west may very well be a part of the Cambrian quartzite." Attention is called to the "conformity of strike" between so-called pre-Cambrian and the Cambrian with the suggestion that the present structural lines of the pre-Cambrian rocks were due to regional orogenic processes in post-Cambrian time.

Mr. Dale's studies in Bristol and Lincoln, as indicated by his map, were made chiefly among the rocks of the front range and those of narrow belts lying on each side of it. The writer's examination of the schistose rocks in the western part of Lincoln township, north of New Haven River, gave results as to principal types of rocks and their distribution very like those which Dale described. With respect to the determinations of relations among these rocks the writer is not able to add anything of importance to Dale's conclusions. He is in accord with Dale's view that the quartzitic schist (sheared quartzite) which at the present surface succeeds the quartzite east of the meridian of Ackworth probably belongs to the quartzite formation, and is of Cambrian age, and recognizes with Dale the general lack of transitions between the two and the absence of structural definition between the sheared quartzite and the various schists that succeed it on the east.

GENERAL SUMMARY.

In each of the contributions which has just been reviewed in a brief way it is apparent that its writer could not free himself completely from reservations in the matter of assignment of age relations of certain members of the metamorphic series that borders the Cambrian quartzite formation on the east. The uncertainty seems to remain even after all observed criteria which apparently serve for making distinctions have been stated. To one at all acquainted with the rocks in the western part of the Green Mountain region an attitude of doubt and caution seems inevitable from the present condition of things. With respect to the age of other members of the series there appears to be less doubt and the reasons for this are reasonably apparent.

The massive quartzite is such a conspicuous formation along the western margin of the Green Mountain upland and has such extensive development in Vermont as well as in Massachusetts and New York that in view of its clearly unconformable contacts with older rocks at certain places and the presence in it of Lower Cambrian fossils at different localities it is not surprising that it should be regarded as not only constituting the normal basal Cambrian in these regions wherever it is found, but as almost *sine qua non* for its recognition. However, in spite of the persistence of the quartzitic rock and its usually great thickness wherever it occurs, numerous observations have shown that at various places throughout its extent it is associated with schistose rocks in such relations that the latter must be regarded as normal members or phases of the Lower Cambrian terrigenous group. Moreover, studies which the writer has made of field relations between the gneisses and Paleozoic rocks in the Highlands of southeastern New York state have shown that the basal portion of the Lower Cambrian grades laterally and downward from quartzite into rocks that represent unsorted, "impure" terrigenous material accumulated on the borders of an overlapping sea. Other studies in various parts of the western border region of the Green Mountain plateau suggest that the basal Cambrian is represented by schistose rocks at numerous places, while a survey of the wide region lying west of the Green Mountains in Vermont indicates

that a variety of conditions prevailed during the accumulations of the Lower Cambrian rocks so that they now present over broad areas great lateral variations and notable vertical ones in both the dolomitic and terrigenous members. It would seem that massive homogeneous quartzite while very common was really a special development of well-sorted terrigenous material and that conglomerate was local in its occurrence.

It has seemed important to establish the fact of lateral and vertical variations within the terrigenous basal portion of the Lower Cambrian because in those places where sharp definition between quartzite and schist is wanting, it is possible to conceive that vertical or lateral variation in the character of the sediment is involved as well as a difference in behavior under shearing stress between contiguous masses of sediment. In the light of observations made by the writer of the effect of shearing stress on a formation of shale carrying relatively thick beds of firmer, siliceous material, in which the thicker beds buckled or ruptured, while the muddy rock above and below was sheared into fissile slate, it is not difficult to understand that a difference in structure might be looked for in a massive, probably somewhat indurated sandstone and an associated mass of thinly-bedded sediment in which probably a good deal of mud was present when these were simultaneously acted upon by powerful forces of compression. In one case the massive sandstone would suffer some folding, doubtless, and some shearing, as is shown by the quartzite in our area, while in the other case a marked schistose structure would be induced, along with the formation of new minerals, which would differ from one place to another according to variations in the character of the sediment.

The considerations just offered are for the purpose of showing why some of the schists lying east of the massive and sheared quartzite in the western part of Lincoln township might possibly be classed with the Cambrian, especially in view of the fact that some of them are not very different from certain schists which are found stratified with the quartzite at certain places. But even if the possibility of a Cambrian age for some of these schists be allowed the problem of where to draw the line between the Cambrian and other rocks still remains.

At the present writing, then, it seems possible to distinguish in our area with any degree of accuracy only two distinct rock series: (1) The western sequence composed of quartzite, dolomite and sheared quartzite; and (2) a metamorphic group lying to the east of the other in Lincoln and Warren. Some of the metamorphosed sedimentary members of the metamorphic group may represent the western sequence, but it is hardly probably that all do. At least one other sequence of different age is inferred in spite of the absence of any features for structural separation. Probably more than one is present. Within the metamorphic area more or less altered igneous rocks are undoubedly present.

The areal group of metamorphic rocks west of the main range in Lincoln seems to be distinguished from that of Warren by (a) an occasional bed of marble or other calcareous inclusions, (b) a rather prominent band of garnetiferous schist, (c) clearly recognizable and not excessively altered basic and acid igneous rocks, (d) apparent absence of talc and serpentine.

Mountain-making forces have given a foliated structure in some measure and usually in a marked degree throughout the region. Probably pre-Cambrian rocks are present, but it has not been proved.

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