REPORT

OF THE

STATE GEOLOGIST

ON THE

MINERAL INDUSTRIES AND GEOLOGY

OF

VERMONT

1911 - 1912

EIGHTH OF THIS SERIES

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STATE OF VERMONT.

OFFICE OF STATE GEOLOGIST.

BURLINGTON, VT., *October 1st*, 1912.

To His Excellency, John A. Mead, Governor:

SIR: In accordance with Section 279, Statutes of 1900, I herewith present my Eighth Biennial Report as State Geologist.

A brief resume of the work carried on during the years 1911 and 1912 is given in the introduction.

As in past years the work of the Survey has been greatly aided by the services of several well known geologists, who have spent a part of their summer vacation in studying certain areas in this State. As this work has been carried on at comparatively small cost a much greater amount of work of permanent value to the State has been accomplished than would otherwise have been possible under the very limited appropriation which is allowed for the expenses of the Survey.

It has from the first been the aim of the Director to make the work of the Survey of the greatest practical value to the people of the State, but a certain amount, of purely scientific investigation is necessary as a foundation for that which is more obviously practical.

Besides a considerable amount of field work, the usual work of the office, correspondence, examination of ores and various minerals etc., has been carried on.

Very respectfully,

G. H. PERKINS,

Geologist.

STAFF OF THE VERMONT GEOLOGICAL SURVEY,

1911-1912

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INTRODUCTION.

This volume is the eighth in the series published by the present Survey.

The following summary of the content of the following pages will indicate the character and scope of the work which has been carried on during the past two years.

The first article has been prepared, as stated, in response to a very often repeated demand for a general account of the geology of the Green Mountain region. As will be readily seen, the geology of Vermont is very complicated, very difficult of interpretation in many places and while much study has been given to it, much more is needed before many of the problems presented can be solved. The article does not claim to do more than give a summary of what is at present known of the structure and history of our rock masses. In the second article, Dr. C. H. Hitchcock continues his discussion of the geology of the eastern portion of the State, other papers by him on this subject having been published in former reports.

In the present article Dr. Hitchcock gives the results of many years of study of the adjacent region carried on while he was resident in Hanover, N. H. Using as a necessary basis for such work the Strafford and Hanover Quadrangles of the U. S. Geological Survey, the author discusses the rocks of the area included and their distribution. Although the Hanover Quadrangle is partly in New Hampshire, more than half of its area is on the Vermont side of the river and the two quadrangles are so associated that any satisfactory study of the region must include both. Dr. Hitchcock's studies are carried south from the area mentioned and he has furnished a most interesting account of the rocks of the south eastern part of the State. The results of this study are unusually important because of the discovery of extensive rock areas which Dr. Hitchcock considers as Devonian, an age not previously recognized in this State, except in a very small spot near Owls Head, in the extreme northern part. The maps which accompany the text will be found of interest to those who wish to know the areal distribution of the different rocks.

Dr. C. H. Richardson, who for five or six years has spent several weeks each summer in field work in some of the northern countries contributes a paper giving the results of two seasons, work in Irasburg, Craftsbury and Albany. In this work Dr. Richardson has had assistance from Messrs. E. F. Conway, M. C. Turner and M. C. Collister of Syracuse University.

The engineering laboratories of the University having been equipped with necessary apparatus for testing in various ways such building stones as might be offered three of the recent graduates undertook a series of tests during the past year the account of which is presented in the papers of Mr. W. A. Bristol who studied the effects of high voltage currents and Messrs E. R. Baker and A. R. Davidson, who studied the strength of marble and slate which he examined.

Professor C. E. Gordon of the Massachusetts Agricultural College has joined the force of the Survey during this season and is investigating the rocks of Bennington County. Professor E. C. Jacobs of the University of Vermont has also joined the Survey and is engaged in a study of the talc deposits of the State and a critical examination of the talc and its associated minerals. Both of these gentlemen expect to furnish reports of their work in the volume following this as they have not yet had sufficient time to complete their investigations. Professor Jacobs has sent in a preliminary statement which will be found in the article on Mineral Resources.

Professor G. H. Hudson, of the Normal School at Plattsburg contributes a paper on the so called Rill Markings often seen on limestone ledges. Although these observations were all made near Plattsburg the phenomena described are common on the Vermont side of the lake and any explanation of those in New York is equally valuable when applied to those in this State.

The final article is designed to give the latest information as to the building stones and minerals of the State.

The geological study of Chittenden County has been continued thru the two years and the Geologist, assisted by Mr. D. B. Griffin has been collecting material for a complete report upon the rocks of this area and much has been gathered, but it has not been practicable to prepare such a report for this volume. The Geologist wishes to add that the papers included in this volume have been printed as received from the authors and they

are alone responsible for whatever views are expressed. As will be seen, the text is quite profusely illustrated and it may not be out of place to note that nearly half of the plates have been obtained without expense to the State.

A General Account of the Geology of the Green Mountain Region.

G. H. Perkins.

INTRODUCTION.

It may be well to state at the outset, that this article has been prepared in response to numerous requests that for several years have been coming to the office of the State Geologist.

Many teachers and also many others who have become interested in the topography and structure of the mountain region of Vermont have asked for some statement that might help them to understand the why and the how fo the rock formations and general surface features that they saw all around them as they went over the State.

As the work of the present survey has gone on during the last fourteen years, such enquiries have been increasingly frequent, especially since pysiography and elementary geology have been added to the studies included in the curriculum of many of our public schools. It is not at all with the expectation of answering these enquiries completely or satisfactorily that these pages are written, for no one can do that in the present state of our knowledge of the geology of this State which, as will be seen later, presents many and great difficulties, but only with the hope that what is here written may serve as a contribution towards an understanding of our local geology.

There are, even after much and careful study and investigation, too many unsolved problems, too many puzzling rock masses, too many over turnings and transformations to make confident conclusions as to much that we find possible.

This is true of those parts of the State which have been most thoroughly studied; such as the region about Rutland or Burlington, and naturally, it is still more true of those parts less carefully explored. Few of the individual mountains that make up the Green Mountain Range have been studied at all, and none except Ascutney and Bird Mountain with such thoroughness as to give anything like satisfactory knowledge of the structure and composition of the mass of rocks that make up the mountains. While it would not be necessary to study every single peak or group of peaks in order to possess a pretty good general knowledge of the whole range, it is necessary to examine with some degree of care and skill a considerable number. If we could only have such complete studies as those of Dr. Daly on Ascutney*, Dr. Dale on Bird Mountain† or other similar studies to be mentioned we should know far more than appears likely to be the case for a long time to come as to the structure of the Green Mountains.

As will be shown in what follows, we do know much already as to the mode of formation, structural features, rocks, etc., of the Green Mountains and the adjacent region, but there is a great deal that we do not know. Such investigation is of necessity slow and the workers in this field are few and with very limited resources.

Until topographic maps of the whole State are available, accurate work is not possible. As yet only about a third of the State has been thus mapped and this has all been done without expense to the State.

Many other States have co-operated with the United States Geological Survey and the entire area, or at any rate, a large part of it, of such States has been mapped. Very little more of Vermont will be surveyed entirely at the expense of the general Government and unless the State will bear a part of the cost, this work will not be carried on more than to a very limited extent. Where such surveys have been made they have been found of very great use in many ways and more than once have saved in various economical enterprises far more than their cost. In any event the United States Geological Survey pays about two-thirds of the cost of the surveying and making the maps. A few years ago the opportunity to cooperate with the national survey was offered to the State through the State Geologist and was by him brought to the attention of the then sitting Legislature, but was killed in the committee to which it was referred. It is hoped that a more enlightened policy may prevail before it is too late to gain

*Geology of Ascutney Mountain, R. A. Daly, Bulletin U. S. Geol. Survey, 209.

†A study of Bird Mountain, Vermont, T. N. Dale, Twentieth Annual Report, U. S. Geol. Survey, Pt. II, p. 15.

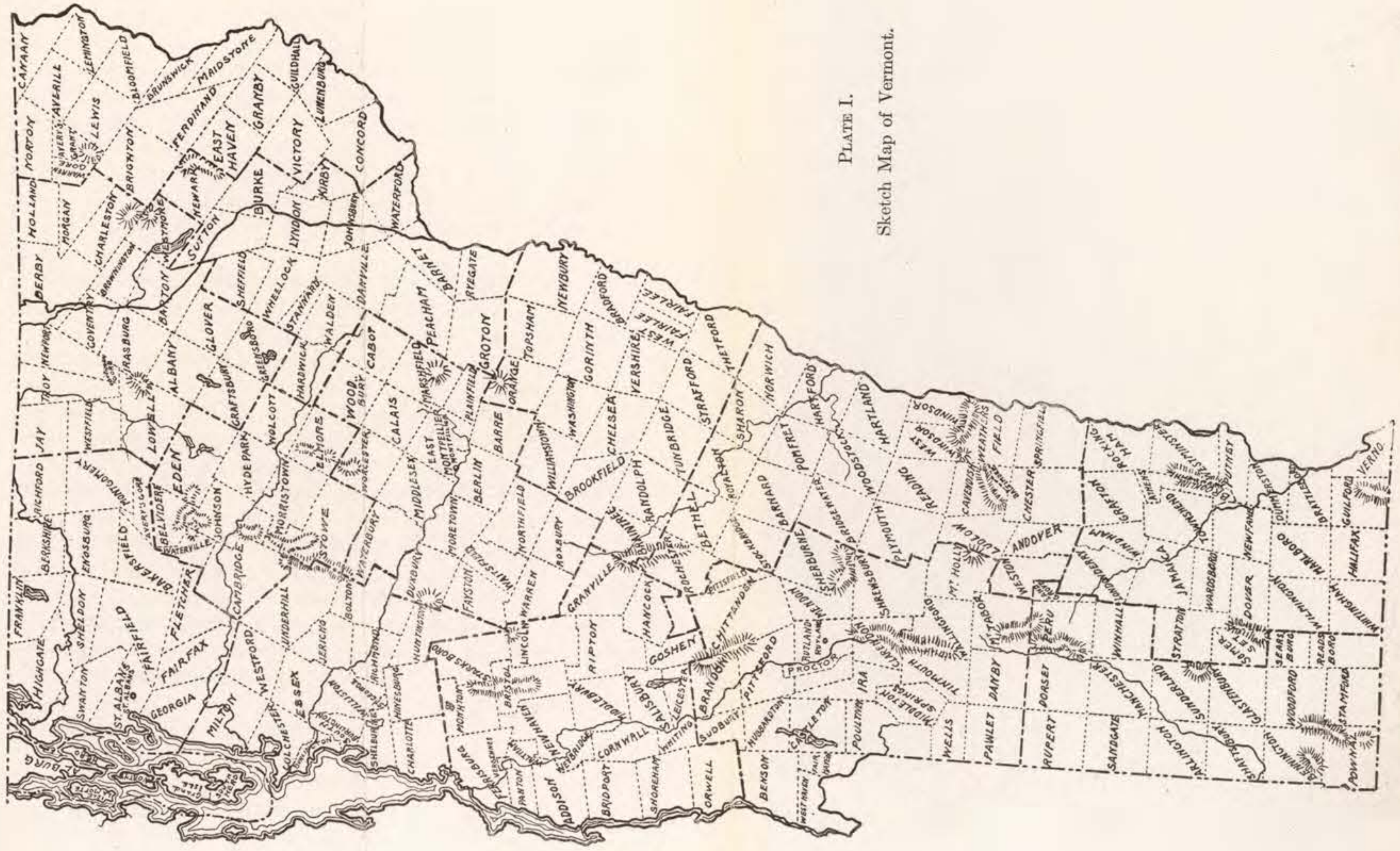


Plate I.

Sketch Map of Vermont.

the advantage of cooperation. The maps when completed are of the greatest use not only for geological purposes, but for all sorts of enterprises such as laying out highways, trolley lines, canals, locating reservoirs, utilizing water power, etc., etc.

Almost from necessity, the work of the present survey has been largely confined to those portions of the State which have been mapped, and this area will first be investigated, for the reason already stated, that to locate and accurately map geologically any region the topographic map must first be made.

Geological investigation has been carried on at intervals in Vermont since the time of Professor C. B. Adams, who was the first to be appointed State Geologist. But the frequent interruptions which have occurred because of withheld appropriations have prevented the accomplishment of much that might have been done.

Much that is of permanent value was accomplished and will always be considered in any full study of the geology of the State, but if we had no other sources of information than such as are furnished by the State reports our knowledge of our geology would be far less than it is. Fortunately, the problems which are presented in various portions of the Green Mountain area have attracted the attention of some of our ablest geologists and from the published reports of some of them we may add very important facts, suppositions and explanations to our previous knowledge of Vermont geology. As will be seen later, these articles are scattered thru a considerable number of journals, periodicals, government reports, etc., and many can be found only in large libraries. It is mainly because of the inaccesibility of much that is important to the student of Vermont geology, as well as because the inherent value of the material makes it well worth quoting, that liberal extracts from these articles will be given on the following pages. I am sure that to some the information thus collected will be valuable.

In the Fourth Report of the present series there is given a bibliography of works on the geology of Vermont. This list includes most of the accessible publications up to the time of publication, but as that list is not quite complete and as the volume containing it is now out of print and therefore cannot be supplied, a revised list is here given for the convenience of any who may wish to refer to it. This list may be found at the end of this chapter. It should be continually remembered that the writer is not attempting to do anything more than give a summary, which must of necessity be somewhat general, of the results of the more important investigations which have been carried on especially during the last twenty years, with such reference to earlier work as may be useful. As has already been indicated, this paper is prepared mainly not for trained geologists, who will find more or less very familiar matter, but for the many teachers and others who may wish some not too technical statement of the past history and development of the physical features of Vermont.

For convenience of reference a map of a State is given in this connection Plate I.

Geology of Vermont Complex.

Vermont, though one of the smaller of the states offers probably a greater number and variety of perplexing geological problems than any other State in the Union in proportion to its area.

There are few square miles among the ten thousand that make up its surface that do not present some puzzling features.

Much of this is due to the changes which in very early geological times were produced in the rocks in connection with the making of the Green Mountains.

These mountains, extending as they do through the entire length of the narrow area and at the north spreading into practically two ranges occupy, with the foot hills and slopes, a large part of the surface of the State. Thus the geological history of Vermont is largely included in that of the Green Mountains, but there are other features which cannot be neglected. This is especially true of the series of small mountains which are quite distinct from the Green Mountain Range found in the south western part of the State. These, the Taconic Range, are later in age than the greater range but are still of the older formations and all of the rocks of Vermont belong to the older time geologically.

In other words Vermont has been a land body, and therefore long exposed to weathering and erosion from early times.

As will be shown later, the surface of the State, the sands gravels, clays, etc., as well as the present contours of much of the surface are of geologically recent age, but the underlying rocks, the ledges and the mountains are very ancient.

In order that those not familiar with geological arrangement

may readily locate the periods to be mentioned the following table is given here at the outset.

Geological time may be divided as follows, beginning with the oldest:

Precambrian Era.

Archean Period.
Algonkian Period.

Paleozoic Era.

Cambrian Period.
Ordovician Period.
Silurian Period.
Devonian Period.
Carboniferous Period.
Permian Period.

Mesozoic Era.

Not found represented in Vermont.

Cenozoic Era.

Tertiary Period.
Pleistocene Period.

Precambrian.

It is quite possible that in the axis of the Green Mountains covered by more recent rocks, there may be those which should be referred to the oldest group, the Archean, but it does not seem probable that there are large masses of such rocks and, so far as present knowledge informs us, it is not certain that there are any.

Of the next period, the Algonkian, there is abundant evidence as will be seen in what follows.

It appears to be true that the foundation of the Green Mountains is of this age.

Paleozoic.

Of the beds which are referred to one or another of the periods of this age there are many. Indeed most of the State is made of rocks of paleozoic time.

No one can even estimate with much probable accuracy the length of paleozoic time. All calculations, and there have been many, are open to grave doubt and it seems much better simply to say that this time was very long, long beyond our clear comprehension, than to attempt any more definite calculation.

CAMBRIAN.

Only the first part of the paleozoic is represented in Vermont. We find next above the Algonkian, as should be the case, the Lower Cambrian with its sandstones, shales of usually a very hard sort, slates and some limestones. In places, along the western border of the State, that is in the Champlain Valley, fossils occur in considerable abundance, but much of the Cambrian here is destitute of fossils. Middle and Upper Cambrian should be found in the State, but neither is well established as yet except a small area in St. Albans in which a hard limestone occurs in a conglomerate, which contains Middle Cambrian fossils. Through the studies of several geologists, but mostly those of Dr. C. D. Walcott the trilobites and brachiopods of the red sandrock and the adjacent limestone have been made well known.

Some of the fossils of the Parker Ledge in Georgia and the dark gray limestones of Swanton were long ago studied by Adams, Billings, Thompson and the Hitchcocks, but far more than these has Dr. Walcott investigated the important localities and in many of his Cambrian papers the fossils have been figured and described.

In several of the preceeding Reports of this series more or less reference has been made to the Cambrian rocks. They are always hard, silicious, and form some of the boldest headlands on the eastern shore of Lake Champlain as at Malletts Bay, Rock Point, Red Rocks, etc.

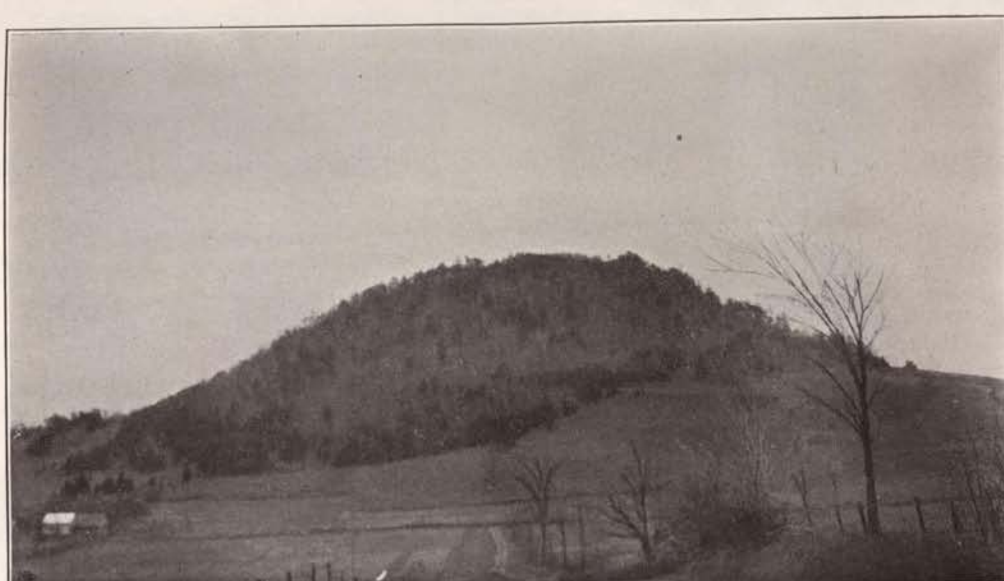
One of the Cambrian outcrops is shown in Plate II which is taken from the north side of Shelburne Bay and shows what is perhaps the finest exposure of the Red Sandrock beds anywhere to be seen. The cliff is one hundred feet high and forms the

Red Rock Cliff, Shelburne Bay. Lower Cambrian Sandstone.

PLATE III.

Lower Cambrian Sandstone, Mallets Bay.

PLATE V.



Mount Philo. Cambrian Red Sandrock.

southern portion of what is locally called Red Rocks. The many layers which compose the mass are of various shades of red and when seen in a favorable light the cliff is very fine. Plate III gives a very common form of Cambrian cliff along the shore of Lake Champlain. The lighter band next the water shows the difference between high and low water in the lake.

Marble Island in Malletts Bay, Plate IV, like other islands in the same region is of the same rock, though most of the islands in the lake are later, limestone or shale. It also forms all or most, of some of the higher elevations between the Green Mountains and the lake. Such hills as Cobble in Milton, Mutton Hill and Mt. Philo in Charlotte, Plate V, and most of Snake Mountain in Addison are examples. These masses of rock are composed of a red sandstone containing more or less lime. Elsewhere, as at the famous Parker ledge in Georgia, the rock is a hard, dark shale in which have been found many of the large lower Cambrian trilobites *Olenellus*, etc. In Swanton and St. Albans there is a hard gray, silicious limestone containing *Kutorgina*, *Nisusia iphidea*, etc. The mottled red and white Champlain marbles form a calcarreous phase of the Red Sandrock. There is also a good deal of quartzite in the Cambrian. All of the above are lower Cambrian.

Because of its ancient and primitive character the life of the lower Cambrian is particularly interesting. In our Vermont beds fossils are usually very scarce, but some of the layers of a gray quartzite found north of Mallets Bay are completely filled with the anterior portions of the typical trilobite, *Olenellus thompsoni*. Plate VI shows a part of one of these layers reduced about one-half. It is quite remarkable that in this locality such abundance of these usually rare fossils is found and of each only the portion shown. Not a single entire specimen nor more than mere fragments of the hind portion of any have been found.

Plate VII is from a polished slab of the Champlain marble. This is a thick bedded, calcareous phase of the Red Sandrock which has been quarried and sold for many years as the Winooski, or later, Champlain marble. Very rarely have fossils been detected in this stone, but in several localities pieces like that shown, containing *Salterella pulchella* have been found.

Students of the Cambrian of America must always be most grateful to Dr. Walcott for the thorough work which he has done and is doing in respect of the fossils of this age as well as for its splendid quality. Dr. Walcott's papers that are of most interest to Vermont geological students have been published in Tenth Report, U. S. Geological Survey and especially by the U. S. National Museum at different times. As many of the specimens described and figured in these works are from the Vermont localities mentioned above, they have especial interest to Vermonters. In Volume X of the Annual Reports of the U. S. Geological Survey Dr. Walcott has a long paper which contains very much of interest on Vermont Cambrian geology.* Although some changes and revisions of what is said of the Cambrian in this article have been made in subsequent publications, this does not prevent the whole article from being of the highest interest and value.

In the Fifth Report of this series Mr. G. E. Edson has written of the Vermont Cambrian as it occurs in a few of the typical localities in Franklin County, (Fifth Report Vermont Geologist, pp. 117-154.) In the Sixth Report, pp. 210-220, Mr. Edson has a second article on the Geology of Swanton in which there are many facts concerning the Cambrian. In the same Report the State Geologist has an article on the Geology of Franklin County, (pp. 178-209) in which there are statements concerning the Cambrian of that county. On pages 221-264 of the Sixth Report the writer has a preliminary paper on the Geology of Chittenden County. Pages 224-236 of this article discuss the Cambrian and Plates XXXIX-XLVII illustrate the text. This subject is continued in the Seventh Report, pp. 249-256. According to Dr. Walcott all these rocks belong to the upper part of the lower Cambrian. In some parts of this Cambrian area there occurs a calcareous conglomerate which Mr. Edson in his articles calls "Intraformational Conglomerate". In company with Mr. Edson I have collected fossils from this horizon and from inspection of these fossils Dr. Walcott concludes that we have in these rocks Middle Cambrian. This conglomerate, the matrix as well as the included bits being Middle Cambrian, does not so far as made out, cover very much of the area of Franklin County, but it is interesting as representing a period not hitherto surely found in the State. So far as I know, the upper Cambrian has not been satisfactorily made out anywhere in Vermont, although it is very possible that some of the beds of metamorphic rock may ultimately prove to be of this age. As will be seen from following statements in regard to Vermont geology, the lower Cambrian is widely distributed along

*The Fauna of the Lower Cambrian or Olenellus Zone, C. D. Walcott, 10th Rep. U. S. G. S. 1890.

PLATE VII.

Salterella pulchella, Billings. In slab of Champlain Marble, Cambrian, Swanton. Reduced slightly.

Plate VIII.

Cliff of Beekmantown Limestone, Thompson Point, Charlotte.

the Green Mountains having been determined at numerous localities, although it is more fossiliferous in the northern part of the State. In actual area, probably, this horizon is most extensively represented in Rutland County for here it is not only found in quartzites, limestones, etc., but the slate belt of the western part of the county, which has for many years been of such commercial importance to the State, belongs to this age. There are a few quarries in which the slate appears to be Ordovician, but nearly all of the purple, green, gray and variegated slate of Rutland County has been shown by Walcott and Dale to be lower Cambrian, while the red slates just over the line in New York are Ordovician.

As is stated beyond, the slates of eastern Vermont, which have been mostly quarried in Northfield, are Ordovician.

ORDOVICIAN PERIOD.

This period is very well represented in Vermont and in the western part of the State many species of fossils have been collected. In the eastern part of Vermont masses of rock referred to this period occur, but for the most part they are destitute of fossils, being largely more or less metamorphosed. All of the subdivisions of the Ordovician are found in the Champlain Valley and are as follows: Beckmantown, Chazy, Black River, Trenton, Utica.

BEEKMANTOWN.

The lowest beds of the Ordovician, the Beekmantown, are well exposed at several localities. They are especially well shown on Providence Island, at Fort Cassin and Thompson Point and to a less extent at New Haven, Middlebury, Salisbury and elsewhere. Plate VIII shows one of the cliffs of Beekmantown at Thompson Point. That at Fort Cassin is very similar in appearance as seen from the water tho not in the same horizon. The most famous locality for the Beekmantown in Vermont has been that at the mouth of Otter Creek at Fort Cassin. This locality does not appear to have been of great extent and at present it is almost impossible to collect anything of much interest.

The characteristic fossils of the Fort Cassin beds are figured on plates LIII-LXII of the Seventh Report. Some of the same species occur on Providence Island and Valcour Island and very likely other good localities will be discovered. Yet the Fort Cassin locality is quite unique in the number and variety of mollusks, especially cephalopods which the rocks have yielded in a very small area. These fossils are so interesting in themselves and form so important a part of Vermont paleontology that two of the six plates given in Professor Seely's paper on the geology of Addison County are reproduced here, Plates IX, X.

The strata of Beekmantown in Vermont are usually hard, more or less silicious and in many cases not fossiliferous. This is certainly true if, as I have supposed, the great belt of limestone which extends thru Addison and Chittenden Counties is of this age. In the Fourth Report, p. 121, Plates LVIII, LXIII, LXIV, the Beekmantown of Isle La Motte is discussed and in the Sixth Report page 252, Plates L, LI, the fine exposure of this rock at Thompsons Point is shown and described.

CHAZY.

From the southern part of Isle La Motte, which is entirely of this rock, south along western Vermont in numerous outcrops strata of this age appear at intervals. A few of the more typical exposures of Chazy strata as they occur along the shores of Lake Champlain, where they may best be studied are shown in Plates XI-XIII, where the heavily bedded rugged, rather coarse character of the rocks of this period as they usually appear are well shown.

Plate XII, taken from another part of the west shore of Grand Isle, shows the same heavy bedding and also the result of wave action upon softer layers below the harder. A different sort of shore is found where the rock is of different character as shown in Plate XIII. This cliff is the most northern of the Chazy exposures on the Island and the rocks vary much in hardness, some of the layers being compact and hard, others soft and shaly, but the softer strata are not at the base and the lake is, with the efficient aid of frost and ice, breaking away the entire cliff and strewing the beach with blocks, some of large size, broken from the cliffs above. The Chazy is as a whole much more fossiliferous than the Beekmantown. The fossils are as a rule small, but very numerous. Some of the strata are almost wholly made up of shells of *Rhynchonella plena* a bivalve shell, others are largely sponges or corals. In some layers the

Plate IX.

Plate IX.

1, 2. *Protorthis cassinensis,* Whitfield.
3, 4. *Protorthis minima,* Whitfield.
5, 6. *Rhinopora prima,* Whitfield.
7. *Murchisonia cassina,* Whitfield.
8, 9. *Maclurea affinis,* Billings.
10, 11, 12. *Straparolina minima,* Whitfield.
13. *Ecculiomphalus compressus,* Whitfield.
14. *Bellerophon cassinensis,* Whitfield.
15. *Isochilina cristata,* Whitfield.
16. *Isochilina gregaria,* Whitfield.
17. *Isochilina,* large figure; *seelyi,* smaller; *gregaria,* Whitfield.

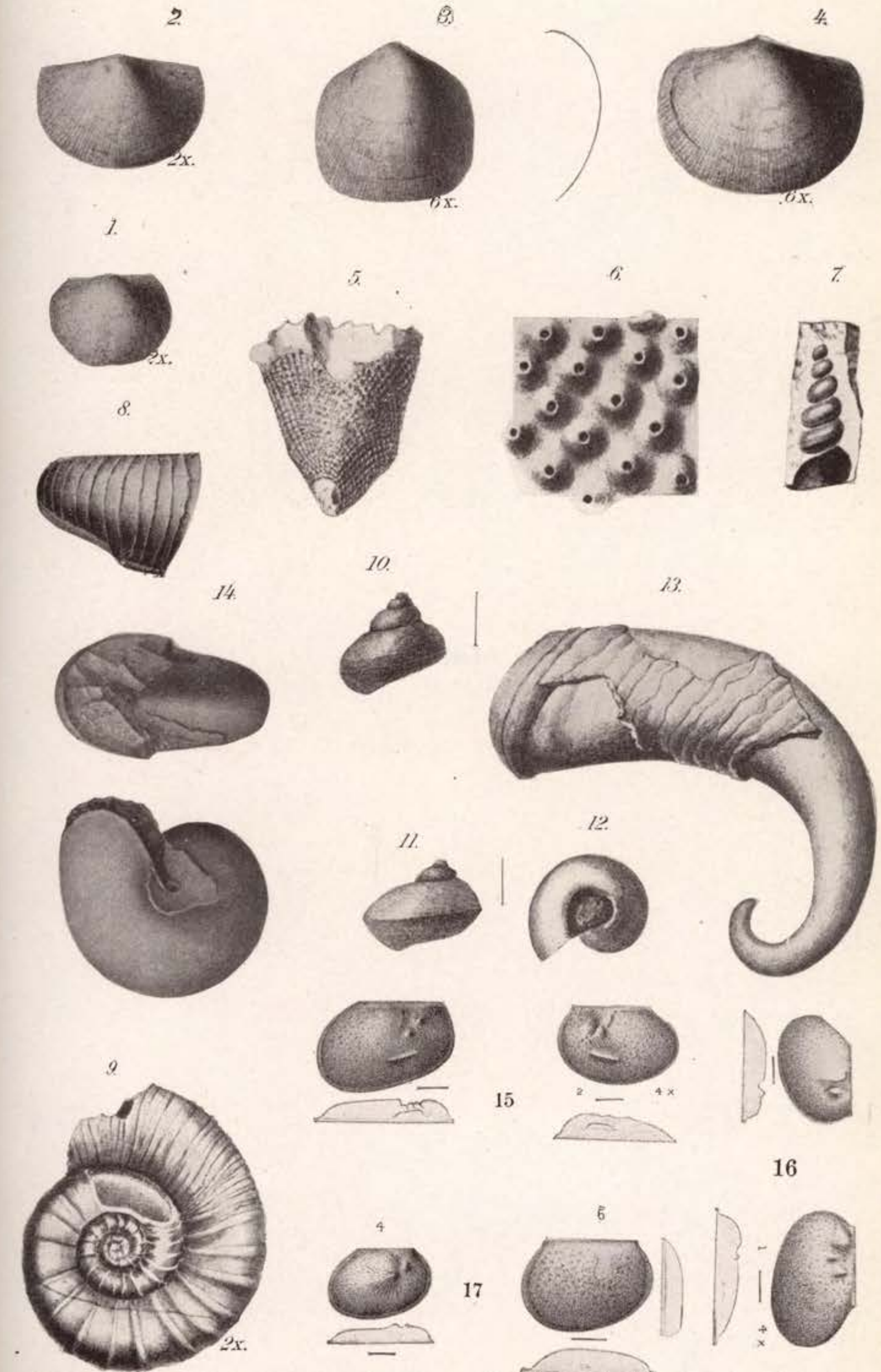


Plate X.

Plate XII.

Contact of Chazy and Beekmantown

fossils are mostly broken and so confused that it is impossible to recognize them.

Plate XIV shows curiously crossbedded Chazy Strata on Isle La Motte. This was probably laid down on a sloping sea bottom.

Plate XV is from a photograph taken from a layer which as is readily seen is filled with small sponges. This fossil is very abundant in some of the Chazy layers in the beds at Isle La Motte and Grand Isle. Larger forms are shown in Plate XVI, but these do not accur so abundantly as to make up the bulk of the stone, tho in some layers very numerous. Many of the Chazy fossils of Vermont have been figured and described in previous reports and in other publications.

The Chazy of the Champlain Valley was first well studied by Drs. Seely and Brainerd and their paper published in Bulletin American Museum of Natural History, New York, Vol. VIII, pp. 305-315, must always be of great value to anyone studying these beds. Professor Seely has also described the Sponges of the Chazy in the Third Report, Vermont State Geologist (pp. 151-161, plates LVI-LIX.) Also the Stromatoceria of Isle La Motte, Fourth Report, 144-152, plates LXX-LXXIV; Beekmantown and Chazy formations in the Champlain Valley; in Fifth Report, pp. 174-187, plates XXXIV-XLV; Geology of Addison County, Seventh Report, pp. 257-315, plates XLVIII-LXII in which article all of the Ordovician beds so far as they occur within the prescribed limits are considered. The writer has in the Third and Fourth Reports described the outcrops of the Chazy as they occur on Grand Isle. Perhaps the most characteristic fossil of the Chazy in this region is the *Maclurea magna* and it is one of the largest. This coiled shell, often four or five inches across is seen in many of the layers of the middle Chazy.

Plate XVII is not intended to illustrate this species, but it is very interesting as it shows a portion of a large slab, one of several taken from the bottom of one of the deeper marble quarries at West Rutland. The fossils are distorted but plainly recognizable and serve to fix the age of the marble. So far as I know these *Maclureas* are the only fossils that have been found in actual marble in Vermont.

A very important paper on the fossils of the Chazy of this region is that published by Dr. P. E. Raymond in the report preceding this. From the plates by which Dr. Raymond's paper is illustrated, one has been selected, Plate XVIII. The whole article.

however, should be consulted with the accompanying plates by anyone who is especially interested in Vermont fossils.

In the paper referred to above by Brainerd and Seely the whole mass of the Chazy is divided into the following subdivisions: A. Lower Chazy. B. Middle Chazy, which is most easily recognized by the presence of *Maclurea magna* and C, Upper Chazy. Each of these is readily subdivided into beds of limestone of different color and structure, a small amount of sandstone and a little slate. These are not geological divisions, but only differences of material.

BLACK RIVER.

Above the Chazy comes the Black River. This limestone is better displayed in South Hero than elsewhere tho not confined to this locality. It is unusually compact, even grained stone that, as some of the plates show, breaks naturally into very regular pieces, that is, it is very regularly jointed.

This is shown by Plate XIX where the blocks that have fallen from the rather high cliff are many of them sufficiently regular in shape to be used for ordinary building without dressing. Some of the old houses on the island were built of just such blocks.

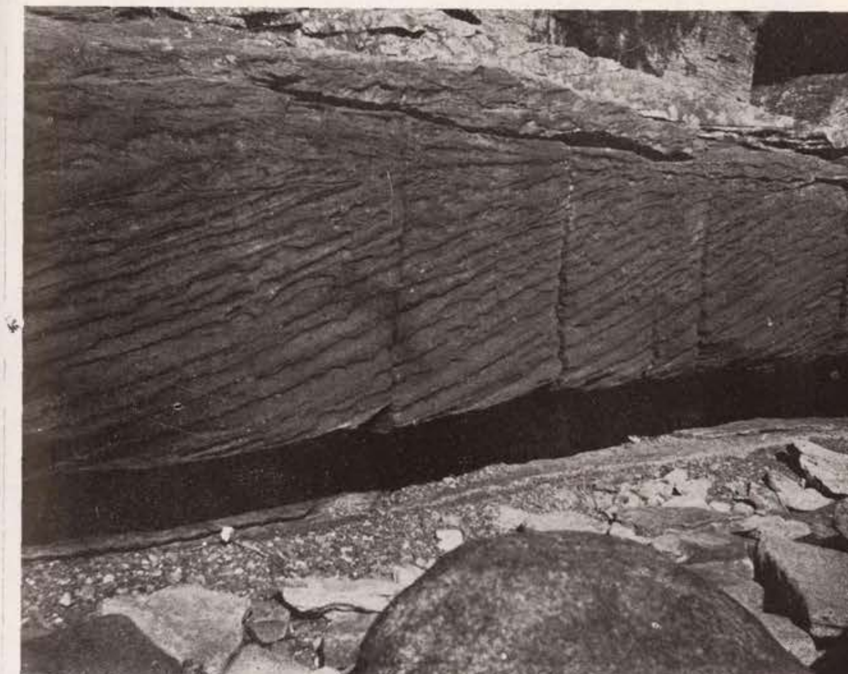
Plate XX, from another locality, shows the same regularity in the joining. It is in some of the outcrops quite black, in others bluish gray with frequent veins of white calcite showing compression. Fossils are far less common than in either the beds of the Chazy or Trenton, which lie below and above the Black River.

Occasional masses of *Columnaria alveolata*, a few cephalopods or *Maclurea logani* or *grandis*, and sometimes brachiopods are found, but by far the greater part of the rock is wholly without fossils. Illustrations of Black River cliffs may be seen in the Third Report, plates 33-37, 60, 61 and in the Fourth Report on pages 107 and 135 will be found some notice of its occurrance on Isle La Motte. From this locality the limestone is found at intervals thru western Vermont as far south as Benson. Its fine grain and the jet black color of some of the beds when polished have in past times brought it into use as black marble. It was at one time quarried for this purpose on Isle La Motte, at Larrabees Point and perhaps elsewhere. As a rule the exposures of the Black River in Vermont are not extensive, tho quite numerous near Lake Champlain.

PLATE XIII.

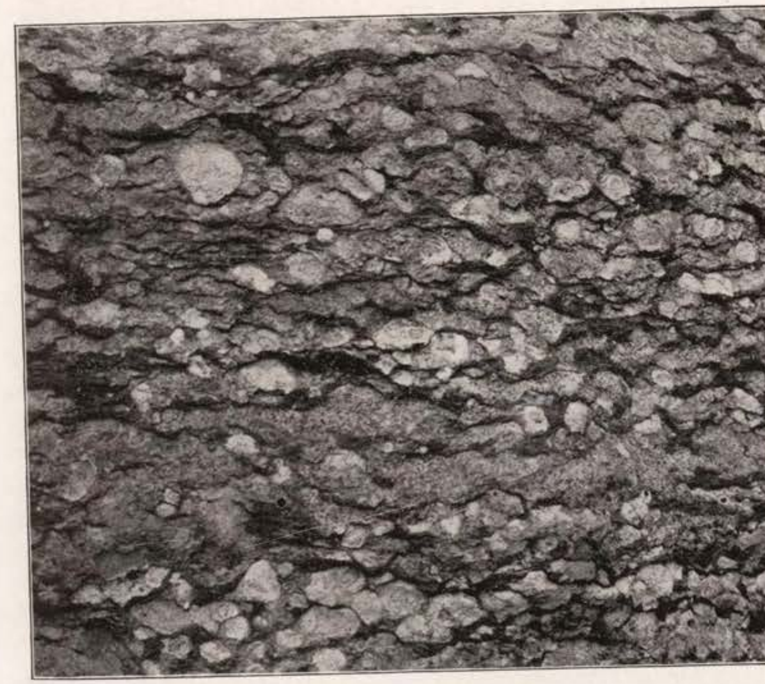
Chazy Cliffs, Rockwell Bay, Grand Isle.

Plate XIV.



Crossbedded Chazy Limestone. Isle La Motte.

Plate XV.



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

TRENTON.

The Trenton, while not so finely exposed anywhere in Vermont as in New York or elsewhere, is nevertheless seen in considerable force at a number of localities. It forms the greater part of the ridge which extends thru the middle of South Hero and there are cliffs on the west shore of the island. In the northern part of the State there is but little Trenton. In Highgate there are Trenton exposures but not extensive ones. There are also small patches in St. Albans. South along the shore of Lake Champlain Trenton does not appear until one reaches Charlotte. Here at McNeils Point and Cedar Beach there are exposures of this limestone, there are also outcrops of usually not great size, in the line of towns of Addison County which border the lake and on southward thru Benson. At Chimney Point and Larabees Point the Trenton is well displayed. In most localities along the lake the Trenton strata are not so much disturbed and in some cases are very regularly horizontal. Plate XXI is a good example of a typical outcrop on the shore. Plate XXII, however, shows somewhat disturbed strata and these are seen here and there. The Trenton beds are usually quite full of fossils and altho the rock is nowhere made up largely of any particular species yet some of the layers contain such fossils as *Prasopora lycoperdon* or *Orthis testudinaria* in great abundance. If Dr. Richardson's conclusions as given in the Sixth Report are correct, there are extensive areas of Lower Trenton east of the Green Mountains. The Waits River limestone and the Memphremagog slates extend from Newport south, with some interruptions for many miles. The Memphremagog slate includes the roofing slate of Montpelier and Northfield. Not only these, but other metamorphosed strata may be relegated to the same age or at least to the Ordovician, very likely below the Trenton. The slate belt of Montpelier and Northfield is well treated by Professor T. N. Dale in Bulletin 275 U. S. Geological Survey. It should be noticed that no certain proof of the age of either the slate or the limestone has yet been found. The reference to Trenton is to be regarded as probable not certain. Illustrations of Trenton exposures may be found in the Third Report, plates XXVIII, XL-XLII, LXII. Notes on the Trenton are found in the Fourth Report, pages 106, 136 and Fifth Report, page 142.

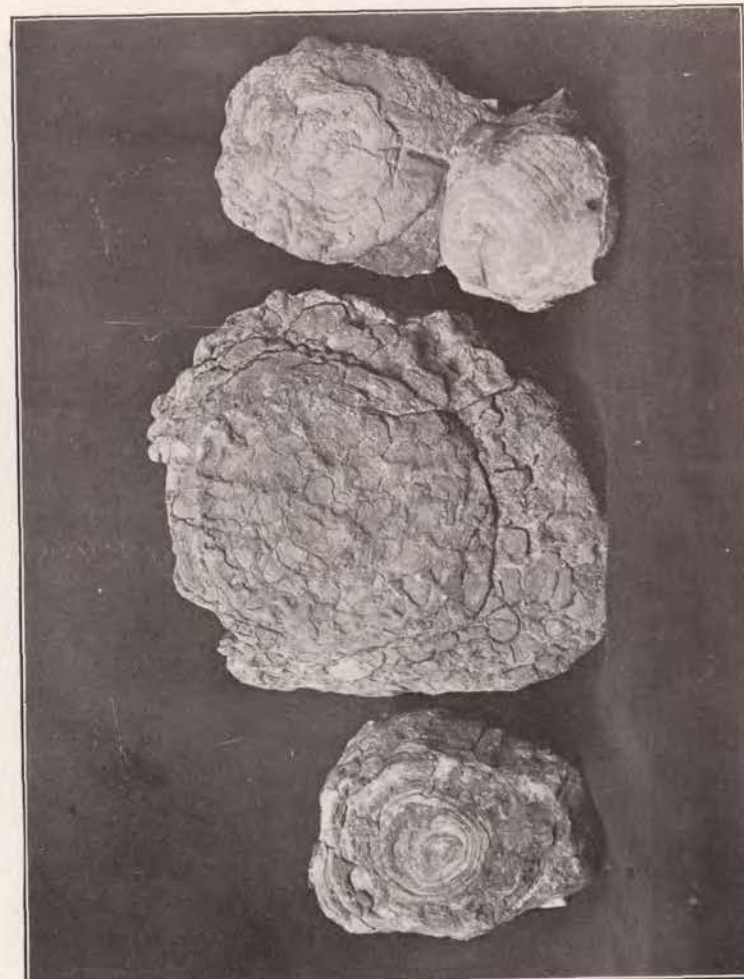
UTICA.

The Utica is largely distributed in the northwestern part of the State. The whole of the Alburg peninsula, North Hero and much of Grand Isle is covered by shales of the age. The soil of these regions is largely due to the decomposition of this shale. Here and there the Utica appears on the Vermont shore of Lake Champlain and in small patches away from the lake.

There is a cliff of Utica not far south of Sandbar bridge on Grand Isle which affords the best example of folding and crumpling that I know of in this region. Plate XXIII shows the central portion of this cliff and other portions are figured in the Third Report. This cliff shows greater disturbance than is seen elsewhere, but it is not usual to find the Utica in such horizontal and regular layers as is seen in the Trenton or indeed most of the Ordovician strata of the Champlain Valley. Evidently the Utica beds were subjected to greater stress than those of earlier formations. The Utica is nowhere fossiliferous to any great extent. A few fossils, few in numbers and few in species, are found in many limited localities, but by far the larger part of the shale is destitute of any trace of life. In some few places the Utica becomes more compact and contains more lime and finally grades into limestone and bears, with typical Utica species, those that are as typically Trenton. Indeed as noted in a former report the Trenton and Utica pass from one to the other and in the Champlain Valley at any rate, no good line can be frawn between them. Thus far no trace of Utica has been found east of the mountains tho some of the rocks of that region may not improbably be metamorphosed beds of this age. In several places, as at Shelburne Point the black shale is thickly traversed by veins of white calcite which are very conspicuous. These veins are of all widths from fine hair lines to bands several inches wide. These white lines and bands are results of the same disturbances that caused the folding and tilting. Plate XXIV shows one of the boldest of the few Utica headlands on the shore of the lake. The Utica is everywhere a soft, shaly rock, with the small exception noted and therefore easily wears away under erosion so that much of what formerly, geologically speaking, formed the lake shore has disappeared. A few of the islands as the Four Brothers, Juniper, Rock Dunder, are of this rock.

With the Utica, the formation of stratified rocks over most

PLATE XVI.



Cryptozoon saxiroseum. One fifth natural size.

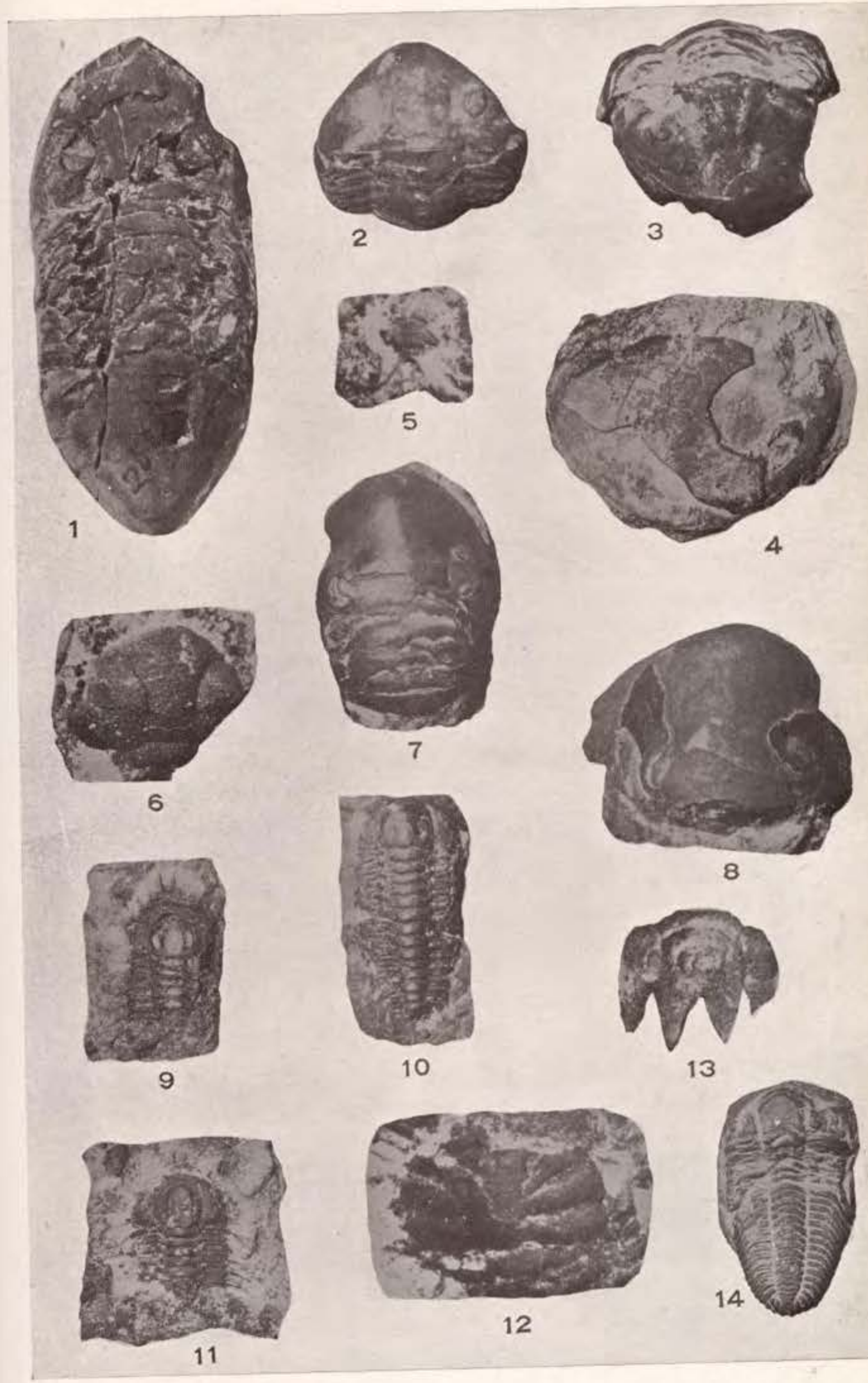
PLATE XVII.

Section of Maclurea magna in Marble from Ripley Quarry, West Rutland.

Plate XVIII.

Plate XVIII.

1. *Isoteloides angusticaudus*, Raymond. An entire, but imperfect specimen from Isle La Motte. Slightly larger than natural size. Vermont University Museum.
2. *Onchometopus obtusus*, (Hall). Cephalon and thorax of an enrolled individual in the Vermont University Museum. From Isle La Motte, Vermont.
3. The same specimen. Thorax and pygidium.
4. The same species. A pygidium from Valcour Island, showing the large punctae of the shell.
5. *Ceratocephala narrawayi*, Raymond. The cranidium of the only specimen known. From McCullough's sugarbush at Chazy, N. Y. About three and one-half times natural size.
6. *Amphilichas minganensis*, (Billings). A young individual whose dorsal furrows do not reach the neck-furrow. About three and one-half times natural size. From McCullough's sugar bush at Chazy, N. Y.
7. *Nileus perkinsi*, Raymond. The cephalon and part of thorax. This specimen is from Isle La Motte, and is now in the Vermont University Museum. Holotype.
8. *Nileus perkinsi*, Raymond. Paratype in the U. S. National Museum. From Isle La Motte, Vt.
9. *Glaphurus pustulatus*, (Walcott). A photograph of one of the specimens. From Chazy, N. Y.
10. The same species. A large entire specimen from Isle La Motte, Vt. Vermont University Museum.
11. The same species.
12. *Heliomera sol* (Billings). A glabella from the lower part of the Chazy at Chazy, N. Y. About three and one-half times natural size.
13. *Nieszkowskia* sp. A pygidium from McCullough's sugarbush at Chazy, N. Y. About three and one-half times natural size.
14. *Pliomerops canadensis*, (Billings). A small specimen from Valcour Island, New York.



Trilobites from the Chazy Limestone of the Champlain Valley.

of Vermont ceased finally, except that there is a very small area in the extreme southern part of the State in Vernon which has been usually regarded as Silurian and another larger area near Owls Head in Canada which is Devonian. That there are other Devonian areas wholly within the State is very probable. Indeed if Dr. Hitchcock's conclusions as given in his article later in this volume are correct, we have in Springfield and Charlestown considerable areas of altered Devonian strata. No undoubted Devonian fossils have been found at any time within the limits of Vermont, tho in the Memphremagog region a few have been found very near the line. After the Devonian there is no evidence that any part of the area of the State was under water and that rock making went on until many ages had passed.

TERTIARY.

In the Tertiary of Brandon we have a most singularly restricted area of Eocene Tertiary with many species of fossil fruits, but no other form of life. The Brandon lignite has been fully discussed in the Fourth and Fifth Reports and many species of the fruits figured and described. So far as our present knowledge goes, we know only of the small masses of lignite near Brandon, but as bits of the same material have been found in boring a deep, well in Waltham, twenty miles north it seems certain that it extends north farther than has been supposed. The lignite is now everywhere covered, tho many years ago it was found at the surface at a few points according to Dr. Hitchcock's account written in 1851.

But no surface showing has been found for many years, all that has been seen having been reached by shafts sunk thru the associated clays. Because of its concealed position it is probable that the true extent of the lignite will never be known. Nor is it possible to know how much of the material, clays, iron, etc., associated with it is of the same age and can be used for determining the Tertiary area.

The 1861 Report, regarding all the associated clays as of the same age, makes out a narrow strip running from Bennington north to Monkton almost without break and, according to these geologists, with considerable breaks, it was found as far north as Swanton. A list of twenty-six towns west of the mountains and three east of them, is given in all of which evidences of Tertiary beds had been found as these geologists thought.

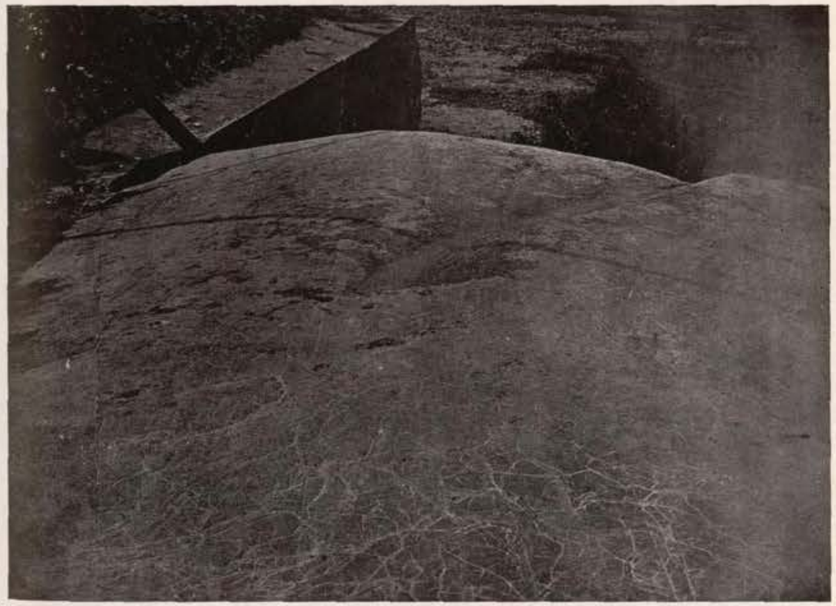
While it is not only probable, but certain, that these rocks do cover a much larger area than can now be outlined with any certainty, it is also very doubtful whether they were as extensive as indicated in the 1861 report. The evidence upon which the conclusions there given are based does not appear at all conclusive. It is indeed, uncertain and at present quite impossible to determine how many of the various clays, limonite, etc., that are found in connection with the lignite are of the same age, but it is certain that some of them are, especially the white clays, kaolin, and those from which formerly "Brandon paint" was manufactured.

As has been shown in the articles in the Fourth Report, pp. 153-212, plates LXXV-LXXXI and Fifth Report, pp. 188-230, plates XLVI-LVIII we find in this small area of lignite a remarkably varied group of trees, so far as can be judged by their fruits. It is also remarkable that only a few leaves, and those fragmentary, have been found, while, as the plates above referred to, show many forms of fruits in good preservation have been collected. There can be no doubt that during the Tertiary, probably about the middle, there were swamps in the western part of the state and that in these grew many trees of a sort that indicate a considerable warmer climate than now exists in this region.

The lignite is usually rather soft, brittle, dark brown in color and has much the appearance of dark hued decayed wood, but is much firmer and heavier. Plate XXV illustrates two bits of this substance. In a stove it burns readily giving off a peculiar odor and leaving a large amount of ash. Plate XXVI shows how perfectly the structure of the wood has been preserved. It is, however, very difficult to study microscopically as, when cut in thin sections, the whole mass crumbles. Only by special methods, which are described in the Fifth report, page 195, can thin sections such as are necessary for use in a microscope, be prepared. So far as I know this has not been successfully accomplished except by Professor E. C. Jeffrey of Harvard University, who made all the sections shown on the several plates in the Fifth Report. Occasionally the lignite is harder and more like coal, but usually it is as described above. Imbedded in the masses of lignite are many species of fossil fruits, using the term in the botanical sense. Plate XXVII shows a few samples of the two hundred species which are described in the Fourth and Fifth Reports. Not only is the woody structure almost perfectly preserved in the best specimens of the lignite but in one piece Professor Jeffrey

Cliff of Black River Limestone, Chippen Point, Grand Isle.

PLATE XXX (a)



Top of Ledge, Fisk Quarry, Isle La Motte, showing Glaciation.

gauge time, of long duration. Sooner or later another change in the climate of this region came about and the ice began to melt and with the melting to recede northward leaving the surface of the country again uncovered though much changed.

As soon, apparently, as the country was inhabitable, animals and plants came to occupy it. Strange animals and at first arctic plants. Some of these plants may still be found, a dozen species, on the summits of the higher mountains or at lower levels in Labrador. But the animals which roamed over what is now Vermont in post glacial time were of species quite unlike those now living here. Two species of elephant left bones and teeth in several localities. Not many, but enough to prove that they did live here. Specimens of these are in the State Museum at Montpelier and elsewhere.

In due time, other changes came about and modern conditions and modern plants and animals replaced those that had preceeded them and we come to the Vermont familiar to us of today. With the melting of the great ice mass immense torrents filled all streams and lakes. These were modified not only by the enormous increase in the amount of water, but also by the dams which not infrequently formed. These were sometimes of the retreating ice itself and of course relatively of short duration, and sometimes of the material moved by the glacier and more or less permanent. Necessarily, these dams of ice, gravel or clay changed for a greater or less length of time the courses of streams and the form and size of lakes. When one considers the probable effect of all these agencies, rise or fall of land, retreat of ice or earth, it is easily seen that during Pleistocene time very great changes in the physiography of the State must have occurred. And yet it is not easy to realize how extensive these changes must have been until we bring together as many of the facts as possible and correlate them with each other. Many rivers flowed in quite different course from those familiar to us. All were vastly larger and therefore eroded larger and deeper channels. All lakes were larger, some of them many times larger than now, and their outlets were not as now. These facts may be illustrated by some examples which are more or less directly connected with the history of Lake Champlain.

(Glacial) Ancient Lakes.

As preliminary to the discussion of the development of Lake Champlain, it may be worth while to notice briefly some of the changes in the water bodies now found in the basin of the Great Lakes and the St. Lawrence. A full account of these changes may not find place here, but the interested reader is referred to Chamberlain and Salisbury, Geology, Volume III, pages 394-405 for further details.

"When the end of Lake Michigan ice lobe withdrew a little within the Lake Michigan basin, a crescentic belt of water formed about its southern extremity and found a point of discharge into the Illinois valley thru a col southwest of Chicago, which it proceeded to erode to greater depths. This valley has since become the site of the Chicago drainage canal. A glacial lake (Lake Chicago) was thus initiated and as the ice lobe withdrew, the lake gradually extended northward." (Chamberlain and Salisbury, p. 395.)

The above quotation is of interest because it is not only pertinent to the locality named, but it indicates what took place in many localities. Various changes went on in the great lakes region. A large lake, Lake Whittlesey formed in the Erie basin and emptied westerly into a smaller lake, Saginaw, and this into Lake Chicago, become by this time much larger than at first. By and by Lake Saginaw became united with Whittlesey and extended east into the Ontario basin forming Lake Warren and this at first emptied westward into Lake Chicago and so on into the Mississippi.

Later the levels changed, and the outflowing waters of the eastern lakes found their escape southeastward thru the Mohawk valley into the Hudson. By and by new changes of level occurred and a lower outlet than that thru the Mohawk valley was found around the Adirondacks into Glacial Lake Champlain that occupied the southern part at least of the present Champlain valley and thence southward into the Hudson. By this time Lake Warren had divided into two smaller lakes, Algonkin and Iroquois. The former was where now Huron and parts of the other western lakes are found and has little connection with Lake Champlain, but Iroquois probably not only occupied the Ontario basin but extended into the Champlain basin. Lake Iroquois appears to have been caused by a dam of ice that formed after the retreat

of the glacier north thru the Mohawk valley. This same ice dam blocked the St. Lawrence and caused the water in the Ontario basin to flow out somewhere near Rome and onwards thru the Mohawk valley into the Hudson valley. "During the retreat of the ice a differential uplift was in progress, greater at the north. Gilbert says that when the Rome outlet was abandoned at the close of the Iroquois epoch the water of the Ontario basin descended for a time along a course beginning near Covey Hill near the Canada line and ending near West Chazy." Besides extending around the Adirondacks into the Champlain basin, it is possible that Lake Iroquois extended east in the St. Lawrence valley towards or to Quebec. There is some difference of opinion among geologists as to the extent of Lake Iroquois. By some it is doubted if it ever reached into the Champlain basin.

Lake Hudson-Champlain.

Before this time there was a lake which Peet calls Hudson-Champlain. This was a body of water that occupied the Hudson valley and extended over the present divide between Whitehall and Troy by which the two basins are separated, into the Champlain basin so far as the ice allowed. Of course as the ice in the Champlain basin by melting retreated north, this lake became larger, by the increase of its northern part.

Concerning the confluence of lakes Iroquois and Hudson-Champlain Mr. Upham remarks "From the time of union of Lakes Iroquois and Hudson-Champlain a strait at first about 150 feet deep, but later probably diminishing on account of the rise of the land about 50 feet, joined the broad expanse of water in the Ontario basin with the larger expanse in the St. Lawrence and Ottawa valley and the basin of Lake Champlain. At the subsequent time of ingress of the sea past Quebec the level of the St. Lawrence fell probably 50 feet or less to the ocean level. The place of the glacial lake so far west as the Thousand Islands was then taken by the sea." In the Hudson valley as the ice retreated north from New York Bay changes somewhat similar to those mentioned elsewhere took place. Professor Woodworth has most fully worked out the history of this region in these times. He writes, "North of Statsburg and thence northward through the Hudson valley there is a record of continuous lacustrine conditions for a time marked by beds of clay and marginal deltas. * * * * To this body of water whose clays were early designated the Albany Clays by Emmons no name is so appropriate as Lake Albany.''

Lake Albany.

Lake Albany doubtless began on the south in the waters standing in front of the retreating ice sheet prior to the opening of the Mohawk outlet of the great glacial lakes to the west.

"As soon as the ice retreated in the valley to a position north of Albany and the drainage of Lake Iroquois came into the Hudson valley Lake Albany properly came into existence. The clays and the deltas marginal to them extend north of Albany at least as far as the Moses kill. At this place the Hudson gorge proper widens out and the Albany clays which mantle the rock terrace marginal to the gorge are separable from the clays of the low grounds northward by reason of the partly ice-swept character of the surface apparently indicating that the northern limit of the lake was at one time formed by an ice margin over the Fort Edward district. That Lake Albany with the melting out of the ice in the Champlain district became confluent with the glacial lake stages of that district is borne out by the extension of clays from one district region to the other and by the extension of the water levels of the Lake Champlain area into the upper Hudson valley thru Wood Creek pass." Woodworth, Ancient Water Levels of the Champlain and Hudson Valleys. pp. 176, 177.

"For a time the waters of Lake Albany extended northward over the Fort Edward district, covering the lower portion of the plateau about Fort Ann; and thence connecting thru narrow defile of Wood Creek united with a glacial lake which was extending northward in the valley of Lake Champlain pari passu with the retreat of ice in that valley. The attitude of the land from Lake Champlain southward to the region of Lake Albany was now that of depression on the north so that the floor of Lake Champlain was below sea level tho the sea was as yet excluded by the ice."

Glacial Lake Champlain or Lake Vermont.

From some cause which can only be postulated from the known conditions of the time and hence probably the effect of the powerful discharge of the drainage thru the Hudson gorge coming not only from the melting ice in the Champlain district but as well

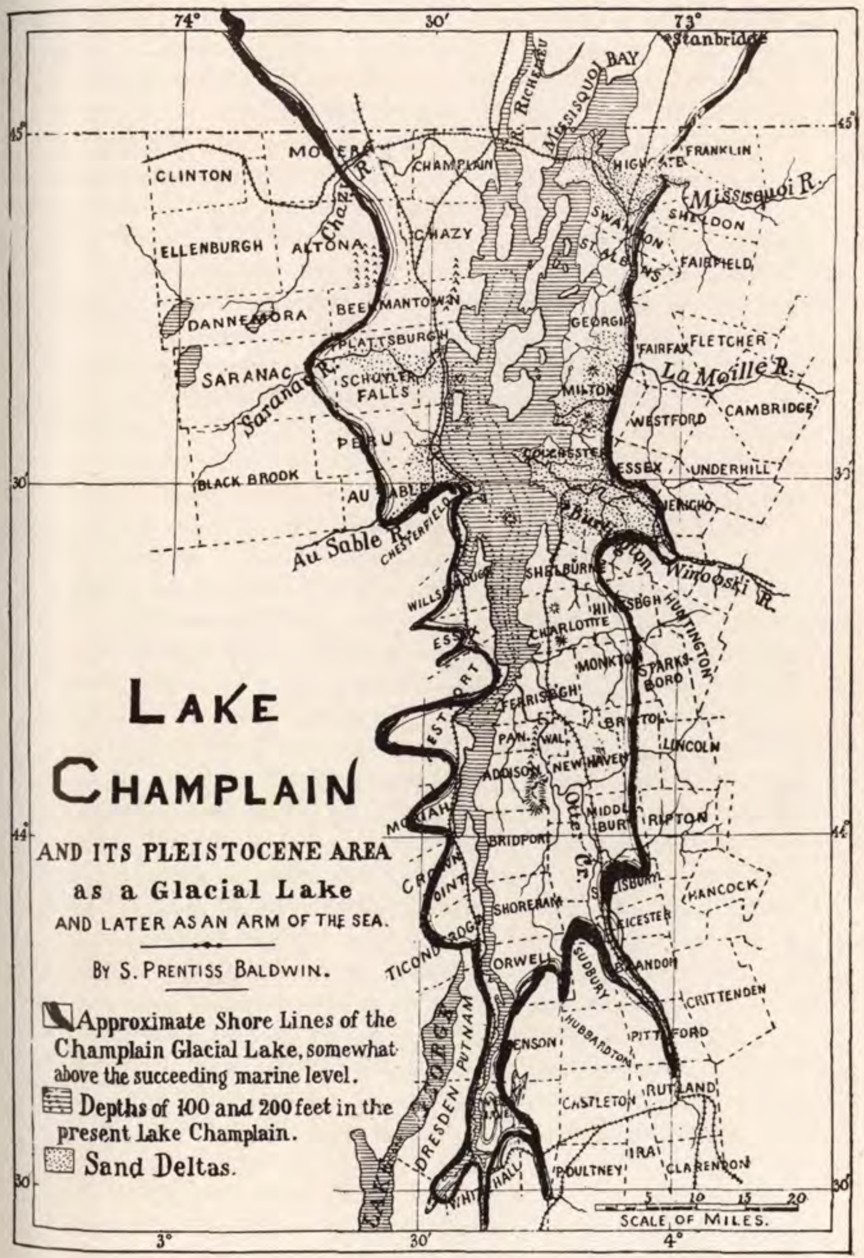
from the intake from Lake Iroquois which was now in existence on the west of the Adirondacks, the waters of Lake Albany were drained off. With the withdrawal of the waters over the Albany district a divide partly of glacial materials and partly of bed rock was revealed between the nascent glacial lake over the Fort Edward basin and in Lake Champlain valley and the region on the south, and waters began to spill over this barrier west and south of Schuylerville across those fields which were later the scene of Burgoynes defeat. Thus Lake Vermont was born, consisting on the south of the mountainous ridges between two of which Lake George lies, of a shallow lake over the Fort Edward district and a constantly enlarging body of water on the north.'' (Woodworth l. c., pp. 242, 243.) Professor Woodworth thinks that the outlet near Schuylerville was after a time shifted into a former channel west of this one entering the channel of the Hudson at Coveville. "Thus was formed the Coveville stage of Lake Vermont.'' It should here be noticed that what Woodworth names Lake Vermont is what most writers have called Glacial Lake Champlain. "The water level was now about 100 feet lower than in the previous stage and if the correlation worked out in this report is correct, the lake was at this time about 200 feet higher than the sea level.'' Woodward, l. c. By the gradual removal of the clays which filled the older gorge of the Hudson, the outflow from the lake went thru this and in time the waters of the Lake Champlain of that time sank lower and lower until they reached the level of the divide now existing Hudson and Champlain valleys in Wood Creek valley near Fort Edward.

"At a yet later stage, following the stand of waters in Lake Vermont under control of the Fort Edward outlet the ice barrier on the north began to give way; the waters leaked out northward, we are at liberty to suppose, thus lowering the lake level step by step; and then when the ice was no longer a barrier the sea came in at a lower level. * * * * The sea appears not to have extended farther south than Whitehall at which time the land was as high on the south if not higher than now.'' Woodworth, l. c.

Professor Woodworth does not regard the confluence of Lakes Iroquois and Champlain mentioned previously, as certainly indicated by the observed phenomena. Professor Woodworth also notes that "During the development of Lake Vermont and as soon as the ice had withdrawn from the northern slope of the Adirondacks, to the very border of that district a powerful discharge of water coursed along the ice front from the St. Lawrence valley to the eastward and fell into the lake near West Chazy. The course of this torrent is marked by the so-called flat rock areas from Covey Hill southward through Altona.''

Lake Vermont, which most writers prefer to call Glacial Lake Champlain has been repeatedly mentioned and a few statements further concerning this predecessor of Lake Champlain may not be amiss. The beginning and something of the progress of this lake has already been stated. At one time a northern extension of Lake Albany and emptying southward thru the Hudson basin, this lake gradually increased with the melting of the ice sheet north until finally it not only covered the present area of Lake Champlain, but more than twice as much. It also varied its outlets from time to time as elevation or depression of the land changed the levels about its shores. Its greatest development is well shown in a map given by Baldwin and reproduced in Plate XXXI. As the map shows its largest increase was towards the north, and the extreme northern border has not been clearly made out so far as I have found. Its width was much greater than now having been not less than twenty miles at the present Canada line and more than this still farther north. At Plattsburg the old shore was ten miles farther west than at present and the old lake extended inland west of the present for ten miles or more in places, as far south as the Ausable River. Below Port Kent the Pre-Cambrian Cliffs come near the present lake and there could have been no enlargement there. Nor could there have been much extension at any point south of there on the New York shore for the same reason. At a few places, however, the cliffs recede so that at Westport, and from Crown Point to Ticonderoga the waters covered the land several miles west of the sites of those places. On the Vermont side there was also large extension eastward. Here the reverse of what has been stated to have been true on the western shore took place for the lake was greatly widened in its south portion, but less in the north. Still, on the whole the waters covered a greatly larger area on the east side than on the other for there were no cliffs near the old shore forming an impassible barrier on the Vermont side as on the New York.

East of Alburg on the Canada line the lake was at least five miles farther east than now and, according to Baldwin, all of Franklin County west of the line of the Central Vermont R. R. was flooded. Also Chittenden County as far east as Essex, Jericho and



Richmond, about half of Hinesburg, most of Shelburne, New Haven and Middlebury, a small part of western Brandon, Salisbury and the northern part of Orwell. The old lake appears to have been more like a river than a lake south of Orwell, as it is now. But from Burlington south to Orwell, as the boundaries given show, our lake must have presented a very different appearance from that seen now, for instead of the narrow outline which it now has it must have been at Charlotte some fifteen miles wide and at Shoreham not less than twenty. There are several surface conditions by a study of which the former extent of a lake may be determined. The most important of these indications of the presence in any locality of a water body are the old beaches. One of these is shown in Plate XXXII. This is on Isle La Motte. The road from the village to the chazy ferry is cut thru the old beach and because of the cut it is very easily studied and its structure seen. It was a shore of Marine Lake Champlain and contains numerous shells of the common mytillus of our present sea shores. Attention has been called to the fact that at different periods, Lake Champlain has had several outlets. Professor Woodworth, while believing that these have not yet been fully made out, thinks that the following can be considered well defined. One was near Quaker Springs and at the time that the water flowed southward into the Hudson Valley the ice mass had not yet melted back as far north as Port Kent. Another outlet was at Coveville. "The cove at Coveville * * * * shows clearly that a large stream at one time flowed southward over the wall of the gorge at this place into the main gorge of the Hudson River, and was arrested after a slight amount o of cutting had been accomplished.'' The next outlet was thru the Wood Creek valley into the Hudson valley near Fort Edward. Professor Woodworth thinks that this was the lowest southern outlet which the Lake found. He also appears to think that probably there, leakage at the north thru which some water escaped thus lowering the level of the lake, but says that this cannot yet be proved. Now came an uplift of the land by which the divide now existing between Whitehall and Troy was at least commenced, and by which Lake Champlain was finally separated from the Hudson valley.

At the time of its greatest enlargement Glacial Lake Champlain was several hundred feet higher than now and it has been thought by some writers that possibly there might at one time have been a flow through the Green Mountain divide into the Connecticut valley.

As to this Merwin remarks "The divide at Williamstown is the lowest one between the Lake Champlain drainage and that of the Connecticut River. It is about four hundred feet higher than the highest stage of Glacial Lake Champlain (Lake Vermont), therefore Lake Vermont could never have had an outlet into the Connecticut River."

It appears probable that during the existence of Glacial Lake Champlain there was at some time, a sinking of the Hudson and Champlain valleys and that this subsidence after it had commenced continued for a long time. In consequence of this subsidence the whole channel of the Hudson River was finally much lower than now and the old channel can be traced by soundings under New York Bay as far as Sandy Hook, or at least in that direction.

Deltas of Glacial Lake Champlain.

When Glacial Lake Champlain was at its greatest extent all the streams emptying into it must necessarily have flowed at a higher altitude than now. They were undoubtedly also much larger and brought down correspondingly greater quantities of material. The Winooski emptied into the old lake somewhere about Richmond and in time formed a large delta which is now seen in sand plains between that town and the present lake. The soft and easily eroded material of this delta has been more or less cut away and is now in places wholly removed or more commonly cut into terraces. In Professor Hitchcock's papers in the Fifth, and Seventh Reports of this Survey, and Mr. Merwin's in the Sixth there will be found interesting data concerning some of the old deltas. The former calls attention to five basins that the Winooski has excavated out of the old delta deposits, which were three or four hundred feet above the present lake. The most westerly of these extends from the mouth of the river to Winooski Village, second between the village and the gorge at the Electric plant, the third between High Bridge and Hubbells Mills, the fourth between the mills and the railroad and the fifth from the railroad to Richmond and possibly farther. These basins may have been eroded by the stream, but as Dr. Hitchcock suggests, it is more probable that they were caused by stagnant ice masses about which the stream accumulated material and when the ice melted the unfilled spaces were left. The flat sand plain between

Winooski and Essex Junction on which stands Fort Ethan Allen and the Athletic field of the University are parts of this delta. In a similar manner the Lamoille River built up a wide delta about Milton, northern Colchester, and the south part of Georgia. Both of these rivers entered the lake farther north than now, the Lamoille north of Sandbar bridge and the Winooski in the neighborhood of Halfmoon Cove, which is not a great distance north of its present mouth. It may have been that one or both of these rivers had more than a single channel by which it entered the lake and that formerly the old channel was used at the same time as that now used. Altho only the two rivers named have been mentioned as having formed deltas, it is as true of nearly, or quite, all the Vermont streams that there were deltas of considerable extent formed at one time or another during the Pleistocene.

Glacial Lake Memphremagog.

Dr. Hitchcock has noted in the Fifth Report the great accumulations of modified drift in the Lamoille district. He states that in Wolcott this reaches a height of 380 feet above the present stream and in adjoining towns the modified drift is from 100 to 277 feet above the river. He accounts for these large piles of drift by what seems to have been the fact Glacial Lake Memphremagog emptied at Elligo pond and into the Lamoille thus discharging vast quantities of material into that river. The exact boundaries of this Glacial Lake Memphremagog have not been fully determined, but it must have been very much larger in extent than the present lake. As to the conditions at this time Dr. Hitchcock remarks "Glacial Lake Memphremagog discharged thru the Elligo outlet into the Lamoille, and the Glacial Lamoille discharged thru the Stowe strait to the Winooski, and even this latter stream poured thru Williamstown Gap into the White River and eventually into the Connecticut. This condition of things could prevail only when the ice filled up Lake Champlain so high that there was no chance for the water to be discharged except thru an eastern outlet." (Fifth Report, Vt., p. 248.)

While it is probable that Glacial Lake Memphremagog was larger and possibly of longer duration than other glacial lakes, there are evidences that quite a number of lakes which have now wholly or nearly disappeared, were formed by the confinement of waters in different basins by the retreating ice front or, more rarely, by morainal material. In the Winooski, Lamoille and other valleys, larger or smaller lakes were formed which continued for a greater or less time until by the melting of the ice mass, or changes in level or other causes the barriers were removed and the water drained off. Mr. Merwin has noted several of these lakes in his paper in the Sixth Report.

MARINE LAKE CHAMPLAIN.

After the divide between the Hudson Basin and that of Lake Champlain had been formed by the elevation of the land south of the lake and by the melting of the ice an outlet to the north had been found the ice probably for a time formed a barrier which effectually shut out the westward extended Gulf of St. Lawrence. But this in turn must pass with the increasingly mild climate and the sea water rushed in and filled the Champlain Basin. There was also a depression to the north of four hundred or five hundred feet. Thus Champlain became for a time an arm of the great St. Lawrence Gulf. The lake never reached so great an elevation during its marine stage as while a glacial lake. It was one or two hundred feet lower than the glacial lake and consequently covered a less area, but it still was much larger than at present.

A much smaller number of species of fossils is found thus far in the Champlain Valley than in that of the St.Lawrence. In all only about twenty species have been collected while in Canada several times as many occur in the Champlain clays. Indeed only three species are common. These *Macoma baltica Mya arenaria, Saxicava rugosa* are found wherever the clays occur.

The most interesting of the fossils found in the clays formed during this marine period is the small whale, bones of which were found in 1849 in the town of Charlotte. As these are fully described and illustrated in the Sixth Vermont Report, 1908 little need be said here. The specimen is very similar to the small white whale *Delphinapterus,* now living in the Gulf of St. Lawrence, but it is believed to be specifically different. The distribution of the shells in the deposits of the Champlain sea is interesting. The *Macomas* and *Saxicavas* are found wherever fossils occur, but the *Myas* are usually less common and in many localities are lacking. In some places, however, they are quite abundant. There is a

PLATE XXXII.

Old Sea Beach, Isle La Motte.

layer on the west side of Providence Island one or two feet thick in which these clams are very abundant tho there are few other shells. So too in the section of an old beach on the west side of Isle La Motte on the road from the village to the Chazy ferry, there are multitudes of *Mytilus edulis*, tho this shell is usually uncommon in these deposits. A list of the fossils thus far found in the Champlain beds of Vermont is given on page 55 of the Sixth Report.

In and about Burlington the only common shells are *Macoma* and *Saxicava* with now and then a *Mya*. These species are found frequently in the various trenches which are opened in the streets as far up as near Prospect street. The southern extent of the lake when it was an arm of the St. Lawrence sea is uncertain and there appears to be considerable difference of opinion among investigators. It does not seem probable from the available evidence that the salt waters extended south of Ticonderoga. There may have been a narrow passage, at any rate in the early part of the period, thru which the waters ran into the Hudson Valley then also an arm of the sea, but this does not appear to be certain and later there seems to have been an entire cutting off, or rather damming up of any such passage by the elevation of the land and the final establishment of an outlet north into the St. Lawrence Gulf.

LAKE ST. LAWRENCE.

Perhaps attention should be called to a more or less hypothetical Lake St. Lawrence which was first mentioned by Mr. Upham.

Leaving for a moment the period of which we have been writing, and going back to a previous period when Lake Iroquois and Lake Champlain, then probably united with Lake Albany or some such body of water to the south, were united and thus a large body of fresh water reaching from and including the Ontario Basin to Quebec as well as the Champlain Basin, we thus have a large lake which Mr. Upham thinks existed for a time and which he calls Lake St. Lawrence. Other writers interpret the terraces, beaches, etc., differently and question the need of postulating such a lake. At any rate, if this lake ever existed, its area must have been covered by the sea when it came in from the east. As to the levels found in terraces in the Champlain Basin, Mr. Peet remarks, "If the upper terrace of the lower series represents the sea level, then on the abandonment of the Fort Edward outlet, the history of the Higher Glacial Lake Champlain was closed and that of Marine Lake Champlain was inaugurated. If during the fall of Higher Lake Champlain level to the upper terrace of the lower series there was no change in the altitude of the land, then since the difference in level between the two series is generally 120 feet, Higher Glacial Lake Champlain must have been at its closing stage 120 feet above sea level and at its higher stage, barring uplift during its history, it must have been 75-100 feet higher. If the upper terrace of the lower series of terraces does not represent the sea level, but does represent the lake level, then Higher Glacial Lake Champlain was more than 100 feet above the sea when its outlet was abandoned. It is to be noted that the level of the Fort Edward outlet valley at Whitehall is close to 120 feet and if the Higher Glacial Lake Champlain at the close of its history was 120 feet above sea level then there has been no change in this part of the outlet since that time, but farther south, at the 160 feet divide near Fort Edward there has been an uplift of more than 40 feet."

"Since the uppermost terrace of the lower series when projected southwards falls below the Fort Edward outlet level, and since marine fossils have not been found south of Port Henry, whose they were found at a level of 140 feet and lower, it is believed that the sea did not reach south as far as the Hudson Valley. It has been calculated, by projecting the terrace gradient southward, that Benson Landing or Putnam Station was approximately the southern limit reached by the waves waters, forming the upper terrace of the lower series." (Peet, Jour. Geology, Vol. 12, p. 628.)

Clay Deposits of Marine Lake Champlain.

Into the waters of the marine lake which occupied the Champlain Basin there flowed, as has been shown, all the rivers now emptying into the lake, but of much larger volume and consequent force. Not only this, but the vast amount of material which had been loosened and much of it ground fine by the great ice sheets was easily moved and therefore there can bo no doubt that an incredible amount was carried by the current into the lake.

In this way a very great amount of rock in various stages from finest powder to coarse gravel or even larger stones was deposited over the bottom of the lake. After the elevation of the

Plate XXXIII.

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

land and the consequent subsidence of the water, some of this came to the surface and the clay soils of western Vermont, as in Addison County or on Grand Isle were the result. While more is said about Champlain *clays* it should not be supposed that only clay was deposited at this time. The softer rocks would, as is always the case, be ground fine and be deposited as clays, but the harder silicious rocks would form sand or gravel or beds of cobblestones. Towards the end of the marine period the land in the northern part of the Champlain Basin had become so elevated that conditions essentially as at present were produced and the sea receded from the Champlain and St. Lawrence basins and Lake Champlain and the St. Lawrence River as we know them were established.

Conclusion.

The published investigations of Baldwin, Peet, Upham, Woodworth and others have been freely drawn upon for the foregoing account of the Pleistocene history of Lake Champlain. The full titles will be given in the Bibliography which follows. Leaving aside the minor divisions of this history we may follow Peet in the statement of the greater stages in the progress of events as follows: Hudson-Champlain, Higher Glacial Lake Champlain, Glacial Lake Champlain of authors, or Lake Vermont of Woodward, Marine Lake Champlain, Modern Lake Champlain.

In conclusion I can give no better summary of the quite complicated and in many respects uncertain historyof the Champlain Valley than to quote freely from the closing statements of Professor Woodworths admirable study of this region and, although his work was confined largely to the New York portions of this valley, yet the results stated must for the most part be equally applicable to the Vermont side. As the Hudson Valley is so closely connected with the Champlain Valley in all its history it will be useful to include some of the conclusions reached in respect of that.

"The ice front after receeding from the moraine at New York Narrows became more and more irregular in outline, more and more reduced to a long narrow loop projecting southward in the Hudson Valley and receding northward in the highlands which formed a wall on either side of it. * * * * When the ice disappeared from the Wallkill Valley about the northern slopes of the highlands it formed a long tongue from Newburg northward covering the greater part of the width of the floor of the Hudson Valley. About its margins were accumulated stratified gravels and sands now in the form of terraces, with kettle holes and ice block holes extending on its eastern margin northeastward probably into union with one or more of the morainal stages described by Taylor in the Berkshire hills. * * * * As soon as the Mohawk Valley was opened a large contribution of water charged with fine sediment came into the Hudson Valley from that direction and was distributed far and wide to the south in the form of clays which may be traced as an almost continuous sheet over the rock benches and in the gorge itself as far south at least as Saugerties. The same body of clays extends northward along the Hudson banks at least to the southern border of the Fort Edward district and probably it is the same clay formation, though perhaps of a somewhat later stage of deposition which is traceable through the valley of Wood Creek into that of Lake Champlain. * * * * For a time the waters of Lake Albany extended over the Fort Edward district covering the lower portion of the plateau about Fort Ann and thence, connecting with the narrow defile of Wood Creek, united with a glacial lake which was extending northward in the valley of Lake Champlain pari passu with the retreat of the ice from that valley. The attitude of the land from Lake Champlain southward to the region of Lake Albany was now that of depression on the north so that the floor of Lake Champlain was below sea level though the sea was as yet excluded by the ice.'' * * * * The draining of Lake Albany, due to unknown, but supposable causes has already been noticed on a previous page. It must have been due in great measure to a deepening of the Hudson channel to the south as there is no evidence according to Woodworth, of any elevation of the land north in the Champlain region, at this time.

After this came what Woodworth has called the Coveville stage of Lake Vermont. This lake having come into existence after the draining of Lake Albany. Gradually the filling of clays in the old gorge through which the Hudson now passes Schuylerville was removed and the discharge from Lake Vermont fell into this lower channel reducing the level of the waters on the north till they fell to the level of the present divide between the Hudson and Champlain drainage in the Wood Creek Valley just northeast of Fort Edward where the lowest point in the height of land between the St. Lawrence and the Hudson Valley is only 147 feet above the sea. This stage of Lake Vermont when all traces of a

PLATE XXXIV.

Black River Limestone, Chippen Bay, looking north.

lake had disappeared about the Fort Edward district, found the Hudson from Fort Edward southward a much more powerful river than it is now.''

Subsequent to the invasion by the sea the land began to rise on the north and to sink on the south a movement which according to the evidence collected by Gilbert and others in the Great Lake district and by Cook and others along the coast east and south of New York, is still going on. In the valley of Lake Champlain we find indisputable evidence of uplift as high as marine shells occur.

About the mouth of the Hudson we observe evidences of recent sinking and though we cannot from what we see there, determine how long the depression has been going on, it would seem as if the land must have gone as far beneath the sea at that end of our line of ancient water levels as it has risen out of the sea on the far north.'' Of the modern lake Mr. Baldwin writes as follows: "As the continent in late Pleistocene times rose to its present height, the sea was drained off, but the great dam formed by the clay plain to the north changed the character of the drainage from that of the preglacial Champlain River to the present lake. The fresh water lake was at first fifty feet higher than now, but the Richelieu has lowered its channel to its present level since. The present lake lies mostly above the preglacial channel but the southern end seems to occupy that part of the old channel and is now little broader than a river.''

But this does not close the history of Lake Champlain for changes do not stop with what we call geological time as has already been intimated. The shores of the lake are not by any means the same as centuries ago. Most, if not all, of the bays which are frequent along the border of the lake have been excavated since the lake was substantially what it is now. The older shores were much more regular and without many indentations. The waves of the lake, the ice breaking up in spring, all eroding activities have been long cutting into the shores and will do so always. Plates XXXIII, XXXIV show two of the bays which are typical of most and which have been cut out from the shore and, as are all the others, continually becoming deeper and larger.

If the reader will recall the more prominent phases that have been mentioned in this history of Lake Champlain from its origin in Ordovician times through the intervening ages until the present the complex processes through which the region now known as the Champlain Valley has been moulded into its present character will be evident.

Nevertheless, Lake Champlain and the territory environing it has nothing especially unique. Many portions of the earth of no greater area have passed thru as many and as great changes, possibly greater. This example is of especial interest to us as dwellers near the lake, but it is only an example of what has been going forward for ages all over the world. Not by few and simple steps, but by many and intricate processes has our world come to be what it is.

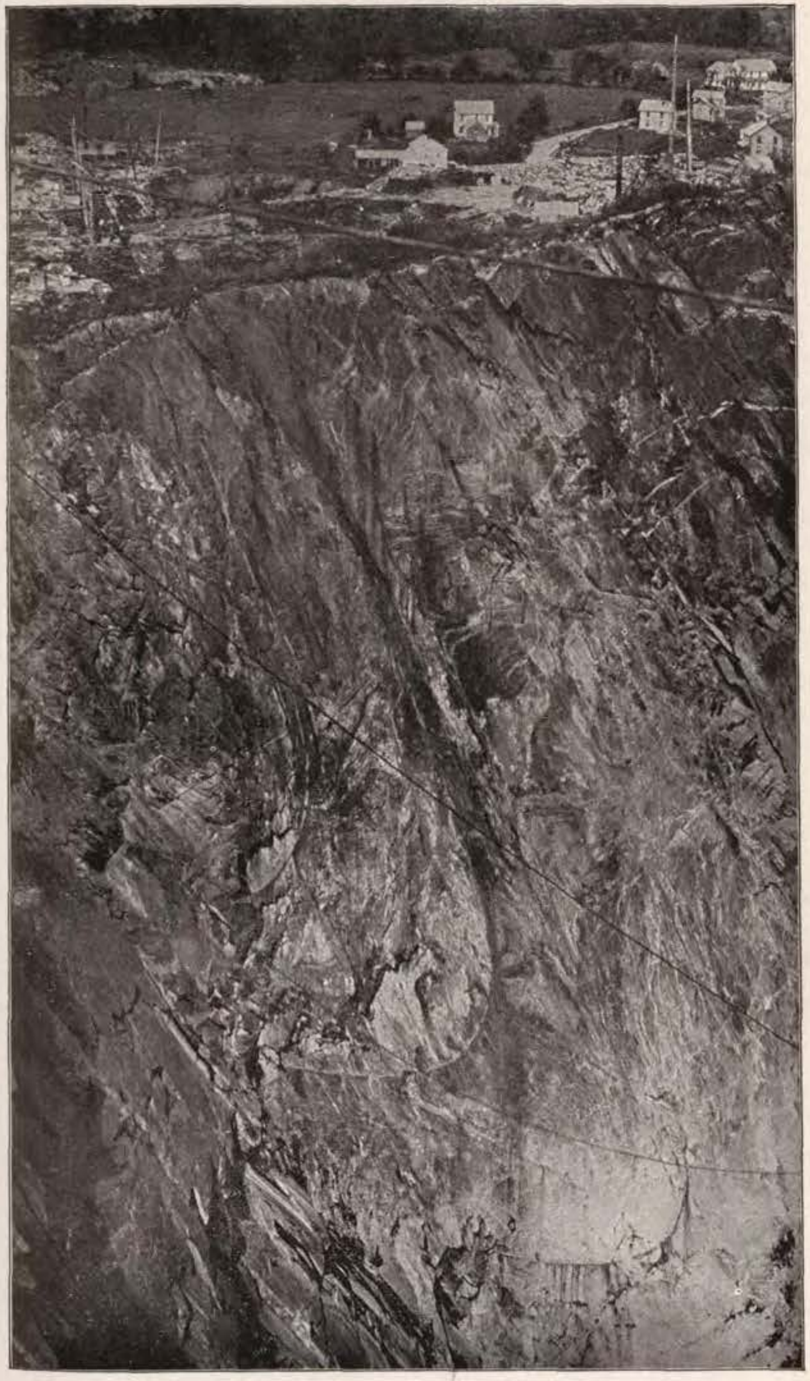
BUILDING STONES.

During or after the deposition of the Cambrian and later rocks other processes than those mentioned went forward the results of which are of the greatest importance to the State. None of the other rock formations have been or can be of as great value to Vermont as the deposits of slate, marble and granite from which large revenue comes annually. These were not produced during the same age and in the case of granite and marble it is not certain that all the deposits of either of these was formed in the same geological period, and it is quite certain that the slate was made partly in the Cambrian and partly in the Ordovician.

SLATE.

The slate appears to have been formed before the other two. The methods employed in quarrying and preparing slate for market are described in the Second Report, pp. 18-30, Fifth Report, pp. 8-19 and in every report of this series there is some statement as to this industry. The most instructive and comprehensive information as to slate is found in Bulletin, U. S. Geological Survey, 275, by Professor T. N. Dale. In the Nineteenth Annual Report of U. S. Geological Survey, pt. III, is an elaborately worked out account of the slate belt of eastern New York and western Vermont with plates and maps, by Professor Dale. Popularly, slate and shale are used to indicate the same sort of rock, but geologically they are quite different and therefore cannot be the same under any conditions.

In quiet, deep water fine sediment accumulates in beds of mud and clay. This hardens into shale, with of course, layers approximately horizontal. If by any change in the sea bottom a bed of this sort is sunk beneath the water so that other material,



Typical Slate Quarry.

say limestone, is deposited upon it so that it becomes finally weighted down by this overlying mass. Then a strong lateral pressure is put upon it, heat and moisture being present, the arrangement of particles of the shaly layers is changed and many are flattened, so that at last when the mass is consolidated and become stone it may not only show the original bedding of the shale, but another arrangement of layers, crossing at a high angle the plane of bedding and, by the conditions finally reached, a slaty cleavage is produced, that is a cleavage into thin sheets across the plane of bedding. By these same processes, too, the stone is rendered more compact, tougher and may be somewhat altered chemically. Shale, even if it splits into thin even sheets is rarely, if ever suitable for roofing or similar purposes. It needs the change that it brought about in forming slate.

I have been somewhat detailed in this account because it not infrequently happens that one and another, finding a deposit of pretty evenly bedded shale is at once inclined to start a slate quarry. In some cases considerable money has been wasted in the futile effort to get roofing slate from a bed of shale. But, as abundant experience in this State amply proves, it is not always possible to get saleable slate from a genuine slate quarry, and there is always much waste material to be gotten rid of in the best quarries. Hence caution and expert advice is always desirable before putting money into a slate quarry. There are many reasons why even what appears to be a good deposit of slate cannot be profitably worked.

Plate XXXV shows one of the larger slate quarries. Our large slate quarries are mostly of the pit order; that is to say, from a not very large opening at the surface, the slate is quarried down more or less vertically, a deep pit being thus made.

There are four slate areas in Vermont, but only one has been extensively worked, though in all quarries have been opened at one time or another. Only two of these areas are shown on the map, because only in these have quarries been operated for many years and the map is only designed to show where recent production has been carried on. Of the areas found in the State, two are east and two are west of the Green Mountains. The map Plate LXXII shows the location of the slate area in the State. In the town of Benson there is a small area of black slate which has never been worked to any extent. The important and largest area of workable slate is that which begins in Sudbury not far from Brandon and extends south thru Fair Haven, Poultney and Pawlet to Rupert. It also crosses into New York, but the quarries of Western New York are not in this belt nor of the same age. As may be seen from the map, most of this region is in Rutland county.

On the east side of the State there are two long and narrow areas. One of these lies along the eastern flank of the Green Mountains from Canada to Barnard. It passes thru Newport, Coventry, Montpelier and Northfield and is the black slate quarried in the last named places. That part of this area which has been worked at Montpelier and especially Northfield is indicated on the map, but the belt as a whole is not shown. According to Dr. Richardson this belt may be subdivided into three which are somewhat different in texture and age altho he considers them all as of Lower Trenton age.

The slate of this area is all black or at least dark gray. The fourth area extends along the Connecticut River thru Thetford, Guilford and Waterford. No quarries have been worked in this area for many years. Because of the above fact the outlines of this slate area are not shown on the map. It is probable that this eastern slate bed is Ordovician in age. All this slate is black.

As has been indicated, the only slate area which is of importance at present is that in Rutland county. The slate from numerous quarries has been sold for many years for roofing and in thicker pieces for a great variety of purposes. While all the slate of the other areas is black or gray that from this is never black and rarely gray. Purple, several kinds of green, and variegated, green and purple, are the colors found. These are often sold under commercial names. In beds of limestone which are associated with some of the slate *Olenellus* and other Lower Cambrian fossils have been discovered thus fixing the age of the slates in this belt. More will be stated as to this later. But not only in the associated rocks are fossils found. On the slate itself worm tracks and impressions of sea weeds are found sometimes in abundance. Fossils of Lower Cambrian age have been found in nearly two hundred localities in the slate belt.

As has been elsewhere noticed in these Reports, all the red slate sold comes from quarries not far from the Vermont boundary but on the New York side of it. These New York slates are with a few exceptions Ordovician in age, altho they form part of what appears to be a continuous slate area.

PLATE XXXVI.

Dike on the Shore of Grand Isle, showing Vein of Calcite in Chazy Limestone.

MARBLE.

The Marble area is found mostly in the same Rutland county east of the slate as is shown by Plate LXXXII. Other quarries produce marble of trade and no fault need be found with the name, but the stone which most correctly is called marble comes from the one area indicated on the map which is nearly all in the country named. The distinction made between true marble and stone which goes by the name in trade is that the true marble is metamorphosed limestone, while the other is used in the same way and so far as trade is concerned may properly enough go by the same name. It is nevertheless unchanged stratified rock, as the Champlain marbles, or a silicious metamorphic rock as the Verde Antique of Roxbury. The age of the Rutland marbles was first determined by the patient and careful investigations of Reverand Augustus Wing, a most retir ing country minister who did very much to elucidate some of the difficult problems presented by Vermont geology. As will be seen later, Mr. Wing not only showed the age of the marble, but of other rocks of his region and placed future students under lasting obligation. We may not yet know the precise age of all the numerous quarries which are worked in the area but it is pretty certain that most if not all are Ordovician and those of West Rutland at any rate, Chazy.

This was Mr. Wing's conclusion and since his death very satisfactory proof of the correctness of his views has been found. One of the most characteristic of the Middle Chazy fossils, *Maclurea magna*, has been found in abundance in the lower layers of the old Ripley Quarry, as see Plate XVII.

Some account of the marble industry in Vermont will be found in all the Reports and in the Second and Sixth are especially full discussions of marble. In the Second Report methods of quarrying and subsequent working are taken up and in the sixth, the different kinds usually put upon the market are described. As stated in that place, probably not less than a hundred different varieties could be obtained from the different quarries, but only about half of these are commonly kept on hand tho the rest could be gotten out if demanded. Like the slate quarries, those from which marble is taken are usually open pits from fifty to several hundred feet deep. I do not know that any of the slate quarries are carried into the side of the quarry in a tunnel, but a few of the marble quarries are to some extent. Illustrations of both slate and marble quarries may be seen in the Reports referred to.

reader who may desire more complete information is referred. These are, *The Granite Area of Barre*, G. I. Finlay, Third Report, pp. 46-60; *Areal and Economic Geology of North Western Vermont*, C. H. Richardson, Fifth Report, pp. 98-109, *Geology of Troy Coventry and Newport Sixth Report, pp.* 279-282.

The Vermont granites are all of them of igneous origin. That is to say they were intruded from below into the schists, or whatever may be the surrounding rock, as molten masses. The question when in geological time did these eruptions of igneous material take place is a most interesting one. Of course, the granites were formed later than the rocks thru which they were pushed and these schists according to Richardson's conclusions as given in the articles referred to above are Ordovician. As will be seen by reference to Professor Richardson's article in the present volume, further investigations fully confirm his earlier conclusions. If the surrounding rocks are Ordovician, probably Lower Trenton, it is obvious that the granites are later than this, but they might be of any of the numerous ages after the Ordovician and it is not easy to determine in which of these succeeding times the granite was formed. Dr Dale is apparently inclined to regard most of the Vermont granites as late Devonian or Carboniferous. Dr. Daly says of the Ascutney rock "the balance of probability makes them of Post Carboniferous or Pre Cretaceous age'' Professor Dale's conclusions in regard to this whole matter are of such interest that, altho they were quoted in the previous Report, they will bear repeating here. It should be noticed that Professor Dale does not insist that these conclusions are final, but as the most satisfactory that can be reached in the present state of our knowledge. He writes:

1—In Algonkian time a period of sedimentation followed by the intrusion of granitic rocks into the sedimentary beds. These granites are the present gneisses of the Green Mountain range.

2—At the close of Algonkian time a crustal movement metamorphosing the Algonkian sediments into schists and the granites into gneisses. This movement was accompanied by folding and elevation. The earlier mountain system of the State was thus formed.

3—In early Paleozoic time the submergence of a large area of Algonkian rocks and the deposition thereon of sediments resulting from the erosion of Algonkian land masses, together with calcareous sediments largely of organic origin.

4—At the close of Ordovician time a crustal movement took place metamorphosing the Cambrian and Ordovician sediments into schist, slate and marble and powerfully folding and also elevating them.

Some of these schists and slates are those which now surround the granite areas in the eastern half of the State.

5—After a long interval, probably at the close of Devonian, or Carboniferous time, another crustal movement occurred accompanied by the intrusion of the schist mass by granitic material in a state of fusion with superheated water. The intrusion produced in places further changes in the schist and injected it with dikes of pegmatite. Fragments of the schist were included in the granite

6—Not long after the crystallization of the granite it was traversed by granitic dikes.

7—The schist and granite masses were traversed, possibly in Triassic time, by basic dikes.

8—Atmospheric erosion of the Paleozoic schists and slates began at the close of Ordovician time and has finally removed those parts of the schist mass which covered the granite domes.

This process of erosion has been accelerated by successive uplifts.'' (The Granites of Vermont, p. 16.)

As will be readily seen, the above quotation has a much wider scope than that of the granites, but refers in some degree to the geology of the larger part of the State. Not only the granites bear evidence of igneous activity in this State, but many other intrusions of one sort or another are found in many parts of the State. The granite usually came up in irregular masses, often of considerable magnitude, but scattered all over Vermont, tho much more abundant in some portions than others, are dikes. These smaller and more regular intrusion are of all ages, some earlier some later, than the granites and of all sizes, from bands of only a few inches width to those of several feet and extending for only a short distance thru the rocks in which they are found, or for several miles. They may often be seen as bands of usually darker and harder rock running thru limestone or w hatever the rock may chance to be. They may be lighter than the enclosing rock but not often. Igneous rock may even be found cutting thru other and of course, older igneous rock. A notable example of this is seen at Mount Ascutney. Here there appears an area of old gneisses thru which the syenite which composes the main mass of the mountain has been thrust, while this syenite has itself been intruded by a mass of quite different granite.

OTHER MINERAL RESOURCES.

As is well known the three materials, slate, marble and granite are by far the most important mineral products of this State, but there are some other materials that are surely worthy of some mention. It is not improbable that a few of these may in time become of much greater importance than now. Most of them occur in other parts of the State than those where they are now worked and as demand increases these now undeveloped properties will grow valuable. As has been repeatedly said in other Reports, Vermont cannot hope to become a mining state so far as metallic products are concerned. Our ores are too poor in quality and too limited in quantity to give any promise whatever of future income, but this is not true of those materials named or of those named below. There is every prospect that the income to the State from building stones and from those other products to be mentioned will increase for many years to come. The supply of slate and marble is very large and that of various kinds of granite is practically inexhaustible. And those lesser products, asbestos, talc, soapstone, etc., are sold in increasing amounts.

ASBESTOS.

Asbestos is mined, or rather quarried, in but one locality, that on the north east side of Belvidere Mountain. Yet more asbestos is produced at this place than in all the other localities in the United States, tho much less than is obtained from the Canadian localities. It is encouraging to note that at this locality, Chrysotile, the work is prosperous and increasing. Further details of the work at Chrysotile will be given in the article in this Report on Mineral Resources. Asbestos is found in other parts of this same mountain and some of these may be developed at some future time.

An account of the rocks of Belvidere Mountain and of the work which is being carried on there will be found in the Fourth Report pp. 86-102 *Serpentine Belt of Lamoille and Orange Counties, W. F. Marsters.* A fuller discussion of this subject is given in the Fifth Report and in the Seventh Report, pp. 315-330 Professor C. H. Richardson in *Asbestos in Vermont* gives the latest study of this region.

SOAPSTONE.

Soapstone has been quarried, tho at no time in very large quantities, for a hundred years or more. The map shows the location of soapstone and talc together as they are usually found so. Indeed, soapstone is a compact talc. Soapstone is quarried in Chester, Perkinsville, Athens, tho not in very large amount.

TALC.

Talc is found in many places in this State, but is at present worked only in Cavendish, Moretown, East Granville, Rochester, Johnson, Hammondsville, Grafton. Beds of talc occur in other places, but are not worked, and in some of those places named it is mined irregularly.

CLAY.

Clay of different sorts is found widely distributed over the State. Where there are wide areas, as in the lake region of Addison County the clay which forms most or all of the surface soil is the result of the great glacier, directly or indirectly, but there are other clay deposits of more limited extent which were formed much earlier as for example, the pure white kaolin beds at Brandon, or the variegated clays from which formerly, the Brandon paint was made. The clays from which the Rutland fire clay is prepared and those near Bennington some of which were sold for paint, (ochre) others were used in the manufacture of china ware. Ochre beds were also worked in Wallingford. But all, except those at Rutland and Forestdale (Brandon) and Bennington are no longer worked and have not been for a good many years. These are most of them of different origin from the more widespread and common clays as they are produced not by the depositing of ground up rock, but from the decomposition of rock and often very hard rock. The white kaolins come from feldspar and the Rutland clays from mica and other schists, the others are an earthy form of oxide of iron. As everyone knows, clay suitable for brickmaking is found in many places. It seems quite probable that the clays of Vermont will in future be far more extensively worked than now.

LIMESTONE.

Limestone suitable, or at least possible, for burning into lime is found abundantly in the western and less so in the eastern part of the State. Formerly, small kilns were built by a few farmers who wished to build, and lime sufficient for their needs burned with no thought of commercial enterprise. The wanderer thru the woods or over the hills now and then comes upon these old kilns, long since unused. Gradually, the business of burning lime fell into the hands of a few companies who employed more efficient kilns and skilled work men and produced and sold lime in considerable amount. At present and for some years past lime has been produced at Highgate, Swanton, St. Albans, New Haven, Leicester Junction, Amsden. The lime made at these different localities is all of it excellent in quality, tho differing more or less in each locality from that obtained in others.

METAMORPHISM.

There has been a considerable material published at one time and another by numerous geologists upon the different phases of the geology of the State. As the most important of the published results of these studies are scattered in a large number of proceedings of scientific societies and in various periodicals, it seems to the writer that it will be helpful to those wishing any extensive knowledge of the geology of the State if the substance of the more important articles be given here. As has already been noticed, the conditions in many localities are such as to render anything like sure conclusions as to the age, method of formation, relation of different beds to each other, etc., very difficult and in some cases even impossible, at any rate in the present State of our knowledge. As one stands on Mansfield, or any of our higher mountains, or even those like Philo or Snake which are lower, the scene that lies below him, always beautiful and greatly varied, is not merely a charming landscape, but a record which he must learn to read if he would know the why and wherefore of that which he sees. But this is only the outside of the record the cover of the book in which is written the manner of making, which resulted in the Vermont we know. Something of the difficulty which anyone wishing to read this record must meet has been repeatedly noticed. The geology of Vermont is not wholly, but is largely what it is because of the Green Mountains for the making of the mountains was the making of the whole State. This can readily be understood if one notices how large a part of the territory of the State is occupied by the mountains and foot

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

hills that belong with them. For this reason there is comparatively little rock in the State which has not been more or less altered from its original condition.

In the neighborhood of the lake along the western border we find limestone, sandstone and shale which has been little changed, sometimes not at all, but except for narrow and rather small areas, we find no rock unchanged and often it has been completely transformed. Change, activity, the manifestation of several geological forces working together, or one after another have produced the results which are familiar to us. First the Adirondacks then the Green Mountains were uplifted to heights that we can only guess and then came the uncalculated period mostly of quiet, when erosion and weatherings slowly, but effectually, broke down the cliffs and reduced the heights until the vast ice masses of the great glacier completed the work that had so long been going on. As has been intimated, there appears to be some rock in the mass of the Green Mountains that is as old as that of which the Adirondacks are chiefly composed, but the larger part of their mass is of later origin.

The interval between the close of the Ordovician and the Pleistocene is often spoken of as a period of quiet, but at some time, or times, this quiet, which probably was characteristic of most of the time, must have been thoroughly disturbed for the dikes of which have been mentioned and especially the Great Fault must have been attended by great earthquake movements and perhaps also volcanic outbursts as certainly was the throwing up of the masses that became the granites.

I have already mentioned Ascutney Mountain as showing volcanic activity. Around the base of this mountain there are schists and other metamorphic rocks, but the main mass is eruptive in character. This does not, however, conclusively prove its volcanic origin. Until recently the main mass of the mountain has been considered volcanic, but Dr. Daly, who has studied the rocks more thoroughly and carefully than anyone else, concludes that they are not. That is not in the ordinary sense. The rocks were not suddenly nor violently thrust up in the form of molten masses thru rifts in the crust, but formed slowly, gradually "by some kind of assimilation of the invaded formations." This is not the place for a discussion of the problems involved. Those interested are referred to Bulletin 209 U. S. G. S., which is devoted entirely to Dr. Daly's discussion of the rocks of Ascutney.

DIKES.

The dikes of the state as a whole have never been carefully studied. Many of them are mentioned in the 1861 Report and interesting data are given, but the study of igneous rocks, as well as the nomenclature of the varieties has greatly changed since that Report was published. Moreover, by no means all of the now known dikes are there enumerated. They are especially numerous in the western part of Vermont near Lake Champlain. For example over forty were found in course of an examination of Grand Isle. These are noticed in the Third Report of this series and a *Petrographic Description* is furnished by Dr. H. W. Shimer. The dikes of Chittenden County are discussed in the Sixth Report and in Bulletin 107 U. S. G. S. Professor K. F. Kemp has published the results of a study of *The Trap Dikes of the Lake Champlain Region*. In this Bulletin there is much of interest to one studying the subject. But there is opportunity for much investigation in this field. The dikes have been mentioned in immediate connection with the granite because they have much the same origin. As has been noticed, they are of different ages. Some of them evidently are very old, but many are, like the granite, of some age after the Ordovician because they cut thru the rocks of that age. Probably some, perhaps many, were intruded during the disturbances accompanying the final uplift of the Green Mountains for in the upheaval, crumpling, metamorphosis of the rocks that make up the mass of these mountains there was much disturbance over the whole area that is now included in the State. A mountain like Ascutney could not have been formed without considerable volcanic activity. And some of the larger dikes may well have been attended by something of this sort as they were forced up thru cracks that broke thru large masses of solid rock. Some of the Grand Isle dikes have cut thru the entire island and appear on both sides. But the most impressive proof of great volcanic or earthquake violence is found in the Great Fault to which Sir William Logan called attention more than fifty years ago. By the Canadian geologists this is usually called The St. Lawrence and Champlain Fault. At or near the close of the Ordovician the whole mass of strata along western Vermont and north in Canada were broken thru and one side raised several hundreds of feet above the other. In places the Trenton and Beekmantown come opposite, tho as formed they must have been widely distant

PLATE XXXVIII.

North Side of Rock Point near Burlington.

the western border of the State near the Lake to Weybridge and the southern part of Sudbury. From here it crosses into Washington County, N. Y., and south on the east side of the Hudson as far as Rhinebeck where it crosses the river and goes on in New Jersey. Thus the fault is several hundreds of miles in total length.

A quite different proof of the great forces acting after Ordovician time is seen in a quarry of the Leicester Lime Marble Company at Leicester Junction. Here the folding is very evident in all parts of the quarry, but in one portion on the west side there is a most curious example of what is known as differential folding whereby the limestone strata acted upon at the same time by two forces instead of being crumpled or otherwise distorted, as is usual in such conditions, have been pretty regularly rolled into a huge cylinder a hundred feet long and over seven feet in diameter. This is larger and more regular than the other rolls in the quarry but there are two others. Plate XL is from a photograph of this roll.

ABSTRACTS FROM WORKS ON VERMONT GEOLOGY.

The earliest reference to the structure of the Green Mountains that I have seen is found in the Second Annual Report on the Geology of Vermont by Professor C. B. Adams published in 1846.

C. B. Adams.

It is remarkable that the author of this statement in the days when all geologists were groping after the solution of many problems which have since been solved, as well as after light upon others which are not yet made plain, should have been more in accord with recent investigators than many who have succeeded him. Of course by this is not meant that the terms used or the conclusions reached by Professor Adams would all, or most of them, be accepted today, but interpreted in terms of modern geology a good deal of what is quoted, would be considered as more acceptable than much that has been written since. Also because of its historical interest what is quoted below will not be out of place. "A much interrupted granite band extends from Lake Memphremagog in a southerly direction thru the State, which in the adjacent parts of Caledonia and Orange counties is dilated so as to occupy

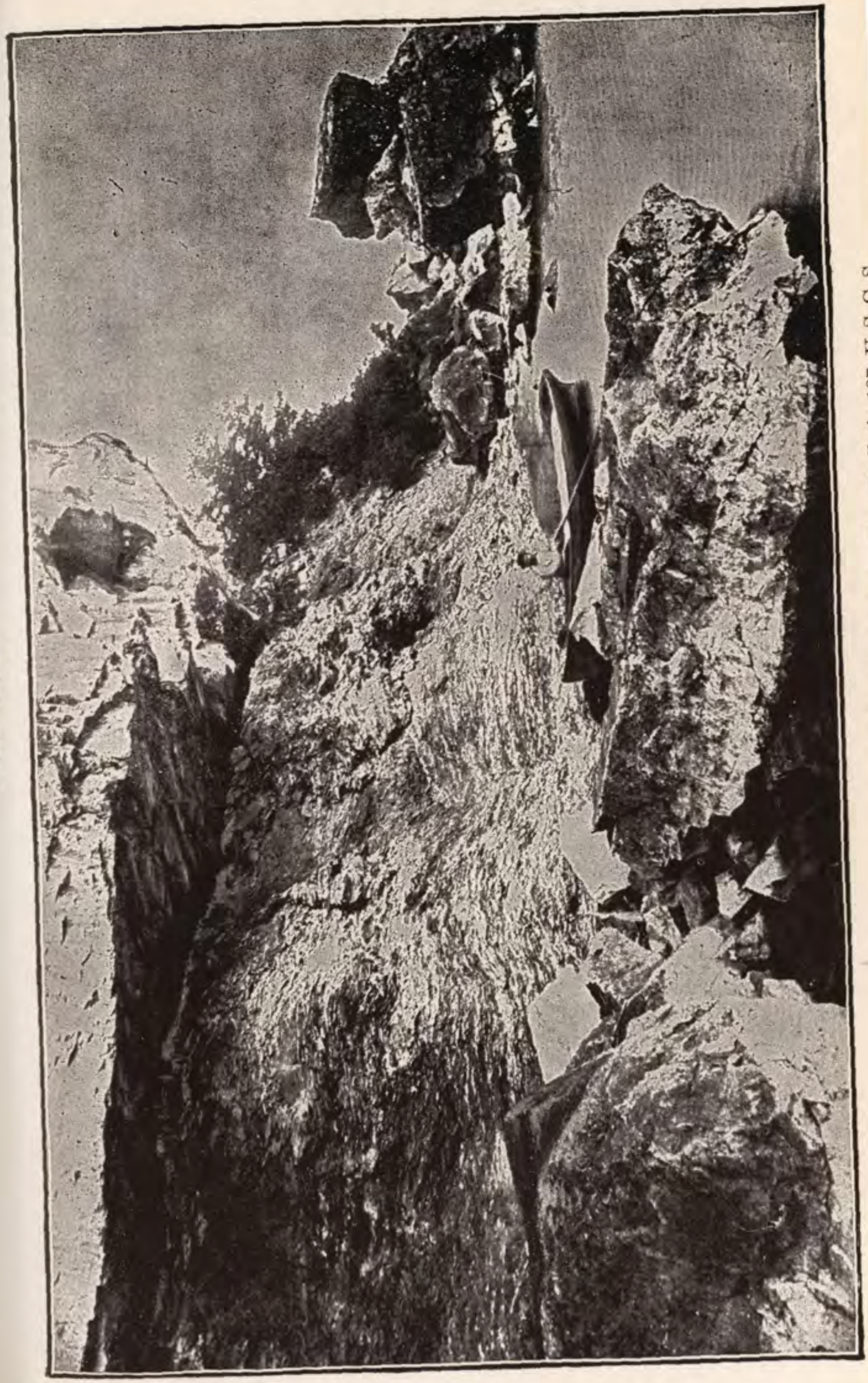


PLATE XXXIX.

From Bulletin 107, U. S. G. S.

most of his active life as a minister, as an avocation took up the study of the rocks of Addison County first and then he extended his field north and south of this county, tho never covering a large territory. His especial study, to which he gave years of exploration and thought was the area of crystalline limestone of Rutland County including the Rutland marble. Professor H. M. Seely has well summed up Mr. Wing's work as follows: "The limestone region of the Otter Valley lies in a great syncline. On the east it is bordered by ridges of quartzite which extend along the western foot of the Green Mountains; on the west by the red sandrock whose elevation and fracture forms the great fault north and south, seven to nine miles from the Champlain shore. The axis of this syncline descends southward while on the north it rises until the worn rims of the silicious rocks the quartzite and redsandrock very nearly approach and unite. Within this trough lie the limestones and slates. These are of the age of those that lie west of the great fault, the fossils of which long ago placed them with the lower Silurian. These strata, originally deposited in regular order, by some grand mountain making movement have been folded and compressed, snapped and displaced, the fossils by the same movement largely obliterated. The great synclinal was left with subordinate north and south anticlinals and synclinals; the whole complex was left exposed to the subsequent abrasions of geologic time."*

Before Mr. Wing's death in 1875, sometiomes in his company, Professor J. D. Dana went over portions of the same ground and afterwards Professor Dana spent some time in the region. His strong commendation of the work of Mr. Wing adds much to its authority, altho it was sufficiently convincing in itself. It is scarcely too much to say that the work of this retiring country minister was the first really valuable geological work that had been done in the area which he undertook to unravel. After the conclusion of Mr. Wing's investigations and the less extensive work of Professor Dana, little was done in Vermont for several years, but in 1890 and the years following much more important investigations were made than had ever been accomplished in the State.

Most of this work was carried on in or about Rutland County, where certain perplexing geological problems attracted several geologists both on account of the interest aroused by the locality

*Life and Work of Augustus Wing, Third Report, Vermont Geologist, p. 27.

and also on account of the relation which some of the rock formations appeared to have with those of the Berkshire region in Massachusetts.

J. E. Wolff.

One of the first of these investigators was Professor J. E. Wolff. The results of Professor Wolff's work were published in Bulletin of the Geological Society, Vol. II, p. 331. The paper was read before the society some months before and the field work was done in 1890. As Professor Wolff's conclusions are of interest to all students of Vermont geology, especially to those who may chance to be in the region under consideration, an abstract of his paper is given. First calling attention to the geography of the area about Rutland, Professor Wolff speaks of the three valleys which are found extending in parallel courses north and south. These are known as the Vermont Valley, Center Rutland Valley and West Rutland Valley.

The first of these is very much larger than the others, extending for some miles north and south of Rutland. Much of it is essentially the valley of Otter Creek, but it includes more than this. At Rutland it is about three miles wide, being limited on one side by the Green Mountains and on the other by a broad elevation called Pine Hill. West of this valley is the Center Rutland Valley. This is much narrower and shorter. It is bounded on the east by the west side of Pine Hill, which separates it from the Vermont Valley, and on the west by a ridge a few hundreds of feet high in which many of the West Rutland marble quarries are located. Most of these quarries are on the west side of this ridge, so that they open into the third valley, that of West Rutland. This West Rutland Valley is still smaller and narrower than either of the others. Its western boundary is the Taconic Hills. Of the geology of this area Professor Wolff writes: "In the high, abrupt frontal range of the Green Mountains there occur crystalline schists, often gneissic which pass eastward into the gneissic rocks proper of the Green Mountains. These schists contain beds of true conglomerate, with a metamorphosed crystalline cement, and pass westward on the slope, into the quartzite of Vermont, which the discoveries of C. D. Walcott prove to be of Lower Cambrian age (Olenellus zone). This is succeeded by a broad belt of limestone occupying the Rutland Valley. Next in Pine Hill we find a partial repetition of the series in the frontal range, namely, massive quartzite underlain by transitional gneissic series, then on the western crest of the hill, a band of black schist in contact with a band of crystalline limestone which occupies the second or center Rutland Valley. The narrow ridge west of this valley is again formed by black schists, succeeded by a third band of crystalline limestone in the West Rutland Valley, and finally, black and greenish schists form the slopes of the Taconic range."

"The character and position of the rocks is as follows: On the slope of the frontal range the Cambrian quartzite varies greatly in lithological character. It is massive or micaceous, contains beds of schist and passes into the metamorphic conglomerate and cement which intervene between it and the gneisses proper of the Green Mountains eastward. This cement rock contains a small bed, or beds, of crystalline limestone, the rocks are very much folded and the structure is very much complicated by secondary schistosity and cleavage."

"The limestone is variable in character. It is in some beds white coarsely crystalline, in others fine gray dolomitic. It is often filled with small rounded detrital grains of quartz so that it resembles phases of the quartzite save that the quartz cement is replaced by lime. * * * * It extends many miles in this valley, but toward the north it is cut off by the rocks of Pine Hill, which bend around to join the main range of the quartzite. In this respect existing geological maps need correcting, for in them this limestone is made to join the next belt westward in Pittsford."

At several localities in the first valley Dr. Foerste and also Professor Wolff found Lower Cambrian fossils and in each of the other valleys Ordovician fossils were found. These show that the limestone of the Vermont Valley near Rutland is Lower Cambrian and that of the Center Rutland and West Rutland valleys is Ordovician. Or, as Professor Wolff states it "The facts here stated prove that the limestone of the Rutland Valley is of Lower Cambrian age, that in Pine Hill it overlies conformably a massive quartzite, with associated beds of metamorphic conglomerate, cement rock, crystalline limestone and gneiss which bend around to join a similar series lying east of this limestone and that Pine Hill quartzite must therefore be of Olenellus age while the limestone, bounded on the east and west by the quartzite series and disappearing to the north lies in a trough of quartzite."

T. N. Dale.

Probably no one man has done as much work of permanent value on the geology of the State as Professor T. N. Dale. Professor Dale began his work in Vermont more than twenty years ago and has at frequent intervals, since, been investigating one or another phase of our geology. Especially are we indebted to Professor Dale for the best work by far that has been done upon the slates, granites and marbles of Vermont and his papers, published by the U. S. Geological Survey and in the American Journal of Science are and always will be of great value to all students of Vermont geology.

In writing of the *Ridge between the Taconic and Green Mountain Ranges,* Professor Dale gives many valuable observations as to the region studied. The entire article is found in *Annual Report United States Geological Survey, Vol. XIV, Pt. II, p.* 531, published in 1892. From this paper it will be well to make a few quotations. Of the Clarendon section Professor Dale remarks "A low broad saddle about six miles south of Center Rutland in Clarendon affords access to the structure of the ridge.

The eastern half of the ridge here consists mainly of quartzite continuous with that which at its north end crosses the Vermont valley to join that along the west face of the Green Mountain range and is now recognized as of lower Cambrian age. This quartzite is commonly interbedded with a very fine grained and finely banded gneiss or schist, consisting of bands of quartz and feldspar (orthoclase, plagioclase, and microcline) alternating with bands of muscovite (sericite) and biotite. In places, however, the quartzite is associated with a chloritic muscovite (sericite) schist, sometimes with thickly disseminated crystals of magnetite." Sometimes this sericite schist "contains a bed of blue quartz conglomerate a foot thick, the pebbles being one-half inch to an inch and a half in diameter. There are also on the eastern side of the ridge certain coarse chloritic gneisses containing small beds of coarse crystalline limestone, rarely hornblendic. On the western side of the ridge is an irregular area of more or less quartzose, bluish gray and yellowish white fine grained limestone It is continuous with that of the Tinmouth and Center Rutland valleys. A small lenticular area of similar limestone occurs in the quartzite on the east side of the ridge. The steep, isolated knoll southwest of Clarendon flats consists of such limestone with small areas of quartzite on its east side. South of this a series of limestone outcrops stretches across the interval to Clarendon Falls."

In West Clarendon fossils have been found in a series of outcrops which extend "off and on for sixteen hundred feet in a northeast and southwest direction. "These fossils are several species of *Hyolithes* which belong to "the upper portion of the *Olenellus* fauna." A fourth of a mile or so north of this locality, which is about half a mile northeast from Chippenhook, there is a limestone area in which Ordovician fossils have been found. A number of very interesting sections are given with this paper. The whole region, including Wallingford, Danby as well as Clarendon, Rutland, West Rutland and adjoining areas is found to be mainly at least Cambrian and Ordovician in age. Mr. Wing long ago determined the age of some of the limestones and presumably, of all in this region. Geologically this is one of the most important in the State since the marbles of Dorset Mountain, Dorset, Danby, West Rutland and Proctor are within the territory considered. By way of a resume of his investigation, as well as of those of others, Professor Dale remarks "The foregoing sections establish the general anticlinal structure of this range, it is a complex anticline of the lower Cambrian quartzite and the associated conglomerates "cement rock," sericite schists and gneisses of the Vermont formation, overlain by the Cambro-silurian Stockbridge limestone followed by a variable thickness of the Ordovician Berkshire schists, representing a total thickness of at least 2,000 feet and on Dorset mountain probably more than 3,200 feet. This anticline has been faulted in two ways, by a double fracture resulting in letting down a somewhat keystone shaped block of schist and limestone several hundred feet in width into the anticline, to a depth of about 1,500 feet and by a reverse fault which resulted in thrusting some portion of the lower Cambrian quartzite and gneiss westward over the lower Silurian (Berkshire schist) the vertical displacement amounting to about 1500 feet. This fault extends from the Pittsford line south into the town of Wallingford, a distance of at least twelve miles, but not exceeding eighteen miles as it does not reach the town of Danby. In this town, at a point about twenty two and a half miles south of the north end of Pine Hill the ridge is crossed by a zigzag east-to-west reverse fault, by which the Cambrian quartzite is brought up to the level of the Silurian schists, with a vertical displacement of about 1400 feet. Thus the northern part of Dorset mountain mass was thrust up to nearly its entire altitude above the next summit of the ridge north of the fault. That this entire range has been subjected to great strain is also manifest from the numerous dikes which traverse it in Rutland, Clarendon, Wallingford and Danby. It corresponds to a line of great strain and least resistance. It has also been subjected to such powerful erosive influences as to have greatly altered in places its form and its height."

As to the age of the rocks in this region it may be added to what has been said above that—"Mr. Wolff and Mr. Foerste have shown the lower Cambrian age of the base of the Stockbridge limestone on the east side of the north end of the ridge (Pine Hill section.) The Clarendon section shows the lower Cambrian age of the lower 470 feet of the same limestone on the west side of the ridge.

Mr. Wings' discoveries showed the Ordovician age of the upper part of the Stockbridge limestone in the West Rutland valley. Mr. Foerste's discoveries in 1890 and 1891 showed the same to be true in the Center Rutland and Tinmouth valleys and in Wallingford, and finally, the Ordovician age of the overlying Berkshire schists, long ago insisted upon by the geologists of the New York Survey has been confirmed by various recent investigations.'' A summary of these observations is also given in Bulletin Geological Society, Vol. II, p. 514. After giving some details of the several sections shown on one of the plates Professor Dale states the following "Inferences" from the observed facts. "The probable synclinal structure of the Vermont valley is indicated by the westerly dip in the Green Mountain range east of Dorset mountain. The general anticlinal structure of the Danby hill schist mass naturally follows. The complex structure of Dorset mountain is shown by the observations. There is an anticline between the two roads on its east side, a syncline between the old stage road and the ravine on its northeast side, another anticline along that ravine, a syncline between it and the high shoulder near the top, and at least one other anticline between the top and the notch, and west of the notch another syncline, judging from the structure of the west side of Danby hill, which is on the line of the strike. The Silurian schists which cap Dorset mountain, there reaching a thickness of from 1500 to 2000 feet were probably once continuous with those of Danby hill north of the fault. The ravines which now carve the north face of Dorset mountain and the gorge cut in the quartzite by Mill brook are but insignificant

evidences of erosion when compared to those afforded by the general structural relations of the rocks on either side of the fault.

The structural significance of the bold north face of Dorset mountain now becomes apparent. It was the result first of a fault crossing the folds of the intermediate range and thus of the Green Mountain system generally nearly at right angles, and second, of erosion, perhaps initiated by the fault itself, in the direction of the fault and then working back onto the masses north and south of it.''

In addition to what has already been given of Professor Dale's work in Rutland County it may be well to notice his investigations of Bird Mountain, a small peak of the Taconic Range just west of West Rutland. When Rutland County is more fully discussed, as it is hoped may be the case in the near future, if possible in the next Report, more will be given concerning this interesting elevation, but for the present, it must suffice to give a part of the conclusions to which the investigations led. ''Bird Mountain is an open syncline within the taconic Range and consists of about five hundred feet of grit and conglomerate interbedded with muscovite (sericite), schistand underlain on all sides by schist of similar character, but frequently containing small beds of quartzite. The presence of pebbles of crystalline limestone, calcareous quartzite and granitic quartz in the conglomerate shows that at no great distance rocks of this kind were above sea level at the time of its deposition. The presence of a carbonate of iron, magnesia and lime both in the cement and the pebble-like masses in the grit indicates that these pebbles may be due to brecciation and solution and that the area of the Bird Mountain grit may have been a basin in which fine ferruginous and calcareous sedimentation took place and in which also coarser detritus was collected. The stratigraphical relation of the schists which underlie Bird Mountain, both to the Cambrian on the west and to the Ordovician on the east, and the synclinal structure and position of Bird Mountain itself indicate the upper part of the Ordovician as the probable age of the grit. While some of its pebbles must have come from pre-Cambrian rocks, others originated in Cambrian beds and the carbonate pebbles may also be of that age." (Ann. Report U. S. G. S., Vol. XX, Pt. II, p. 23.)

In the American Journal of Science, Vol. XVII, Fourth Series, page 195, Professor Dale has an article on *The Geology of the North End of the Taconic Range.* This includes the northern part of Rutland County and the south eastern part of Addison County. This locality is taken up because, as Professor Dale remarks, there is here a meeting of the principal formation of the Taconic region, namely, the Cambrian Slate, Stockbridge Limestone, and Ordovician Schists. After giving reasons for assigning the different rocks to Cambrian, and Ordovician age the writer sums up the matter as follows:

"The interpretation of the facts set forth in the map and section is this: The lower Cambrian slate formation, which is now regarded as the offshore equivalent of the quartzite of the Green Mountain ranges was folded at the close of Lower Cambrian time and in places, raised above sea level, forming one or more islands in the Champlain oceanic arm. The direction of this Cambrian folding was generally the same as that of Ordovician time, known as the Green Mountain movement, but at this point the axes of the Cambrian folds, for some reason, had a more easterly course, resulting in N. E. strikes. A very gradual depression, beginning during the latter part of Stockbridge limestone time and continuing into Hudson time, caused the deposition of some of the limestone and of all of the schist upon these former islands of Lower Cambrian rocks. This resulted in some places in an overlapping of the limestone by the Hudson schist and slate and in others by the deposition of the schist and slate immediately upon the Cambrian slates. * * * * Then came the Ordovician folding. * * * * Denudation thru long geological periods must account for the presence of only shred-like remnants of the great mass of Ordovician argillaceous sediments and for the severance of the northern extension of the schists from the Taconic range and generally for the exposure of the Stockbridge Limestone. The salient fact is the unconformity between the Lower Cambrain and the Ordovician, which is masked in the slate region of Washington County."

Professor Dale says that "The Ordovician age of the schist and slate masses bordering the Cambrian is shown by the presence of red roofing slates, typical of the Hudson, a mile S. S. E. of Hyde Manor and three-fifths of a mile E. S. E. of Sudbury Church, and again, apparently in badly weathered condition, one and one-fourth mile E. N. E. of Huff Pond on the east side of the Cambrian belt."

This is interesting, for so far as I know, this is the only appearance of red slate in Vermont. As has been shown in former reports, the red slate comes very near the State line in numerous places between Poultney and Pawlet, but it is always on the New York side tho some times within easy stones throw of Vermont.

Professor Dale's observations in the region of the north end of the Taconic Range are supplemented by further notes published in the Am. Journal of Science, Vol. XXXIII, p. 97 in which he calls attention to a small area of Ordovician limestone in Sudbury near Hyde Manor. Excavations and drilling were carried on to ascertain the real character of the rock. Some details of this work are given and the following conclusions reached by the author: "The isolated mass of Ordovician limestone on the old golf course of Hyde Manor in Sudbury, Vt., is surrounded and underlain by schists of Lower Cambrian age upon which it rests unconformably and with which it is interfolded in synclinal attitude and on a part of its northern side in a direction at right angles with the strike."

"The main mass of Ordovician limestone west of the outlier is probably continuous with that interfolded with the Cambrian schists at excavations 4 and 5 and was, of course, once continuous with the outlier or the beds adjacent to it. * * * * The general importance of the outlier is that it is as yet the only point in western Vermont and Eastern New York where the Ordovician can be seen unconformably on the Lower Cambrian

"The little outlier is a structural specimen, still in situ and small indeed, but preserving the record of one transgression, two crustal movements and two periods of erosion which affected several hundred square miles of the Taconic region."

During the past few years Professor Dale has at different times studied the region included in the Brandon Quadrangle, but most of the results of this work are not yet published. However, in the Am. Journal of Science, Vol. XXX, p. 267, there is an account of Cambrian Conglomerate of Ripton. This is a conglomerate long known and is mentioned in the 1861 report. It has numerous outcrops as shown on a map which is given with the article named. It is a coarse mixture of pebbles of blue quartz and others of gneiss. "The cement of the conglomerate is highly metamorphic, generally a muscovite quartz schist with more or less magnetite. More than half the pebbles are blue quartz, the rest are gneiss. The age is found to be Cambrian." The author concludes that, "The generally rounded or discoid form and the unstriated surfaces of these pebbles point to their having been formed on a beach and their magnitude points to their local origin which is younger rocks, the core of the folded range shows itself in a variety of old granitic and gneisses rocks, cut by intrusives and with extremely irregular structure.''

Professor Pumpelly supposes that "The Cambrian transgression found an Archean elevation forming the western border of an Archean dry region. To the west of this lay the great Paleozoic ocean of America.

I imagine also that the rocks of this dry area had become disintegrated to a greater or less depth and that the products of this action varied from kaolin and quartz at the surface to semikaolinized material with fresh cores at depths. While the abrasion of the deeply disintegrated rock was progressing along the advancing beach line the detritus of sand and pebbles arising from this disintegrated material was deposited with varying proportions of constituents in a continuous sheet in progressive transgression over the previously dry land. * * * * During the progress of this removal and deposition of ready-prepared material there would be places where the underlying unaltered rock would be washed clean and recovered with sand and gravel. There would be others where the material removed from the disintegrated mass would be derived from a zone of semikaolinized, fragmentary disintegration and places where this material would be deposited without having been much rolled and in beds alternating with finer material. And, again, there would be places where the disintegration was deeper and where this material escaped removal and was covered by sedimentary beds.''

Whether in all respects one agrees with the writer or not, it is certain that the above hypothesis throws light on the formation of the Green Mountains.

C. L. Whittle.

In the American Journal of Science and Arts, Vol. XLVII, 3d. Series p. 347, 1894. Mr. C. L. Whittle gives the results of three seasons of field work "along the highest portions of the Green Mountains from Chittenden on the north to Stratton on the south and defined east and west by the Windsor and Rutland valleys.'' These limits should be borne in mind when reading the following quotations. As Mr. Whittle's study of the above region seems to have been very careful and thorough I shall quote

quite freely from his article. All of what is given is not new, but it is so grouped as to be of value for reference. Indeed the entire article is a valuable contribution to Vermont geology.

"Lower Cambrian quartzite and limestone occupy the Rutland Valley. The quartzite lies at the base and is next above the series of metamorphosed clastics lying between it and the still more metamorphosed core of the range. Plymouth Valley is also occupied by limestone which extends north to Sherburne, but its age is undetermined. Field evidence points strongly to its equivalence to one of the limestones in the metamorphosed clastics mentioned above occurring on the west side of the range. The rocks of the range below the Olenellus horizon (that is below Lower Cambrian) seem to fall into two groups: 1, a border series consisting alone, so far as I am aware, of metamorphosed sediments; and 2, a core series more metamorphosed, differing lithologically and carrying igneous rocks antedating the border series. When one first visits the eastern or western border of this area he is at once struck by the great variety of rocks and the apparent simplicity of their structure. Throughout the border areas the strike of the most prominent structure is commonly N. 10°-15° E. and the dip is generally steep easterly. This strike, as is now well known, corresponds to the trend of the main Appalachian folding in New England. Further study of the rock shows its secondary nature, traversing as it does rocks of the most varied texture and composition regardless of the real stratification, now usually not decipherable, but in many places still present where it has escaped the destructive dynamic action to which the rocks have not only once, but several times been subjected. * * * * The eastern and western borders are belts of near-shore deposits of original coarse to fine conglomerates, sandstones and shales. * * * * Such a belt indurated and metamorphosed has given rise to a series of more or less crystalline rocks which, owing to their extreme diversity of composition have resulted in schists and gneisses whose recognizable continuance of horizon is difficult to follow. * * * * Along the western border the schists are bent into minute compressed puckerings commonly overturned to the west. These puckerings in turn, compose much larger folds which in the same manner are overturned to the west. * * * * Throughout the core of the Green Mountain axis even a greater diversity of structure and rock exists. * * * * In the towns of Shrewsbury and Mount Holly and extending southward the folding and shearing and consequent metamorphism are so great that final and satisfactory decipherment seems hopeless. Days may be spent without obtaining observations that would be of service in unravelling the tangle of schists and gneisses. In the towns of Mt. Holly, Shrewsbury, Wallingford and the western part of Ludlow are areas of amphibolite now possessing a thoroughly schistose habit. At Summit station the railroad traverses this rock for nearly half a mile. Such a series of amphibolites probably represents a period of volcanic activity vastly older than the Cambrian and of greater areal distribution than occurs at present. There are many other areas of this rock in the region some of which are undoubtedly dikes, others, owing to their extent, are considered to be intrusives or surface flows. Following the classification of pre-Cambrian rocks now adopted in this country none of this area studied in Vermont can be referred to the Archean age and must be placed in the Algonkian. The lowest rocks exposed in Shrewsbury and Mt. Holly although of extreme age and gnarled and crinkled into a hopelessly involved structure still in larger part reveal their sedimentary origin by associated beds of crystalline limestone, now altered in part to serpentine or amphibole and scattered outcrops of quartzite. * * * * The upper part of the Algonkian, or border series, affords evidence of at least two periods of orographic disturbance.

Section VI of Hitchcock passes through Mendon and Sherburne where the border rocks are exposed capping the summits of the highest peaks, furnishing a key to the structure along this line. As a working hypothesis the following sequence of metamorphosed clastics exposed in continuous section on the west slope of Blue Ridge Mountain making a border series, has afforded positive results in deciphering Green Mountain structure; descending geologically from the base of the Olenellus quartzite the next rock is a bed of chloritic mica schist very much crumpled. It seems to be always present in this part of the State. In Vermont the mica schist at a minimum has a thickness of not more than fifty feet but in places it is certainly five hundred feet in thickness and may reach a thousand feet. Below the schist comes in several hundred feet of micaceous quartzite locally assuming a schistose phase or on the other hand becoming massive and compact. All phases carry numerous pebbles of orthoclase microcline and quartz, feldspar being most abundant. The quartzite horizon also varies greatly in thickness and may thin out entirely. Next below is a

white crystalline limestone, carrying the same varieties of pebbles, some phlogopite secondarily developed, and graphite. In places, areas have escaped recrystallization and are still blue in color promising with careful search to yield fossils. Two hundred feet may be postulated as its maximum observed thickness in the heart of the range.

Another thin bed of micaceous quartzite occurs below this containing one or more beds of interstratified limestone ten or fifteen feet in thickness. These lie upon the lowest member of the border series, the metamorphic conglomerate horizon which is separated from the lower rocks by no line of demarcation whatever—the two horizons possessing a structural conformity due to dynamic processes. This conglomerate is by no means invariable in its character, but is subject to great differences of habit.

Normally, it may be described as a conglomerate gneiss in which more or less detrital material can still be seen. Its clastic character may be entirely lost when it passes into a chlorite-muscovite schist or when it is represented by a vitreous quartzite or quartzite breccia. It forms with the mica schist the most persistent horizon in the pre-Cambrian rocks known to me.

After mentioning the often observed fact that in the Green Mountains the eastern slopes are generally less steep than the western, as would necessarily be the case in masses having an eastward dip, Mr. Whittle speaks of the extreme tension which at one time existed in the rocks. "A measure of the stretching and consequent thinning of the strata on the backs of the folds is frequently found in the effect produced on pebbles in the quartzites or upon secondarily developed tourmalines. Pebbles of feldspar having an original diameter of a quarter of an inch are now drawn out to four inches; crystals of tourmaline which one may fairly assume were not more than one inch in diameter are now seen as linear films over a foot in length."

In brief the structure of the whole is given as follows: "The structure of the main axis of the Green Mountains is thus seen to be a series of sharp, compressed folds striking approximately north and south and overturned to the west in most localities so that induced schistosity and stratification dip eastward. Localities on the western border have a steep western dip in many instances, in others the border series as a whole is nearly in a vertical position. Many areas occur along this belt where the series is overturned to the west, but the exact angle at which the strata lie is difficult of determination." Mr. Whittle has closed his very helpful and important article with the following summary:

1. Immediately below the Lower Cambrian quartzite in Vermont there is a series of more or less metamorphosed clastic rocks of no inconsiderable thickness; the upper member of this series being a dark chloritic mica schist; the lower member a highly metamorphosed conglomerate and between these several pebbly limestones and pebbly micaceous quartzite strata. Evidence for and against an unconformity at the top of the schist is presented, but no satisfactory data are advanced to sustain either interpretation. The evidence for a time break at the base of the conglomerate is thought to have been established and the data in support of this conclusion are discussed in some detail. These rocks are referred to the Algonkian Period and are provisionally called the Mendon series.

2. That below the Mendon sedimentary rocks, a still older, more metamorphosed and more variable series of stratified rocks of Algonkian age occurs, together with gneisses and schists, whose origin is unknown, and abundant metamorphic equivalents of old basic igneous rocks.

Many of the varieties of rocks occurring in this series are enumerated, and, together with their structure are contrasted with the rocks of the Mendon series, whose basal member, the conglomerate, delimits the series above. From their typical development in the town of Mount Holly, Vt., it is suggested that these rocks be called the Mount Holly Series.

In the *Journal of Geology*, vol. 2, pages 396-429, 1894, Mr. Whittle further elaborates the views just given. Altho much of this article is a restatement of that which is given in the *Journal of Science* from which the above quotations have been taken, there is much that adds to what has already been given and for that reason several quotations from the article in the *Journal of Geology* will follow. This article is entitled *The Occurrence of Algonkian Rocks in Vermont and the Evidence for their Subdivision.* Omitting the first part of the article which is well worth reading by anyone interested in Vermont geology we come to Mr. Whittle's consideration of the two subdivisions of the pre-Cambrian rocks to which we have already referred.

As to the upper or "*Mendon Series*" our author says "As far as known the best section of these rocks occurs in the town of Mendon, one mile north of Mendon village on the west slope of Blue Ridge Mountain. All the members identified occur here, tho no single section thus far examined has all the members developed characteristically or of maximum thickness.

Each member thickens and thins out along its strike in a remarkable manner. On Nickwacket Mountain, just north of the Rutland sheet, for example, the pebbly, micaceous quartzite member attains its greatest thickness, and the pebbly limestone as well, while in the heart of the range, east of Chittenden Flats, the lower quartzite conglomerate horizon attains its maximum development. The mica schist is best seen along the Mendon section. Provisionally, therefore, for descriptive purposes, the name Mendon Series will be given the rocks. * * * * Beginning with the Olenellus quartzite which strikes N. 5 W. to N. 5 E. the next rock descending geologically, is mica schist. It occurs along the west base of the hill situated in the northwest corner of Mendon. Near the quartzite it appears conformable, but as one ascends the hill, going east, the rock becomes more crumpled, two hundred feet from the quartzite the stratification has been practically destroyed, while the regional schistosity, characteristic of the Appalachian Range in New England, takes its place. * * * * The structure of the schist consists of minute plications and larger ones, many feet across, closely folded and often overturned to west. Minute faulting along the axis of the crenulations has produced the schistosity which has been mistaken for dip by the early workers in this region. In some localities it is not over 50 feet thick but just south of Chittenden Village more than 1,000 feet occur. All thru the area the schist carries abundant lenses of secondary quartz, introduced along the bedding and cleavage planes. Phases of the rock are without such lenses and are nearly free from quartz; other phases are largely quartz layers with thin folds of mica between. * * * * Beneath the schist is the micaceous quartzite horizon, poorly represented in this section, but on Nickwacket Mountain having a thickness of 500 feet at least and carrying several thin beds of limestone. On White Rock Mountain its place is occupied by a well marked sandstone carrying some biotite.

Immediately below the quartzite are fifty feet of pebbly, crystalline limestone, the pebbles being largely feldspar, like those in the quartzite. All through the mountains of the Rutland sheet it forms an easily recognized horizon. Near the summit of Pico peak it occurs and by its rapid removal it has given rise to escarpments on the southeast slope of the mountain. Some fifty feet of green muscovite schist occurs next below, which may be considered a laminated phase of the micaceous quartzite which usually appears below the limestone. This grades downward into a flinty quartzite along this section.

Locally, the quartzite carries pebbles of quartz and as one goes east it is seen to grade into the metamorphic conglomerate that has become classic through the contributions of the elder Hitchcock. Another phase from the Mendon section is a well developed conglomerate in which the pebbles vary in size from a pea to a small boulder. The larger ones are nearly all of vitreous quartz, many of a fine blue color. At East Clarendon nearly all detrital matter is obliterated by the shearing action that has developed a perfect lamination observed there. Exposed south of Mendon village, this horizon is a vitreous, massive quartzite, probably 500 feet thick, devoid of all evidence of stratification. Three miles south of there the quartzite has disappeared and a well laminated muscovite gneiss similar to that occurring at East Clarendon and Bald Mountain east of Rutland takes its place. * * * * Many phases of this schist occur characterized by accessories such as chlorite, biotite, magnetite. An important and wide-spread variety carries ottrelite in prisms and radiating bundles (See Am. Journal of Science, Vol XLIV, Oct., 1892.) Muscovite predominates over other micaceous minerals, both colorless and green varieties occurring, while feldspar is only sparingly present.

The lower or *Mount Holly* Series—The rocks of this series occur well developed in the towns of Mt. Holly and Shrewsbury and extend south probably near to the Massachusetts line.

In nearly every way these rocks are contrasted with the Mendon Series. Mr. Whittle does not give a detailed description of the various rocks of this group, but mentions those in a few characteristic localities. "Along the south slope of a hill just south of Mechanicsville a section is exposed showing fine-grained biotite gneiss at the base, passing imperceptibly into a sugared quartzite above. This in turn is overlaid by a coarse saccharoidal limestone and a muscovite, garnetiferous schist overlies this, capping the summit of the hill.

A section on the southwest slope of Ludlow Mountain, two miles southeast of here, exhibits at least two beds of coarse limestone grading into tremolite and green hornblende interstratified

with layers of schist. All through the core there are patches of these coarse limestones in a great variety of association. * * In all cases the limestones are in irregular lenses and are extremely local. * * * * They probably represent remnants of a once great sedimentary series older than the Mendon." Mr. Whittle writes quite at length upon the differences found to exist between the rocks of these two series. In course of this discussion he alludes to the "Conglomerate-gneiss horizon.'' This rock is mentioned in the 1861 Vermont Report by Dr. Edward Hitchcock and it was in this that he found specimens which suggested his most interesting and valuable theory, proved to have been well founded, of the formation of crystalline gneiss from sedimentary strata. This is really the most valuable contribution to geological science contained in the Report mentioned. The conglomerate appears to be somewhat widely distributed as it extends from the southwestern part of Vermont northward to Canada. But it is not the presence of this conglomerate that is here considered so much as the peculiar condition of the pebbles in it as found in some of its localities. The original account of this as given by Dr. Hitchcock is interesting. On page 28 of Volume I, Geology of Vermont, Dr. Hitchcock proposes his theory in the following words: "We have found striking examples where the pebbles of conglomerate have been elongated and flattened so as at length to be converted into the silicious folia of the schists and the cement into the mica, talc and feldspar.'' Dr. Hitchcock adds: "This we regard as the most decisive evidence we have met of the former plasticity of all the schists and of gneiss.'' This statement was at the time it was made quite revolutionary, but the proof was at hand in convincing form in specimens from the Vermont conglomerate. After mentioning the conglomerate found near Newport, Rhode Island, Dr. Hitchcock describes the conglomerate found in Plymouth. Speaking of the pebbles of this conglomerate he writes: "They are elongated, often very much, in the direction of the strike. They are flattened, but not so strikingly as they are elongated. They are indented often deeply by one being pressed into another. They are sometimes a good deal bent, sometimes in two directions. They are cut across by parallel joints or fissures, varying in distance from each other from one or two inches to many feet.'' After discussing the rock of the Newport, R. I., locality and that found in Wallingford in this State, Dr. Hitchcock takes up the Plymouth rock. He finds that the processes, "Begun at Newport and carried still farther at Wallingford, are completed in a most satisfactory manner.'' The locality is near the west shore of Plymouth Ponds. "As the ledges crowd closely upon the road a fine opportunity is presented of seeing the quartz pebbles that have not been much flattened on the exposed surfaces, having the aspect of a decided conglomerate. Yet if joints cross the rock, or if it be broken across in the direction of the strike, the pebbles will for the most part appear so flattened that they become almost lenticular or even folia. And if a fracture be made, or a joint occur, in a perpendicular direction, that is the direction of the dip, the pebbles almost wholly disappear, or rather seem converted into quartz folia of talcose schist.''

In a block of this stone, we may see these facts well shown for on one side we have plainly a conglomerate. While on another side we have as plainly a schist.

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Areal and Economic Geology of Northwestern Vermont, C. H. Richardson, pp. 63-132, Plates 17-33.

Geology of St. Albans and Vicinity, G. E. Edson, pp. 133-155.

The Cryptozoa of the Early Champlain Sea, H. M. Seely, p. 173, Plates 34-38.

Beekmantown and Chazy Formations in the Champlain Valley, H. M. Seely, pp. 174-187, Plates 39-45.

The Lignite of Brandon, Second Paper, G. H. Perkins, pp. 188-194, Plates 46-48.

The Lignites of Brandon, E. C. Jeffrey and M. W. Chrysler, pp. 95-201, Plates 49-51.

Description of Fossils, G. H. Perkins, p. 230, Plates 52-57.

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The Drinking Waters of Vermont, G. H. Perkins, pp. 254-344.

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The principal papers in this Report are:

Report on the Mineral Resources of the State, G. H. Perkins, pp. 1-57, Plates 1-9.

The Granites of Vermont (Abstract of the Bulletin) T. N. Dale, pp. 58-75.

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Some late Wisconsin and Post Wisconsin Shore Lines of Northwestern Vermont, H. E. Merwin, pp. 113-138, Plates 21-22.

Also published in Bulletin Mus. Comparative Zool. Cambridge Vol. VII, No. 7.

Geology of the Hanover, N. H. Quadrangle, C. H. Hitchcock, pp. 139-186, Plates 23-37.

Preliminary Report on the Geology of Franklin County, G. H. Perkins, pp. 189-211.

Geology of the Town of Swanton, G. E. Edson, pp. 210-226.

Preliminary Report on the Geology of Chittenden County, G. H. Perkins, pp. 221-264, Plates 39-53.

The Geology of Newport, Troy and Coventry, C. H. Richardson, pp. 265-291, Plates 59.

The Granites of Vermont, T. N. Dale, Bulletin U. 404 U. S. S., pp. 138, 1909.

The Cambrian Conglomerate of Ripton Vermont, T. N. Dale, Am. Jour. Science, Vol. XXX, 4th Series, pp. 267-270.

Seventh Report, Vermont State Geologist, 1910. The principal papers are:

History and Condition of the State Cabinet, G. H. Perkins, pp. 1-75, Plates.

The Granites of Vermont, T. N. Dale, pp. 77-197.

The Surfacial Geology of the Champlain Basin, C. H. Hitchcock, pp. 199-212.

Trilobites of the Chazy of the Champlain Valley, P. E. Raymond, pp. 213-248, Plates XXXII-XXXIX.

Geology of the Burlington Quadrangle, G. H. Perkins, pp. 249-256, Plates XL-XVLII.

Report on the Geology of Addison County, H. M. Seely, pp. 257-314, Plates XLVIII-LXII.

Asbestos in Vermont, C. H. Richardson, pp. 315-330, Plates LXIII-LXVI.

Mineral Resources of Vermont, G. H. Perkins, pp. 331-352, Plates 67-81.

The Cambrian Conglomerate in Ripton, Vt., T. N. Dale, Am. Jour. Science, Vol. XXX, 4th. Ser. pp. 267-270, ~~1819.~~ ? 1918

The Ordovician Outlier at Hyde Manor in Sudbury, Vt. T. N. Dale, Am. Jour. Science, Vol. XXXIII, 4th Ser. pp. 97-102, 1912.

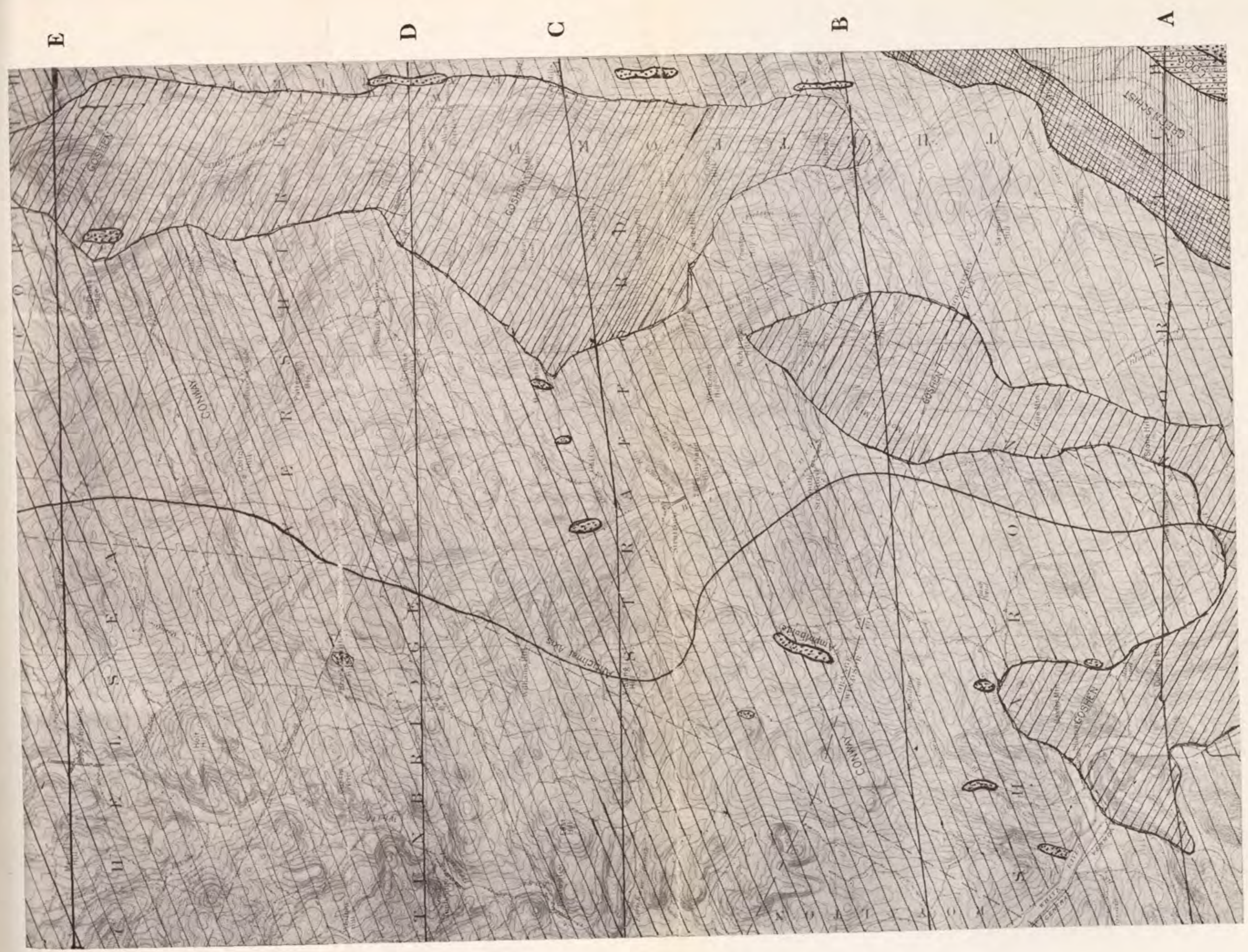
THE STRAFFORD QUADRANGLE. to 146

C. H. Hitchcock.

This has been partially described in connection with the Hanover Quadrangle in the Fifth Report. It lies wholly in Vermont, embracing the whole of the town of Strafford, and portions of Chelsea, Corinth, Vershire, West Fairlee, Thetford, Tunbridge, Royalton, Sharon and Norwich; is between latitudes 43 degrees, 45 minutes and 44 degrees; and between longitudes 72 degrees, 15 minutes and 72 degrees 30 minutes. It was first published by the United States Geological Survey in 1896.

More than half of the area drains into the Connecticut River by the tributaries of Waits River, most of the Ompompanoosuc River and Bloody Brook in Norwich; the western portion drains into White River, which discharges into Connecticut River in the Hanover Quadrangle, the principal stream being the eastern branch of the White River. The whole of White River flows through the southwestern corner of the Quadrangle for a distance of five miles, from 460 to 420 feet elevation above the sea. The Ompompanoosuc leaves the quadrangle at the elevation of 412 feet. Ten of the peaks exceed 2,000 feet in altitude, the highest being Colton in the west part of Vershire, and half of them are in the same town. The extremes of elevation are 2412 and 420 feet. In the Hanover Quadrangle only one summit reaches 2,000 feet. As explained before, the summits may be conceived of as lying in a plain or sheet, and this sheet rises gradually from the southern to the northern part of the Quadrangle. It continues to rise in proceeding northerly, culminating in the great granite batholith east of Montpelier. In accordance with the doctrine of the previous report, the original altitude of this plain may have had the minimum of 3,500 feet above the sea, and the resultant erosion from 1,100 to 3,000 feet.

Plate XLI.



Map of Strafford Quadrangle. Lines show the location of sections, Plate XLII.

Because so much of the rock is calcareous, deep channels have been excavated by the streams. The depth of the valley at Chelsea Village upon the East bank of White River is 965 feet; at Tunbridge village the same. Following down the stream into White River, the depth gradually increases, being 1,100 feet deep below the village of Sharon. Upon the west branch of the Ompompanoosuc in the north corner of Strafford the depth of the valley is 580 feet; at the central village 600; at Union Village upon the lower Ompompanoosuc the depth is 722 feet. Upon these two streams the depth of the channel increases in the descent. The depth is more uniform upon the Ompompanoosuc through Vershire. There are corresponding depressions upon all the tributaries of these streams, so that both the water courses and the excavated valleys have the same arborescent spread. No other rock in this section of country originates such a deeply dissected topography. Though the hills are steep the soil is good, and excellent farms are to be found over the entire area of the quadrangle.

THE GEOLOGY.

The character and arrangement of the rocks in the Vermont part of the Strafford and Hanover Quadrangles is the same. Because of the better understanding of the extension of the Bernardston Devonian formations into New Hampshire and Vermont, to be particularized later, it will be best to drop the term Coos as a member of the old Calciferous Mica schist group and to substitute therefore the name Goshen, because it has priority over the later suggestion of Dr. Richardson of the use of Vershire schist. The Calciferous Mica schist group as explained upon page 154 of the Sixth Report was divided by Professor Emerson into the Goshen and Conway members. The term Coos should now be restricted to the rocks stretching northerly from Massachusetts in the Connecticut valley of later age. The former interpretation was based upon petrographical similarities. Now it is conceded that the same kind of schist may be present in both the Goshen and the restricted Coos periods.

As thus defined the rocks in the Strafford Quadrangle may be arranged as follows:

The Hydro-mica, Chloritic and Sericitic Schist groups.

Leyden phyllite slates and argillites.

Goshen mica schists.

Conway mica schists with limestone beds.

Amphibolites, granites and basic dykes.

The Goshen and Conway members predominate; the chlotitic and slate groups are confined to the southeast corner. The igneous rocks are also insignificant in amount, while the cupviferous veins of Copperfield and Copperas Hill have been important for the supplies of copper and copperas furnished by them.

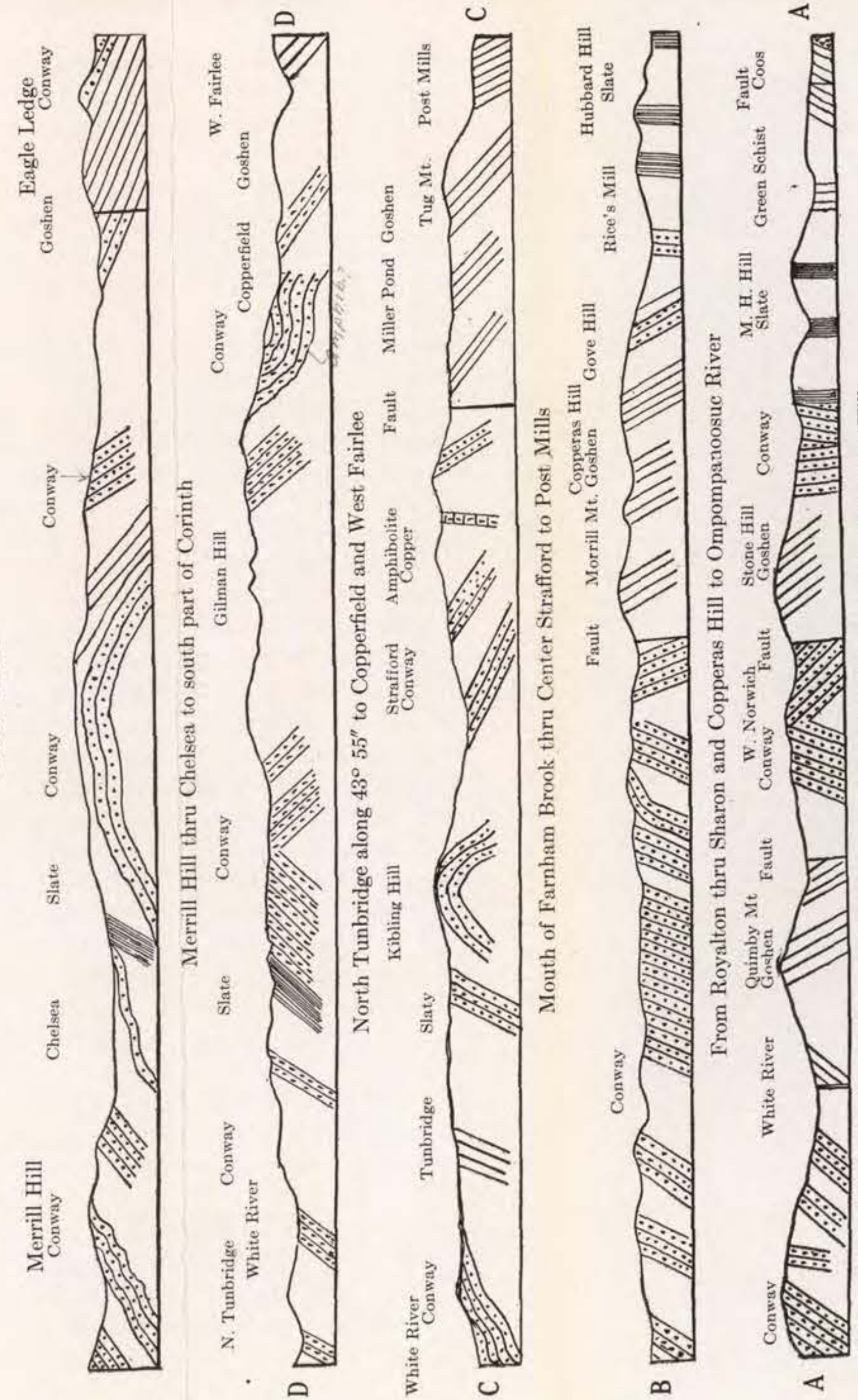
Plates XLI and XLIII are outline Geological maps of the Strafford and Hanover Quadrangles. The substance of the first appeared in the Sixth Report but owing to certain changes in the nomenclature, and somewhat in the distribution of the rocks it is best to reproduce it in the revised form. Detailed descriptions will not be presented except so far as they are embodied upon the accompanying plates, XLII, XLIV, XLV, which are sections across the quadrangles drawn along the lines given upon the maps. In addition to this areal distribution, a prominent line indicates the course of the anticlinal axis, which is one of the most important features of our study. It is believed that the lettering and markings will sufficiently indicate the distribution without further remark.

In order to be in agreement with the petrographers I have introduced the name of phyllite to take the place of the argillite of the previous report. For our purposes the term slate by itself would be adequate.

Commencing with the Strafford quadrangle it will be seen that it is traversed by five sections from east to west, numbered by the first letters of the alphabet. The horizontal scale is the same with that of the quadrangle, about one mile to the inch. The vertical is twice as great. Parallel lines are used to denote the green schists and the Goshen group. The same very close together represent the slates. The Conway has dots between the parallel lines. The amphibolites have the same dashes at various angles, not parallel. The granite is marked by variously placed angular lines. Where nothing is presented it is usually a want of information, rather than a covering of earth. Sections B, C, and E correspond to numbers VII, VIII and IX of the Dartmouth College collection.

Section A starts from Blood Mountain and crosses Meeting House Hill, Stone Hill and Quimby Hill, passing through West Norwich. The relations of the hornblendite of Blood Mountain to the Coos mica schist have been set forth in the description of the

PLATE XLII.



Sections Across the Strafford Quadrangle.

contact phenomena near the Norwich poor farm, in the Sixth Report, page 161. The band of mica schist is the south prolongation of a larger area in Thetford and belongs to the series developed on the New Hampshire side of the Connecticut, and must be separated by a fault from the green schists to the west, because of the different angles of the dips, twenty degrees or more. Fig. 4 of the Sixth Report, page 146, sets forth the relations of the rocks named. The narrow band of slate has not been recognized upon section A.

The Meetinghouse Hill slate is uniformly divided by nearly vertical cleavage planes. The synclinal along the east border of the Conway schists as developed northerly from Hartford is recognized along this line. It is more closely appressed in going northerly. Two or three additional sections in Norwich, between A and B show the same feature.

The topography of Norwich and Sharon suggest our geological interpretation of the Goshen and Conway groups. Stone Hill properly underlies the calcareous group. There is here an elevated mass of it connecting north with Gile Mountain in Norwich and Morrill Mountain with the Copperas Hill region in Strafford and extending westerly to connect with Quimby Hill and Baxter Mountains in Sharon. The mountains specified may owe their existence to the greater ability of the quartzose layers to resist disintegration. But there is evidence of a fault upon the west side of the Stone and Gile ranges since the Conway limestones have the anticlinal attitude in the lower ground about West Norwich and farther north. And this fault should extend around the curve between Stone and Quimby Mountains—the steep north side of Quimby Mountain marks the line of this fault. West of White River the distinctions between the Goshen and Conway schists are not so clearly defined as there is a scarcity of limestone; so that the boundary between them is no more satisfactory than the reference of the great mass of the schists in Norwich to the Conway group. It may be noted that the mineral kyanite is abundant in Norwich both in the broad area west of Meeting House Hill and the southerly projection of the Coos schists from Thetford.

Three more restricted sections, Plate XLVII, A. B. C. illustrate features clearly alluded to in the broad Conway area adjacent to Section A. The distances are from the town map. The first follows the regular road to Sharon from a sawmill less than a mile northwesterly from the village of Norwich to West Norwich. The slate carries a dike of Camptonite and there are suggestions of an anticlinal on the east border of the Conway rocks. This section lies to the south of A.

Section B runs from near school house No 17, along the road to Strafford from Norwich. First is the vertical slate, followed by signs of an anticlinal and synclinal in the Conway group with scanty limestone. But the road from West Norwich at the west base of Gile mountain runs on solid limestone, with a smaller easterly inclination than what pertains to the elevated part. And all these facts suggest a fault between the limestones and silicious schists.

Section C shows the positions of the several groups between the crossing of the town line near the north corner of Norwich and S. H. No. 6 through New Boston, indicating the positions of the broad Conway area, the slates, green schists, and the southerly projection of the Coos schists from Thetford. The early edition of this quadrangle makes the road continuous from the north boundary line on the hill east from Gile Mountain. More than a mile of this has been abandoned—being the hilly space between two houses. It can be followed on foot but not with a team without difficulty.

Section B corresponds to a part of Section VII of the Dartmouth series, starting from the Ompompanoosuc River near Thetford Center, through Rice's Mills, Copperas Hill, Morrill Mountain, the north part of Sharon, and a short distance into Royalton. The first rock is the slate with vertical cleavage at Thetford Center and Hubbard Hill. At D. Butler's saw mill the rock is horn-blendic dipping 61 degrees east flanked on both sides by the slate. Hubbard Hill is in the neighborhood of the contorted slates figured in Plates XLVIII and XLIX, and the question of the true dip of this band is still a matter of study. Apparently there is a low westerly dip crossing the vertical cleavage. The rock of Hubbard Hill is more silicious than that of Thetford Hill and seems to merge into the Goshen group quartzites farther north. At Rice's mill the strata are crumpled in a zig-zag fashion, vertical with distinctively calcareous bands; the dips here and on the hill west present a synclinal with its steep side on the east.

From Gove Hill across to Morrill Mountain the rock is quite silicious with dips normally from fifty to sixty degrees easterly. It is fine grained so as to suggest compression developing cleavage

PLATE XLIII.

Map of the Hanover Quadrangle. The lines show the locations of the sections on Plates XLIV and XLV.

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planes. The beautiful curves in the strata Plates XLVIII and XLIX come from this area—and in the ledges adjacent there is such an alteration of material as to make certain that the strata correspond generally with the cleavage plans. The copper veins of Copperas Hill and the Elizabeth mine lie within this area.

The antic linal in the Conway schists passes from near South Strafford southerly. Morrill Mountain has been pushed through the east flank about a mile from the arch. The Conway rocks continue to the west line of the quadrangle, occupying mostly the area of Sharon.

Section C corresponds to VIII of the Dartmouth series, from Post Mills to Tunbridge. Easterly dips prevail in the Coos rocks—at first fifty and sixty degrees. Tug mountain is a large mass of schists, dipping forty-five degrees easterly on the town line of Thetford and Strafford. They contain fibrolite, the only locality where I have seen this mineral in either quadrangle, though it is common in the New Hampshire mica schists. The dip is considerably less near Miller Pond. The Conway schists succeed at the top of McMaster's Hill and the dips are discordant, though all are inclined easterly. Masses of hornblende and a cuperous vein appear upon the western slope before reaching "old city". There is more of the hornblende in the valley of the stream coming from the north corner of the town. The limestone becomes massive, with a lower dip, twenty-five degrees, in the central village of Strafford.

Going west up the hills towards the west line of the town the calcareous rocks predominate in large blocks pitching in different directions and the anticlinal is reached at Kibling's Hill near the town line. The westerly dips prevail to the village of Tunbridge, in calcareous schists except a slaty mass in District No. 3. The dips are smaller and the rock more massive in the Valley of White River.

Section D passes through the Ely copper mine, over Gilman Hill and terminates at North Tunbridge. Special mention will be made presently of the cupreous rocks at Copperfield and Copperas Hill.

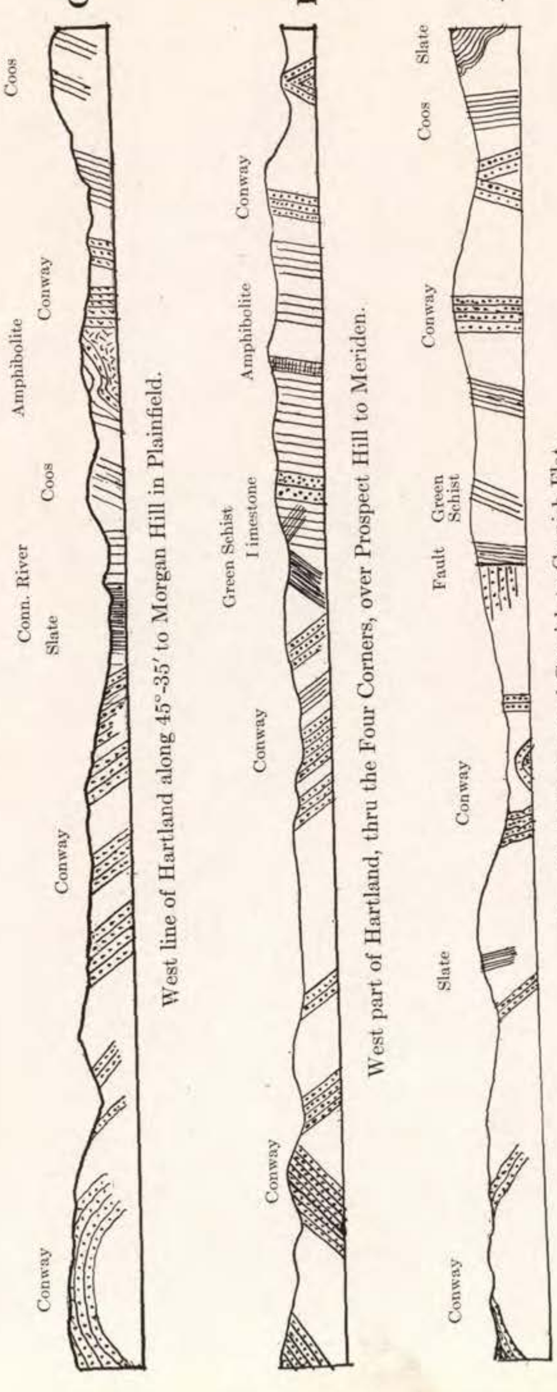
Section E corresponds to a part of the Dartmouth section No. IX. Nowhere is the anticlinal in the calcareous member so well developed as along this line. It has greater breadth and it is adjacent to Mount Colton, the highest eminence in the quadrangle. Along Jail Brook are many interesting small granite veins, properly pegmatites and strata containing pargasite. More twists and dislocations than usual appear upon Merrill Hill west of the court house. At the extreme west end of the section the limestone prevails to the exclusion of schists. The limestone is massive through most of Vershire with low dips, and is separated from the great range of the lower group by a fault. The greater altitude of the mica schists is well shown at Eagle ledge and for two or three miles eastward. While certain divisional planes dip easterly, there are others seen rarely dipping northwesterly. These are real strata and the formation is sinking, so that it disappears before reaching the south branch of Waits River in Corinth. The limestone wraps around this projection and narrows to a point in the southern part of the town of West Fairlee.

As an illustration of the want of identity between the petrographical and stratigraphical characters of our rocks, may be cited the presence of a considerable band of mica schist in the Conway group. It crosses Jail Brook upon Section E, and may be followed to the mouth of Beaver Meadow Brook and then to the east part of Tunbridge upon Section D, and possibly to the south of East Hill in the same town. To call it Goshen will involve stratigraphical difficulties. It seems to be rather a member of the Conway series, and as such comparable to two corresponding developments in Hartland, as represented upon Plate XXV of the Sixth Report. As there represented, the structure would be that of the presence of segments of the Goshen member forced upward by faults through the higher series. A corresponding subordinate member is conceived to be developed in the west part of the village of Woodstock, which would be allied to the strip already described as extending through Chelsea and Tunbridge. We still lack a definite enumeration of the several members of the Goshen and Conway groups as well as estimates of their thickness.

ILLUSTRATIONS OF CLEAVAGE PLANES CROSSING CONTORTED STRATA.

Plates XLVIII and XLIX are taken to show the ledges near W. F. Davis' house in District No. 1, Thetford, mentioned upon page 150 of the Sixth Report. Doctor Richardson figured the first named ledge on page 83 of the Third Report. This figure was not properly oriented, it should have been tipped to the left ninety degrees. In the photograph the cleavage planes are prominent,

PLATE XLIV.



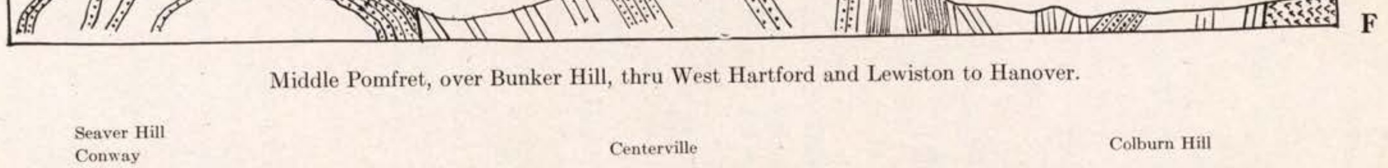
West line of Hartland along 45°-35' to Morgan Hill in Plainfield.

West part of Hartland, thru the Four Corners, over Prospect Hill to Meriden.

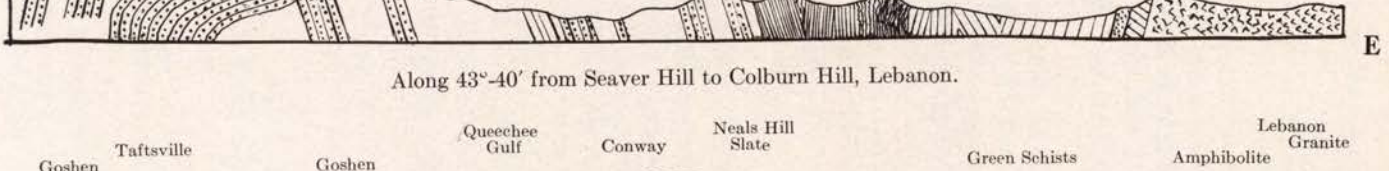
Thru West Windsor and Cornish to Cornish Flat.

Sections A B C across the Hanover Quadrangle.

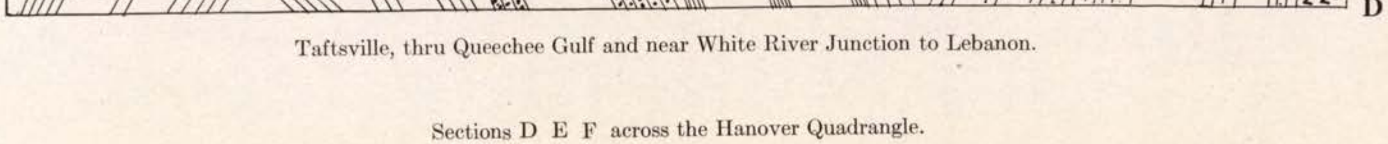
Plate XLV.



Middle Pomfret, over Bunker Hill, thru West Hartford and Lewiston to Hanover.



Along 43°-40′ from Seaver Hill to Colburn Hill, Lebanon.



Taftsville, thru Queechee Gulf and near White River Junction to Lebanon.

Sections D E F across the Hanover Quadrangle.

standing nearly vertical or eighty-five degrees N, thirty degrees E. Two curved white lines are quartz veins dipping fifty-two degrees N., thirty degrees W., which represent the stratification. Plate VII is a precipice not many feet away where the white quartz nodules and lines represent the strata, dipping forty degrees. These are mentioned in the Sixth Report, page 175. At the bridge by W. P. Ladd's the dip of the cleavage is fifty degrees S. E. The strata dip, twenty degrees northerly.

Plate L shows curved crystalline strata in a loose block of stone by the roadside in the west part of Thetford. It carries biotite and many small garnets and belongs to the Goshen group. Another example is to be found about a mile north of Thetford Hill near some igneous ejections. The slates dip fifty degrees N., sixty degrees E., all over the field. At one point a mass of curved strata rests directly upon the edges of the cleavage dip. The material does not seem to be essentially different from that which shows the cleavage, so that the conclusion is forced upon one that the curved lines represent the true position of the strata. Other examples like those figured in Plates XLVIII and XLIX may be seen along the road following the Ompompanoosuc to the west of the Davis locality. All these cases cited belong to a formation assigned with difficulty to our classification; whether a slate, phyllite, or argillite, corresponding to the range that has been followed northerly from Plainfield, N. H., through the two quadrangles—or to the Goshen schists that merge into them. Both are fine grained rocks, whether nearly pure argillaceous or silicious: and I am not satisfied with the division line between them. Both are masses of crumpled strata so compressed that the original structure has been generally obliterated. The curved quartz veins are evidently strata from which everything soluble has been leached out, leaving the silica, or infiltrations occupying spaces left by the removal of material.

Upon the geological map Plate XLVI, no attempt is made to distinguish between the fine grained rocks in the west part of Thetford and the north edge of Norwich. It is certain that limestone bands characteristic of the Conway group occur along Bloody and Avery brooks and with fine grained schists that would otherwise be classed as Goshen; and they commence at Rice's Mills to connect with the better defined area along Abbott Brook and Central Strafford. The reference to the Conway group is fortified by the folding of these rocks around the north end of the Goshen rocks in Corinth, traceable nearly to West Fairlee. The direct connection of this range with the synclinal through section A of Plate XLVI, and the three figures upon Plate XLVII is plain, supposing that the bulging upward of the Goshen rocks would pitch out the Conway schists, and the necessary presence of a fault to the west of the slates.

In the 1861 report mention was made of related phenomena as noted in Richmond and Fairfax, and they were referred to foliation. The following quotation is taken from page 390 in the description of the "Talcose conglomerates" which are apparently the same with the Mendon series described lately by C. L. Whittle.

A question of much importance is naturally suggested by these observations. In the western part of Vermont where metamorphism has not changed the aspect of the rocks so much as in the central and eastern parts, the marks of strata are entirely obliterated. Now why should not the marks of stratification be entirely obliterated in the more thoroughly metamorphosed regions, so that the observations recorded of various dips and strikes of the strata are those of foliation? We confess that our confidences in the truthfulness of our observed marks of stratification has been somewhat shaken by these examples of foliation. If some additional planes could be discovered elsewhere in the metamorphic rocks, to correspond with marks of strata, it will confirm this view. And it would probably reduce the very great thickness, which we have felt compelled to ascribe to the strata of the different species of metamorphic rocks."

What is called foliation here is simply cleavage.

SECTIONS ACROSS THE HANOVER QUADRANGLE.

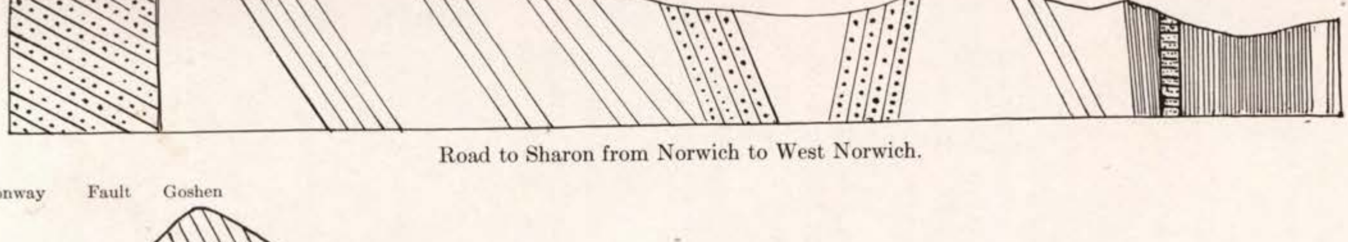
Plates XLIV, XLV.

Six sections cross the Hanover Quadrangle, designated by the first six letters of the alphabet, capitalized.

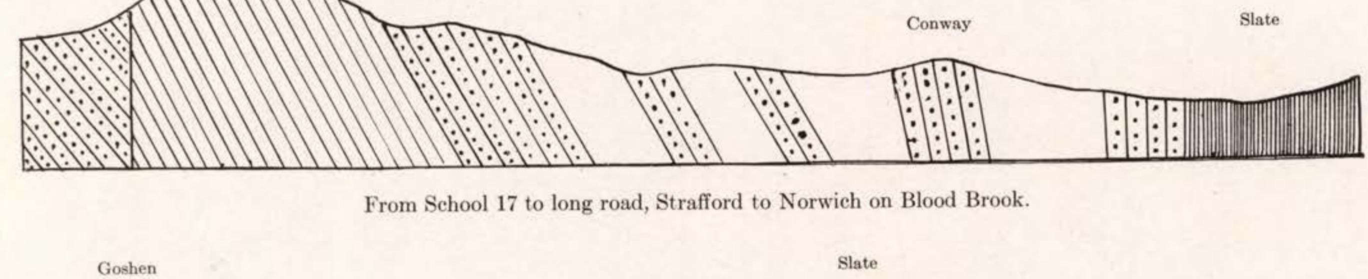
A lies near the southern boundary from near Cornish Flat in New Hampshire to the north part of West Windsor. Slates very much crumpled and broken occupy the corner of the sheet dipping southeasterly. Between the hill and the Flat is a band of micaceous chloritic schist, weathering to a lighter color, inclined at a higher angle, and having the appearance of a dislocated block, referred to the Coos. Along the valley line, reaching up the north slope of Fernald Hill are schists crumpled wonderfully, and frac-

Geological Map of Hanover and Lebanon, N. H.

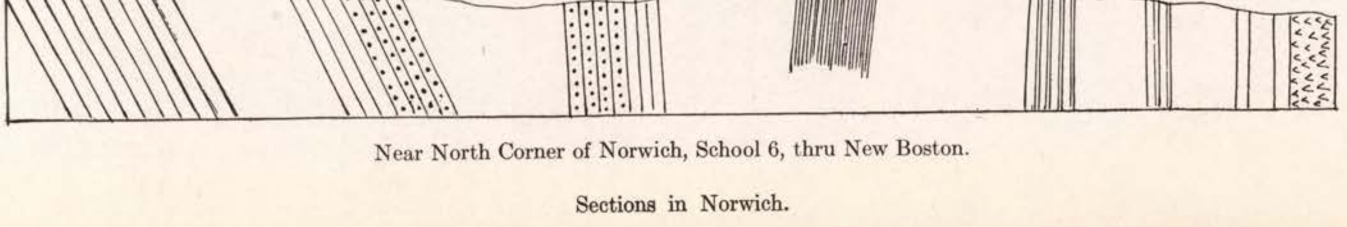
PLATE XLVII.



Road to Sharon from Norwich to West Norwich.



From School 17 to long road, Strafford to Norwich on Blood Brook.



Near North Corner of Norwich, School 6, thru New Boston.

Sections in Norwich.

tured. Even in a country noted for its disturbed condition these ledges stand out conspicuous. The strata have a strike of N. 50° E., and then change abruptly to be about east and west; and there is a difference of 60° in the position of the cleavage planes. The broken masses adhere together as firmly as if the new were the original condition. The rock is regarded as the same with that lying west of the slates.

In the valley a little south of the village of the Flats, the Conway schists with their associated limestones predominate, standing nearly vertically in an anticlinal attitude. Fernald Hill is a mass of the same strata, vertical in the higher parts. The exposures west of the hill are inclined westerly, and correspond to the greenish schists mentioned as following the slates, and believed to be the same strata wrapped around the hill and of later age.

Upon the highland, west, near the town boundaries of Cornish and Plainfield, the predominating rock is the green chloritic schist, containing a bed of white limestone, with overlying conglomerate holding distorted pebbles dipping 40° to 60° N., 60° W. The limestone was once quarried for the manufacture of quicklime, and appears to have been the material analyzed by Dr. C. T. Jackson. Johnson's quarry — silicious matter 59.6, peroxide of iron 3.4, alumina 4, carbonate of lime 22.6, carbonate of magnesia 13.8, total 99.8 containing 12.72 per cent of lime. The conglomerate at one place has been thrown quite a distance to the east.

Upon the west slope of the hill, Conway rocks appear, the first with a northerly dip of only ten degrees; much lower down the dip is 70° East, and by the Connecticut River at the mouth of the Blowmedown Brook is a small anticlinal, agreeing with the attitudes of these calcareous schists farther north, a ledge being in each township, Plainfield and Cornish. Our conclusion is that the Conway schists are broken into large blocks on the east side of the Connecticut.

On the Windsor side are many ledges adjacent to the railroad with very high easterly dips. On Hubbard Brook is located a quarry of a slaty rock like that seen by the road south from Windsor, with nearly vertical strata. It was called phyllite by R. A. Daly, containing about ninety per cent of silica. Farther west near the School House District No 6, the rock is a mica schist with a low dip. In west Windsor the calcareous rocks reappear in anticlinal attitude.

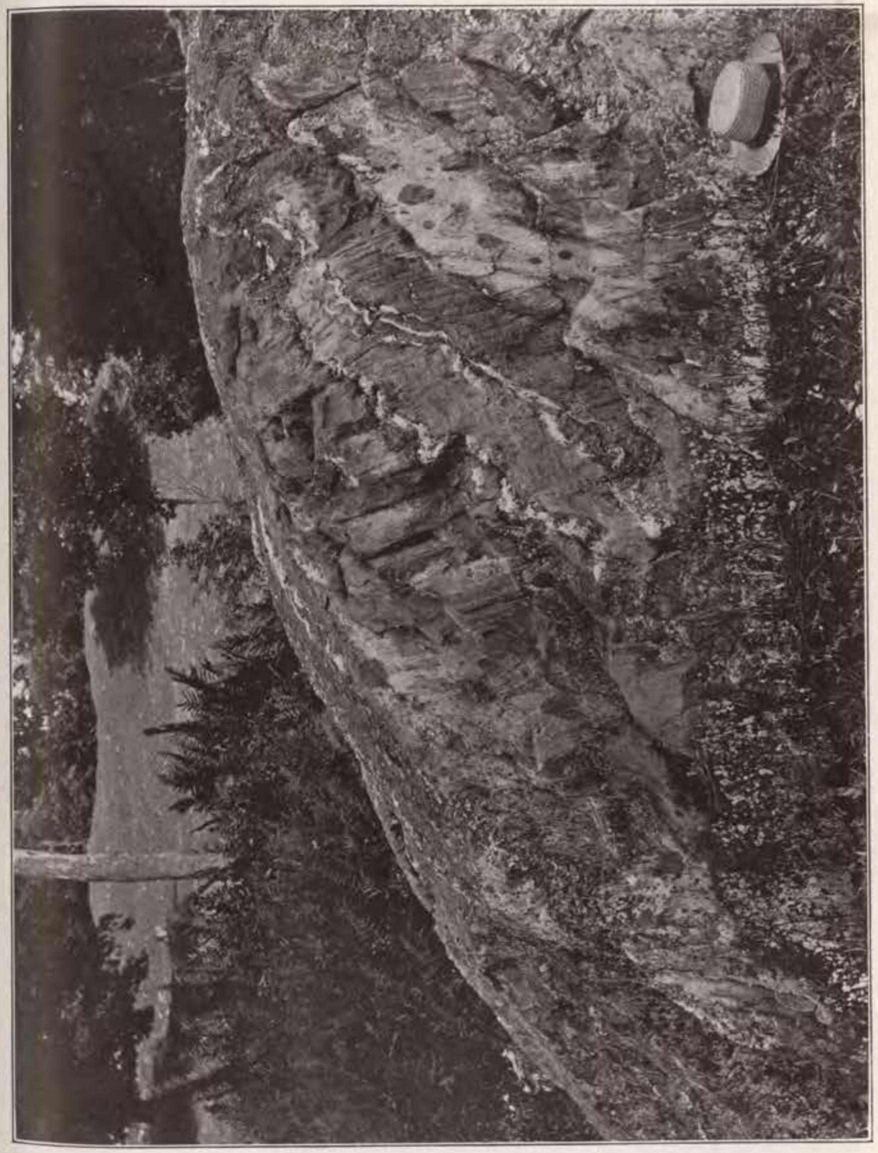
Section B runs from the west part of Hartland through the Four Corners and over Prospect Hill to Meriden, N. H. At Meriden there is a close pressed anticlinal which may represent the north end of the area of the Conway schists, extending from Fernald Hill and perhaps including French's ledge. The upper Coös rocks with two bands of amphibolite occupy the section across to Prospect Hill with westerly dips. The limestone belt traced from Johnson's quarry in Cornish has its maximum development upon Prospect Hill with easterly dipping cleavage planes succeeded westerly by the Howe Hill mass of slates, a part of which display zigzag courses of beds of limestone, elsewhere referred to the Conway group. The slates are better defined near the river. In Hartland the limestones are prevalent, the ledges being very numerous with the normal dip. There is a fine anticlinal in the southwest part of the town including a thick mass of schist supposed to be a part of the Conway group and not the Goshen to which they are closely allied.

Section C runs from the west line of Hartland along the line of 43° thirty-five minutes to Morgan Hill in Plainfield, N. H. Nowhere are the chloritic parts of the Coös group developed more abundantly than here, and a good theory for their origin is their derivation from hornblende schists. The green schists are nearly vertical, rather of an anticlinal attitude. At the woolen mill in North Hartland the igneous diorites, diabases and camptomites seem to have taken possession of the formation. In the slates the true strata are apparent, dipping 36° to 50° S. and 37° W., faint lines crossing the vertical schists dip 50° E., 10° S., along the slate range cleavage planes. The Conway a half mile farther south, and similar positions are recorded frequently across to Alder Meadow Brook farther west. Upon the last meridional road upon this latitude the strata are horizontal, preparatory to a dip down the west flank of the anticlinal, reached not far from the west town line.

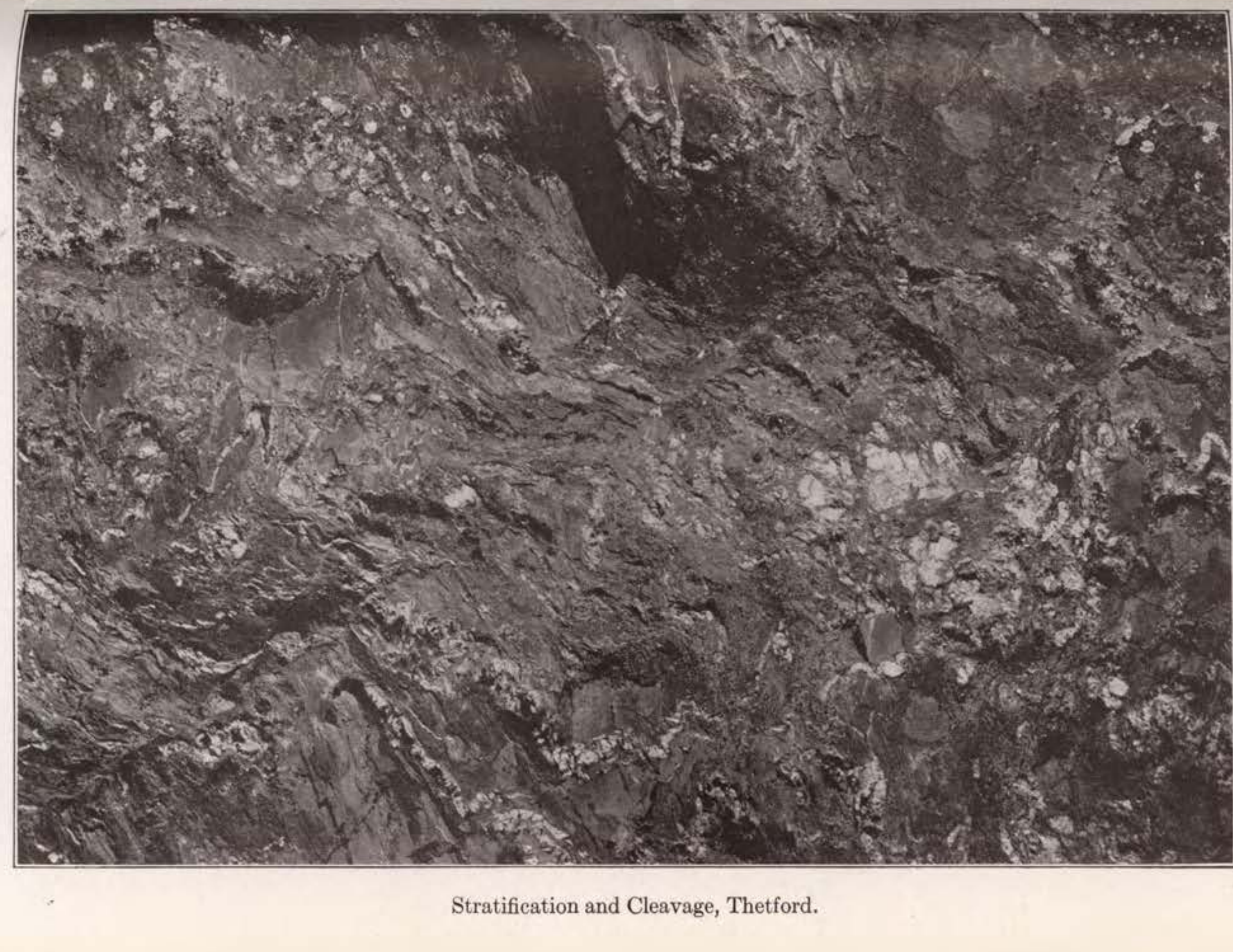
Section D runs from near Taftsville through Quechee gulf and near White River Junction to the edge of the village of Lebanon, N. H.

The south end of the great granite batholith reaches to the west part of Lebanon, and the schists adjacent show the effect of the heat, in induration and silicification, besides the absorption of inclusions into the igneous magma. The phenomena of contact phenomena are conspicuous in cuts along the railroad. To

PLATE XLVIII



Curved Strata and Cleavage, Thetford.



Stratification and Cleavage, Thetford.

the south the fragmental character of the strata are apparent. Next to these visible effects of heat is a broad band of the Coös schists with bands of amphibolite, both massive and foliated. Towards West Lebanon are mica schists with very large spangles of biotite. In the green schists just across the river are two conical hills of hornstone conparable to the bases of ancient volcanic eruptions. Near them to the south are exposures of limestone and conglomerate, suggestive of the related rocks in Plainfield and Cornish. The allied green schists occupy the lower ground for more than a mile, when ordinary slates succeed having a greater altitude and constituting Neal's Hill. There is reason to believe that the slates have been pushed up adjacent to the green schists—the divisional line between them being a fault—showing itself from North Hartland through Hartford into Norwich. The slates have been broken and badly twisted next to this supposed faulted plane. The effect of this elevation may perhaps be seen between this slate and the Conway group, with its normal dip of 67° easterly across the flat land adjacent to the gulf. Dikes of olivine diabase and camptonite cut its schists in the walls of the gulf and the locality is an excellent one in which to study the phenomena of dike intrusion, of igneous alterations, as from olivine to chlorite and the production of zeolites; of the erosion of a gorge and the manufacture of pot-holes. Toward Quechee is a hill of the underlying Goshen schist continuous to the end of the quadrangle. A fine anticlinal is exposed near Taftsville, supposed to underlie the rock that has been traced from section to section upon both the sheets.

Section E runs along the line of 43°, forty minutes from near Seaver Hill to Colburn Hill in Lebanon, N. H. Colburn Hill is composed of protogene granite with inclusions of the mica schists. Divisional planes corresponding to the strata dip to the west down towards the river. Precisely along the section line may be seen a faulted segment of the mica schist with an igneous dike dipping towards the east. Amphibolite succeeds with some schists having the normal westerly dip to the river nearly opposite Wilder. At the Lower Falls near the mouth of the old canal the dips of the hornblende schists are less than 50° westerly. The green schists are mixed with the igneous diorities and diabases and were thought to represent three or four folds when all these rocks were classed as stratified. They do not rise so high as the slates at a very favorable location just north of Hartford Village, and the latter are much twisted and thrown about as if by the pressure of the more solid material. A related condition is beneath the iron bridge across White River where there is an interval between the two rocks. The slates being the softer rock have been pressed into folds and there are occasional patches of an original stratification quite diverse from the cleavage. The Conway schists about Centerville dip easterly, as well as the great hummock of the Goshen rocks to the west, so far as known. I think a careful study will show the continuation southerly across Sections D and E of the faulted synclinal block of the Conway group described upon section F and farther north. The bluffs upon both sides of Centerville suggest dislocation more or less connected with such a displacement. The next development of the Conway schists is the anticlinal structure. The south flank of Seaver Hill has the petrographical appearance of mica schists associated with hornblende. Upon Whitman Brook in Pomfret are more calcareous beds.

Section F runs from middle Pomfret over Bunker Hill through West Hartford and Lewiston to Hanover. At the east end is the great mass of protogene granite, showing on the west flank of Balch Hill a valley of erosion where the massive rocks come in contact with the mica schists, all inclined westerly. These rocks are mostly concealed beneath the modified drift of the Connecticut flood plain, and their dip has determined the dip of the amphibolites upon the Observatory Hill and Dartmouth park. Occasionally layers of the micaceous rocks are visable. The proof of the igneous character of the amphibolites is afforded by the induration and silicification of the green schists adjacent to them near the steam saw mill. The green schists are nearly vertical, varying to either side without apparent cause. There is an appearance of faulting at the east base of Morley Hill between these schists and the slates, the latter presenting an anticlinal attitude. The Conway schists show first the supposed faulted synclinal block, which has been followed a long way north and probably to the south. The next and widest part is decidedly the calcareous division with easterly dips. Between Jericho and West Hartford the Goshen schists prevail with the easterly cleavage dips. The superinduced character of the structure is evident from its slaty-like uniformity. A fault is looked for in the valley of White River, followed by massive limestones which swell up into the splendid arch of Bunker Hill. Beyond this to the end of the section the limestones dip westerly with many local slips.

PLATE L.

Curved Strata and Cleavage, Thetford.

THE GREAT ANTICLINAL.

The sections across the two quadrangles show conspicuously a great anticlinal axis. It appears upon every one of them, mainly in the Conway division of the rocks, and upon elevated land, except in Hartford, where the axis seems to be developed in the underlying mica schists. From Chelsea the anticlinal line runs a little west of south to Kiblings Hill in Strafford and then turns southeast to South Strafford. From here it runs due south to West Norwich, where it terminates, only to appear after a shift of three miles in the southwest part of Sharon. The mass of Quimby mountain separates these two termini. The western line courses due south to near Taftsville and there is directed a little west of south into West Windsor. The line may be traced in the adjoining territory south to Hammondsville in Reading, where it comes in contact with the Reading-Halifax range of gneiss or granite and terminates. From the Chelsea hills it may be traced northerly through Washington and Orange where it terminates as before in contact with the larger mass of granite in Groton and Marshfield. This northern granitic mass divides the schists into two parts with opposite dips which close together again at West Danville. The domed structure may be traced to Sutton. Farther north it is not certain that this peculiar feature can be recognized as distinguished from the normal structure. In the Canadian extension of the formation the dip is uniformly westerly; while on the Brownington and Derby lines several axes are recognizable, and the Goshen schists have not been identified. Possibly an analogous division may be indicated on Section XV, if the Conway rocks of Clarksville, N. H., may be esteemed as the eastern flank of the anticlinal.

At Hammondsville the disposition of these rocks bifurcates; part lies to the west of the granite in Cavendish, coming to a point south of Proctorsville, while the major portion extends into Massachusetts on the east side. Just south of the granite area in Halifax a strong anticlinal is represented, having the same position with that north of Hammondsville, so that the western flank of this fold should correspond with that described north of Proctorsville.

The granite masses producing the bifurcation of the schists in Reading and Orange are fifty miles apart; and the suggestion arises naturally that the folding of the schists has been produced by the development of igneous matter beneath, pushing upwards. This plication is made manifest chiefly in the upper group, though the Goshen schists are believed to be recognizable at Hammondsville, and in the analogous anticlinals farther east at Shelburne Falls, Mass., and Brattleboro.

As in Canada, the more normal attitude of the formation may be recognized in Massachusetts. Then there is the natural anticlinal with moderate dips of the Hawley, Goshen and Conway schist in the towns of Chesterfield and Goshen.

SECTION LINES ACROSS THE STATE.

The plan proposed by President Hitchcock for the original survey of the State in 1857 provided for the measurement of east and west sections across its entire breadth. Thirteen of these were delineated in the report of 1861, and specimens to illustrate them were placed in the museum. The same method was adopted by me in the Survey of New Hampshire, and has been continued in later years for the benefit of the museum of Dartmouth College, where eighteen of these sections are displayed, amply illustrated by diagrams and specimens, extending across the States between Maine and New York, and including the adjacent territories of Canada and Massachusetts. For the convenience of students of Vermont geology I will present a list of these in order from south to north and their numbering. No description of them has been published since they numbered thirteen.

Section Number	Location
M	Near the north line of Massachusetts.
I	South Vernon to Pownal.
II	Brattleboro to Bennington.
III	Westminster to Arlington.
IV	Springfield to Rupert.
V	Windsor to Poultney.
Va	Hartford to Fair Haven.
VI	Norwich to Benson.
VII	Thetford to Orwell.
VIII	Fairlee to Shoreham.
IX	Bradford to north part of Shoreham.
X	Newbury to Panton.
XI	Barnet to Charlotte.
XII	Lunenburg to Burlington.
XIII	Guildhall to South Hero.
XIV	Bloomfield to Isle La Motte.
XV	Canaan to Alburg.
XVI	Near the south line of Canada adjacent to Vermont.

Nearly 7,000 specimens illustrate the sections as gathered from the two States and the contiguous territory. Each one is placed in front of the colored profile where its exact location is indicated by numbers, and the eye views both the character of the rock and the interpretation of its geological age with scarcely any shifting of the lids. Adjacent to the sectional display is a relief map of the two States upon horizontal scale of one mile to the inch, colored geologically. The quadrangles of the United States Geological Survey have been used for the basis of the relief so far as they have been completed. Not half of the territory has yet been mapped by the survey. All that has been done so far has been at the expense of the general government. The cooperation of the Legislatures of Vermont and New Hampshire is earnestly desired to make the series complete.

THE COPPER DEPOSITS.

The copper deposits at Copperas Hill and Ely or Copperfield in Vershire have been worked extensively, and were well known to the public before the now famous mines west of the Mississippi were discovered. Their economic aspects have been set forth in this series of reports from time to time so satisfactorily that no further mention of them is necessary. As the mines are situated upon the quadrangle described in this report, some mention should be made of their geological features, in which the locality at Corinth might be included.

The deposits occur in our Goshen formation—a rock to be compared with a micaceous quartzite—originally sandstone and shale, but now metamorphosed sericitic schist. The area in Vershire is broadly speaking an anticlinal, the flanks dipping east and west while the mass pitches northerly and is completely covered in the south part of Corinth by the Conway or calcareous member. Most of the mineralized part is silica, mixed with flakes of sericite—a muscovite mica—and there are many intercalated masses of clear quartz that have filled small irregular lenticular spaces in the minor foldings.

The so-called veins are bedded deposits conformable to the general structure, or lenses that overlap. Instead of following one cupreous mass through the country, the first will be succeeded by a second, the second by a third. A lens over one hundred feet across has been mined out at Ely, and one seven hundred feet across at the Elizabeth. The maximum thickness of the first is twenty feet; of the second, more than one hundred feet. At Ely it has been followed downwards 3400 feet at an angle of 22°.

The ore consists of pyrrhotite or magnetic pyrites filled with grains and masses of chalcopyrite with a sprinkling of pyrite and zinc blende. The vein stuffs are quartz, actinolite, garnet, biotite, and calcite, while cyanite and zoisite are neighborhood minerals. The average composition of the Copperfield ore is Copper 3.31, Iron 30.39, Sulphur 14.71, Insoluble 36.67.

In the Elizabeth mine the average is about the same, the best ore being in the central six or eight feet of the ore-body. The hanging wall part carries 2.30 percent of copper; the central part 4.64 percent, and the foot wall, 4.28 percent.

At this mine the ore-body constitutes a lens whose axis pitches gently northwards. The foot wall dips seventy degrees easterly. To the south the vein has been uncovered continuously for seven hundred feet, varying in thickness from twenty-five to one hundred feet. The ore is upon a steep hillside and has been uncovered continuously without sinking deep shafts. Those already excavated do not extend more than a hundred feet below the natural drainage of the locality. The impression prevails that the ore thins out in the descent—whether such diminution should extend to the companion lower lying lens remains to be proved.

Many authors have assumed the geological identity of the Orange county ores with those of Gardner mountain and Milan in New Hampshire, and of the Eastern Townships in Quebec. Such statements are illustrations of hasty generalization, without any foundation in fact. The associated rocks are totally unlike one another.

A similar deposit occurs in the Ducktown district in Tennessee, and they are so nearly alike that features scantily developed in

one may be more pronounced in the other. The gossan and the copper oxides leached out from it in Tennessee are wanting in Vermont because of the action of the glaciers of the ice-age in the north and their absence in the south. Any debris derived from the outcrop of the vein in Vermont in pre-glacial times must have been swept away when the ice scoured the country.

The following are the principal periods in the gneiss and development of the copper veins. First the deposition of sedimentary sandstone and shales. Second, the production of sillicates and the alteration of the sediments to mica and quartz schists; with the production of the calcite quite plentiful in Ducktown but sparingly in Vermont. Third, dislocations along the lines of the present veins and the introduction of pyrrhotite. Fourth, other movement fissures shattered the pyrrhotite and introduced the chalcopyrite into the crevices. Fifth, the latest stage has been the formation of black oxides and a little metallic copper at about the lowest level of the drainage.

THE MEMPHREMAGOG SLATES.

In the 1861 report the suggestion was made that the slates and limestone about Newport might be traced as far south as Montpelier. In my map of 1878 I put a broad belt of these slates between Calais and Randolph. Their best development was on the latitude of Montpelier, as well as at Northfield, eight or ten miles in width. Except for the abundant black slates present one would call the whole series the Conway group because of the existence of so much limestone. The same peculiarity was perceived again in 1909 upon Section IX, between East Brookfield and Braintree, a breadth of five and one-fourth miles. The limestones are as massive and constant as upon the same line in Chelsea and Vershire, with dips usually to the west at variable angles. The slates thin out from Randolph southerly, but increase in Barnard to a breadth of over two miles with a large amount of limestone. The slates are black and show strata crossing the cleavage planes. The limestone decays differently from that in the normal Conway regions, and one keeps a constant lookout for fossils, especially as in both the localities named the limestone had the peculiar fracture and color of the Georgeville, P. Q. Upper Silurian.

It must be that still farther south in Massachusetts the same Memphremagog slates are recognizable in certain black slates and schists in Heath and Charlemont. A reason why I had regarded the slates bordering the Conway schists in the middle part of the State of Vermont as older was because they flanked the latter on both sides and were adjacent to the two adjacent hydro-micas. There seemed to be the natural succession of hydro-mica, slate, and Conway. With our present knowledge there still are presented to us two ranges of slate above Springfield upon the opposite sides of the green schists and still more markedly farther north. Commencing in Plainfield, N. H. a broad slate band crosses over into Hartland, and extends north through Hartford, Norwich, Thetford and Fairlee, repeated in the north part of Bradford. This slate lies west of the hydro-mica, while the Leyden band may be traced without a break from Massachusetts northerly past Bellows Falls into Claremont and so on to Orford. This lies east of the Conway group and has no direct connection with the other range. The two are probably of the same age and may be represented by the two slate bands in Springfield upon the opposite flanks of a narrow hydro-mica anticlinal. It seems in better accord with the general arrangement of the formations to regard the Memphremagog and Leyden slates as having been deposited in separate basins, though very possibly of the same age.*

SURFACE GEOLOGY.

The phenomena associated with glacial action are the same in kind on both the Hanover and Strafford quadrangles; so that the principles enunciated in the Sixth Report do not need restatement. Because of the abundant dispersion of limestone, resistant ledges are fewer upon the Strafford quadrangle, and therefore glacial striae are less common. For the same reason the transported blocks of limestone have disappeared, the fields are smoother and stone walls fewer. Boulders of granite are conspicuous when present. Because of the limited area covered by this rock, the blocks of granite transported short distances are scant; and those from the larger batholiths farther north have been carried farther

*See Vol. 7, p. 510 Bulletin Geological Society of America.

PLATE LI.

Glaciation of Gile Mountain.

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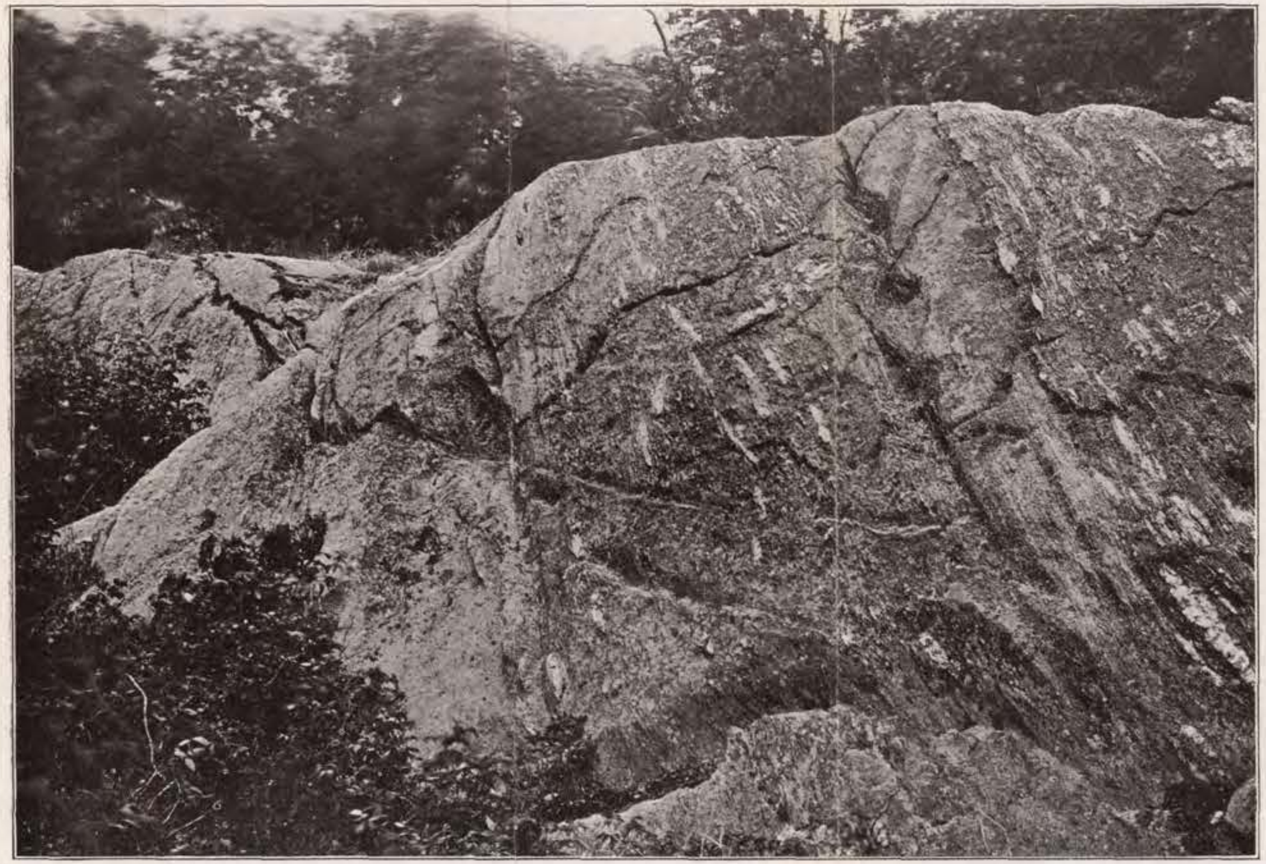


Glaciation of Gile Mountain.

east. These conditions have enlarged the number of arable acres in the district.

It is supposed that the whole area was swept by the southeasterly ice movement during the height of the glacial period. The following observed courses belong to this category:

Gilman Hill, Vershire, S. 10° E.

Near Brocklebank Hill, Tunbridge, S. 3° E.

South edge of Corinth, 750 ft. above Bradford, S. 15° E.

At Prescott's west edge of School District No. 8, Corinth, S. 5° E.

Gile Mountain, Norwich, S. 30° E.

At F. Martin's, Norwich, S. 10° E.

Gile Mountain, Norwich, 1,917 feet, is the highest eminence between the Connecticut and White Rivers and was therefore the point the most exposed to denudation. Only the highest part of the mountain shows the southeast markings. The weathering causes the ledges to decay more and more every year, so that the striation as seen a dozen years ago may now not be discernible in many cases.

The smoothing in the background of the photograph, Plate LI, and upon the summit of the ledge, was produced by the later movement, and is to be found upon all sides of the summit. The southeast planation is to be found only upon the lee side of the later glaciation and that upon jointed surfaces. Out of many exposures the present one was selected because there are two grooves upon it made at the time of glaciation, although obscured by subsequent disintegration. Patches of white quartz are the best index to the striation, because they do not decay and these are common. Farther south and a few feet lower down, the embossment produced by the earlier movement extends for about 200 feet, upon a descending slope; the stria here run S. 30° E. The summit of the mountain is sparsely wooded, having once been entirely cleared. This locality was mentioned upon page 175 of the Sixth Report. Nearly all the glaciation to the east in Norwich belongs to the later period. The southeast course is plain upon Griggs' mountain in Norwich, upon Wright's mountain in Bradford, Potato Hill in Thetford, Sprague and Hurricane Hills in Hartford, hills in the south west part of Hartland, Mt. Ascutney, and the eastern rim of the Connecticut basin from Moosilauke to Grantham mountain.

The following instances of the movement west of south, are regarded as worth preserving:

Near S. H. No. 9, Norwich, S. 18° W.

Near S. H. No. 8, Norwich, S. 20° W.

Top of Stone Hill, Norwich, South.

High ridge near west line of Sharon, 2 miles north of White River, South.

Top of east spur of Gove Hill, Thetford, 1,200 feet, S. 13° W.

One mile north of Thetford Hill, S. 23° W.

Ledge recently uncovered at Copperas Hill, S. 20° W.

North of Gilman Hill, Fairlee, S. 20° W.

Near Union Village, west, S. 20° W.

Near Union Village, east, S. 15° W.

Northeast corner of Norwich, S. 20°, 30° W. several.

The only example of the glacial smoothing of valleys supposed to have been produced by ice tongues is on the Ompompanoosuc. At Rice's Mills the striation courses S. 22° E., South at the junction of the West and Vershire branches. It does not require a great imagination to picture a mass of ice stranded in the Ompompanoosuc valley at Thetford Center, kept in place perhaps by coarse blocks at the crossing of the stream by a road trending to the southwest. For two miles above this road is a broad meadow, which might have been the place where the ice was stranded.

There is an excess of fine grained modified drift upon the Ompompanoosuc River. The lower part connects with the Connecticut flood plain at its mouth, by the railroad station, and in connection with the esker. The highest terrace on the Connecticut is at the level of 520 feet. It rises to 580 feet in District No. 6. Upon the hill east of Union Village the contour map shows a shelf of sandy materials 640 feet high where a cemetery has been established. Corresponding levels that have been carved out of moraines are on the opposite side of the river. The sand fills the valley up to Union Village, and makes a dome-like hill a mile farther north, blocking the valley so as to push the road to one side. Remnants of it may be seen up to Thetford Center in one branch and to the base of Hubbard Hill, 650 feet, a rise of seventy feet in three and a half miles. The great amount of fine sand in this valley suggests the presence of moraines higher up from whence the material has been derived. Above this

imagined mass of stagnant ice, where the streams from Lake Fairlee, Brackett's Brook and from the northeast converge is a sand hill above the 700 feet contour, which may be traced to a connection with Lake Fairlee terrace, nearly 800 feet high. Hence there was really a flood plain from the Connecticut at Pompanoosuc 520 feet to Post Mills of 800 feet. At several localities there are groups of earthy mounds suggestive of recessional moraines, as on the east branch of Bloody Brook below New Boston and connecting with the great sheet of till more or less continuous from the southern edge of the quadrangle on the White River valley. A second area would lie between New Boston and the north corner of the town; another upon Lord's Brook southeast from Gove Hill in Thetford. There are some accumulations of this sort near South Strafford, at North Tunbridge and thick till upon Jail Brook east of Chelsea. Below Sharon, and between the mouth of Broad Brook in Sharon and South Royalton in the northeast corner of Royalton. In Corinth to the north of our quadrangle are moraines which connect with more conspicuous examples in the extreme east part of the town which are related to extensive moraine accumulations in the Ammonoosuc district of New Hampshire.

In the northeast corner of Royalton many acres of land have been damaged by torrential washouts. It is a case analogous to those in the Southern States, that have been illustrated in large diagrams distributed by the National Department of Agriculture. Where the land has been ploughed so that the furrows run down the hillsides; channels are formed in which the rain water will flow and wash out both the arable soil and the underlying earth, with the resultant loss of the crops and frequently the ruination of the field for agricultural purposes. If the plough circles horizontally around the hillsides, the flow of water will be impeded and the formation of crevasses prevented. So faithfully has the story of the ruin effected by unscientific ploughing been told, that one now scarcely sees the faulty method of breaking the ground as he travels over the railroads of the south. The horizontal furrows attract attention by their constancy. In Vermont, a region that could easily be damaged by unskillful ploughing is the calcareous tract characterized by steep hills in Orange and Windsor counties,

OLD BED OF THE CONNECTICUT IN HANOVER.

When a river has been obstructed by ledges so that falls have been created, it is common to say that there has been a change in the bed, as at Bellows Falls, and it has been due to the accumulations of sand, clay, and gravel which have obstructed the original channel and compelled the water to fall over hard ledges, incidentally developing a water power. No one seems to have noticed the application of this principle to the history of the Connecticut River in connection with the fine water-power at Wilder. On referring to the maps and reports it will be seen that there is a continuous valley in the modified drift from the great bend two miles north of the village of Hanover, east of the College to the high terrace southeast from Wilder, neglecting the excavation at Mink Brook, a distance of more than four miles. There is reason to believe that were the earth removed the river would flow today at a lower level from the great bend at Lovelands to the Lower Falls without encountering ledges. Reliance is placed first upon the general principle as stated; second upon borings for water at Mr. John L. Bridgeman's, half a mile south of the bend, where a boring as deep as the level of the river failed to penetrate through the sand; and third to the fact that no ledge is found in either the cross valleys of Gile or Mink Brooks. Since the formation of the esker the whole of the plain has been filled with silt, which caused the river to cut across the gravel ridge at the bend. The map does not do justice to the abruptness of the bend, nor to the configuration of the banks below the Ledyard Bridge. The United States Geological Survey refused to accept corrections offered by the Thayer School which would have greatly improved the map and removed a blemish which is a disgrace to the surveyors.

THE 560 FEET LEVEL OF MODIFIED DRIFT.

Mink Brook flowed into the flooded Connecticut at the level of 560 feet as seen at Prexie's Garden about a mile from the College. The fan shaped arrangement of the sand brought down by the stream was in part a reason why this delta was regarded as a local affair; the stream perhaps attaining a higher level when the volume of the water happened not to coincide with level of the main flooded river. Prof. Dana insisted that this delta represented the level

C H Hitchcock

of the Connecticut—and hence gave the flood a higher level than that ascribed to it by Mr. Upham in the Geology of New Hampshire, and I subscribed to this latter view. But the discovery of several other levels of the same height in the open valley make it clear that the main flood reached this altitude. Without citing the delta of Jacob's Brook in Orford, we may look at the nearest island to the Mink Brook delta—the rock and till less than half a mile southwest from Mr. Frank Spencer's in the edge of Lebanon. This rock seems to have been an island barely rising above the water but sufficiently important to have the fine grained materials collected on its southern side, below the level of 560 feet. The private road from the Allen barn to Wilder has cut through loam and sand at the height named. Low down very large boulders of rock are imbedded in it as if they had been rafted to their present position. On the road to West Lebanon there is a large stretch of sand above the 500 feet contour that is connected with the earth from the Spencer island. It is above the so-called highest normal terrace and reaches across to the base of Colburn Hill.

In Hartford the flood must have connected Norwich and Hartford by the Christian Street coll and the streams from the hills west (Dothan) discharged at this same high level, bringing sediment. Farther south along the same street the summit of the Modified Drift back of Wilder has this same altitude, and it may be followed to the high sand plain adjacent to the Camp Meeting ground, from whose brink there is a long descent to White River Junction. About a mile southwest from the Junction, near the State Agricultural park the sand is oppressive in the road, and its upper level affords the space needed for the exhibitions. This is also 560 feet high.

Much sand appears at the same level in Lebanon nearly a mile east of the Electric Plant as the road turns from the east and west road to the southwest. A small plateau lies just below the crossing of Mascoma River by the road a mile and a half east of the Electric Plant; also upon the north and west flanks of Mt. Finish. The higher parts of the Modified Drift Plain between the White and Quechee Rivers attain the same level. It is not necessary to cite other localities of this highest level of the old flood plain. These that have been mentioned are sufficient to establish the proposition

OLD BED OF CONNECTICUT RIVER FROM LANCASTER TO WELLS RIVER.

In the 1861 report, page 116, I ventured to suggest that the Connecticut River may once have run from Lancaster through Whitefield to join the lower Ammonoosuc and follow its course down to rejoin its present bed at Wells River. This view was based upon the absence of modified drift along that part of its course known as Fifteen Miles Falls between Lunenburg and the mouth of Passumpsic river, and its presence in fine condition below Littleton. If that were true, there was a time when the boundary between Vermont and New Hampshire was more direct, and consequently more scientific than it is at present; and some four or five townships would have been added to our territory, including the Ammonoosuc mining district. Since 1861 I have had occasion to study the surface geology of this region anew and think the early theory is tenable; and will present a brief statement of the facts concerned.

The Connecticut has cut through the Gardner mountain range below Lancaster, and descends 370 feet in twenty miles. The bed is a nearly continuous slope of coarse till with no ledges except at the lower end. The rapids are a natural division between the Lower and Upper Connecticut. If ice blocked up this channel the water would be turned either to the Androscoggin through Jefferson and Randolph to Gorham, or else work its way over the divide at Whitefield. The divide at Randolph is 1500 feet; at the Railway summit in Whitefield 1030 feet. For six miles along the Whitefield summit there is a broad lowland two miles wide, with the high Dalton mountain upon the west side and the elevated Kimball Hill region upon the other, elevations that would correspond to the hills upon both sides of the Connecticut almost anywhere in the neighborhood, especially if the earth in the lowland under discussion were removed. This lowland is made up of coarse materials. I had difficulty in finding enough ledges in it to indicate for the geological map what its formations were. More than that the large oval hill 1360 feet high blocking up the lower part of the valley is evidently a moraine, perhaps hundreds of feet deep. Now if there were ever an old bed of the Connecticut here the water probably flowed in a channel hundreds of feet deeper than the present surface. There is reason to believe that there

was an old channel here in which the river flowed, and that the material causing the obstruction was pushed down the Ammonoosuc valley from the White Mountains by a glacier.

This was not the ordinary ice of the glacial period; it was part of a glacial system centering about Mt. Washington. I have published descriptions of this Ammonoosuc glacier, starting in the wide valley about Fabyans and carrying the rocks of that neighborhood in a westerly direction down this valley in a direction the reverse of that taken by the great northern glacier. Stones from it can now be picked up as far south as White River Junction. The course of this glacier crossed the ancient Connecticut at the Wing Road Junction just where the debris would dam up the river from the north and compel it to seek its present channel down to Barnet.

In Littleton, Lisbon, and Bath are enormous moraines connected either with this local ice stream or the great mass of the northern ice. For size they excel any other hills of till about the mountains or in the Connecticut valley. Eustis Mountain in Littleton and Walker Hill in Lisbon are two of them. There is no finer field for the display of rough transported boulders than the country between the lowland plain of southwest Whitefield and Alder Brook. When the glacial ice was converted into water the finer parts of the till were washed out and transported down the Ammonoosuc to make the beautiful terraces of Littleton, Lisbon, and Bath while there was no material provided to build up similar deposits along the present valley, till the Passumpsic river was reached.

These considerations thus imperfectly presented seem to be adequate to a belief in the former flow of the Connecticut through Whitefield and the Lower Ammonoosuc valley to Wells River.

THE DEVONIAN IN VERMONT.

It has been generally believed that the Devonian was wanting in Vermont. Not only is it a fact that we have a considerable development of this age, but it was announced in the early geological reports of the geologists officially appointed for the State work. In the 1861 Report there are descriptions of the Upper Helderberg limestone and the overlying quartz rocks and slates as they were known in Bernardston, Mass., and the related formations just over the line in Canada upon Lake Memphremagog; from both of these localities it was claimed that there were extensions into Vermont. As time has gone on that conclusion is confirmed and extended.

In 1870 I maintained that there was a great series of rocks in the Connecticut Valley that could not be correlated with any of the known systems in either New Hampshire or Vermont and gave to them the local name of Coos. This conclusion was based upon both the petrography and stratigraphy. It was a group of quartzites, slates, mica schists characterized by the presence of staurolite, hornblende schists, etc., situated unconformably upon the other crystalline schists; and they were separated from the previously known mica schist areas. Our knowledge of the group was imperfect; some statements made about them have proved to be erroneous; too much reliance was placed upon mineral characters as a guide to age; but after every fresh discussion there still remains the fact that there is a large development of the Devonian in the Connecticut Valley. I will first briefly refer to the history of opinions and then describe such of the areas as it may be profitable to mention at this time.

President Hitchcock was the discoverer of the fossiliferous limestone in Bernardston. By his direction I described the occurrence of the rocks displayed in that town, as well as those entering the State from the north. Prof. B. K. Emerson in his report upon these rocks in the Geology of Old Hampshire County, Monograph XXIX of the U. S. Geological Survey, says that in this statement "is given the best section yet published (1898) of the rocks in question," which must include my own later descriptions in the New Hampshire report and the papers of Professor J. D. Dana. That my later conclusions failed to be satisfactory was due partly to mistaken theories, and partly to misunderstandings. It will not be profitable to waste time in explanations of what has been erroneously stated by myself and others.

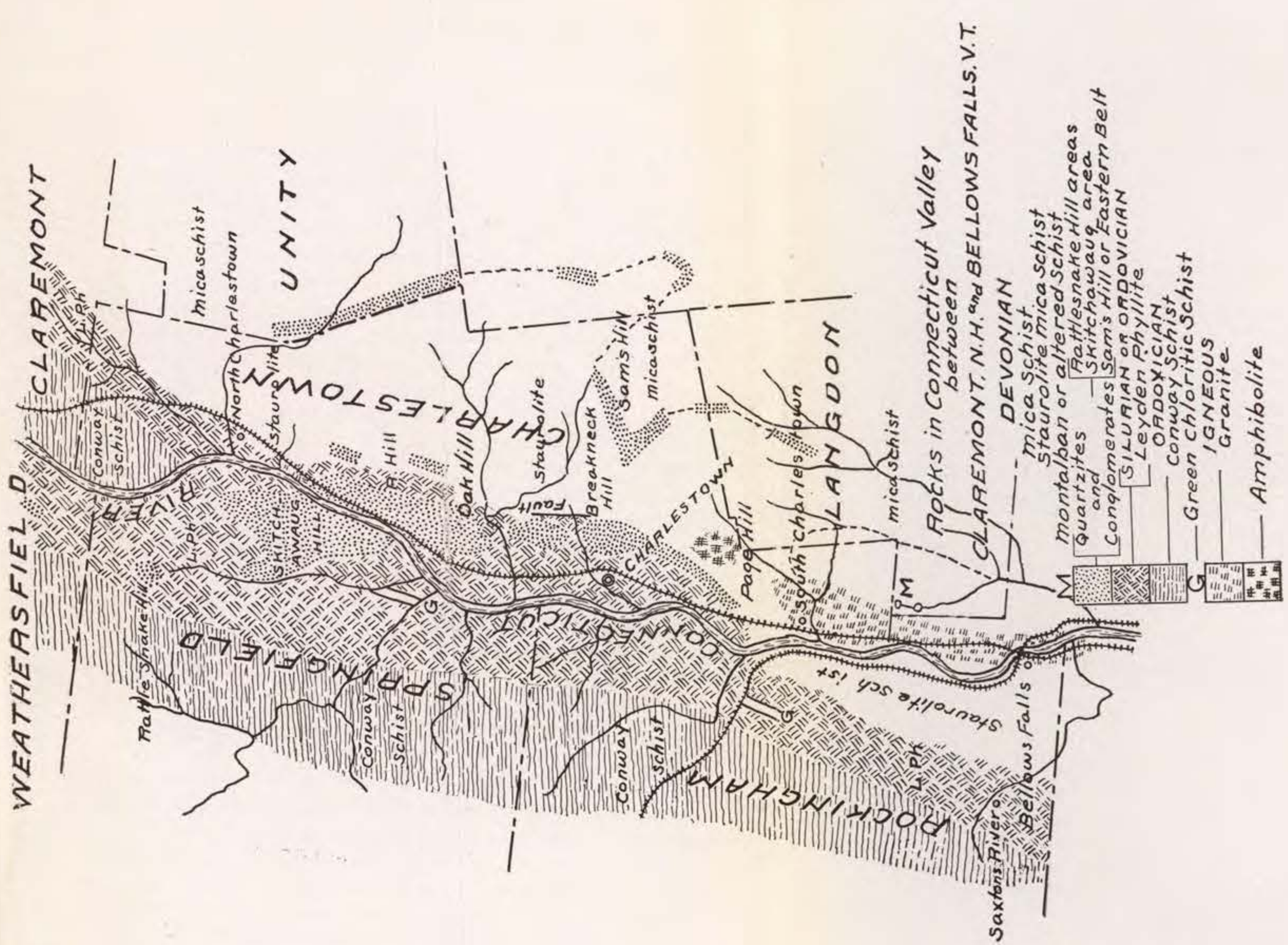
The one important statement, made as early as 1872, which all accept, is that the Bernardston rocks are the equivalent of the Coos series, quartzites, schists and slates; and that therefore their extension up the Connecticut valley belongs to the Devonian. My New Hampshire geological map shows where they are to be found; and they will be seen to extend from Massachusetts to Canada, partly in Vermont and partly in New Hampshire. To properly understand them it will be necessary to recall first their order and arrangement in the original Massachusetts locality.

My original section is concerned only with what is seen on the Williams farm in Bernardston. At the base of the stratigraphical column is a slate with an apparent higher dip. This was known as the Guilford slate in the early days, and later the Leyden-phyllite. It was called Cambrian and Silurian later by different parties; neither of which names are justified by the presence of fossils. Next succeeds a quartzite 656 feet thick capped by about twenty feet thickness of encrinal limestone, which is the proper Upper Helderberg. Above this is a second quartzite 443 feet thick. The highest member of the section as figured upon the farm is a second band of slate passing into mica schist, 73 feet thick. It is only a part of the formation. The figures are those of Professor Emerson, who has carefully mapped the overlaying rocks farther east in Massachusetts which are alternately mica schist and amphibolite, seven bands in number, four and three respectively. The basal slate he calls the Leyden argillite, overlying Conway mica schist, "both upper Silurian." The thickness of the mica schists is estimated to be 370 feet and the hornblende rock 508, both possibly too great. The amphibolite beds were thought to have been derived from limestone. In the search for the upper limits of the Devonian, I found the mica schists extending to the modified drift plains of the Connecticut. Crossing the river to Gill station the same schists are conspicuous, with granite veins, with dips not over 12° northwest. On climbing to the west slope of Bear Mountain the dip changes to northeast, and there is a considerable thickness of quartzite which I interpret to be the uppermost member of the Bernardston Devonian series. The mica schist is continuous to a junction with it and both have the low dips characteristic of the locality. Granting this conclusion, we must add a quartzite to the group making three silicious members. This relates only to that part of the Devonian which is being compared to the Coos group. There are other rocks in Northfield, as on Brush Mountain, which will be assigned to their proper places by others in the future. Following the course of the strata towards the north this upper quartzite may be traced to the locality on Perchog Brook in Winchester described upon my section I in contact with gneiss on the east and with the Coos schists on the west side. This is the connecting point between the Bernardston and Coos rocks. Both appear to stand nearly vertical, but the schists dip at lower angles easterly farther west. It is a region of great disturbances so that any interpretation is liable to correction. The reference of these schists to the Rowe and Savoy formations in the old Hampshire report is certainly erroneous. The various fossils found at Bernardston indicate a horizon near the base of the Chemung of New York. They are sufficiently numerous to make the identification satisfactory.

There is an oval area of granite partly in Vernon and partly in Hinsdale, which I have correlated with the Bethlehem Gneiss of New Hampshire. There is a series of these areas along the east part of the Connecticut basin extending through the whole State north and south of which the best characterized was the one in the town of Bethlehem, and another in Hanover and Lebanon, the last referred to in the present report, Plate XLV, Sections D, E and F. Farther discoveries since the first publication about these rocks prove them to be truly igneous, and hence to be called granite rather than gneiss. All of them cut areas of the Coos rocks. It was a surprise to find the first area, so far as it appeared in Vernon, to be mapped as the Bernardston quartzite in the Old Hampshire monograph.

Quite near the granite is another igneous mass called Porphyritic gneiss in my report. Following the usage of the time this report was written, this was correlated with the *Augen gneiss* of European geologists who generally accepted that rock as of Archean age. Without claiming that all the rock thus labelled in my report is of uniform age and character or that any of it is ancient, it is sufficient for my present purpose to say that the area in Hinsdale and Winchester has the marks of igneous origin upon it, equally plain with those of the Bethlehem granite, and that this particular area must consequently be an igneous rock of later age than the Devonian. These granites have rendered obscure the northward extension of the quartzite on Perchog River. It may be correlated with the corresponding rock in the east part of Hinsdale on Kilburn Brook and Bear Hill. But there are conglomerates and quartzites on the same line, extending northerly into the porphyritic area in Winchester; and there are related rocks in Keene and Surry. It will require further study to make certain to which line of outcrop the Perchog quartzite belongs.

It will not be needful to discuss the character of each rock in detail proceeding north from Massachusetts, to set forth what may properly be Devonian. Instead I will select a limited area between Bellows Falls and Claremont, including Springfield, Vt.,



and Charlestown, N. H., where these rocks have a fine development, and compare their peculiarities with those of the original field in Bernardston, together with their relations to adjoining formations. Fortunately I have extensive notes upon those in Springfield and Charlestown from the studies of the late Mr. G. D. Hull, a native of Charlestown, of the class of 1892, Dartmouth College, and my assistant for one year in college work. At my suggestion he undertook these studies and he left his notes upon them at the Public Library of his native town in manuscript where they will always be accessible to the public.

This restricted area will be of special value in our comparative study because of the general absence from it of the amphibolites. The little that is present is easily referred to an igneous origin. It is to be regretted that the limestone has not yet been identified in this area. Mr. J. H. Huntington thought some of the slates as at the Devil's Gully in Charlestown and at Paper Mill Village—Alstead—belonged to the Calciferous mica schist (Conway). The specimens left by him do not seem to be definitive. Possibly good limestone may be found later in these and other localities. I have myself been ready to pronounce some of the schists now clearly seen to be altered slates as belonging to the Conway group, and so can understand the erroneous reference of these slates to the limestone. Better still, as calcareous rocks are occasionally found in the Leyden slate, these examples may be regarded as belonging to that series and need no longer be referred to the Conway or Goshen.

MAP OF THE SPRINGFIELD-CHARLESTOWN SECTION.

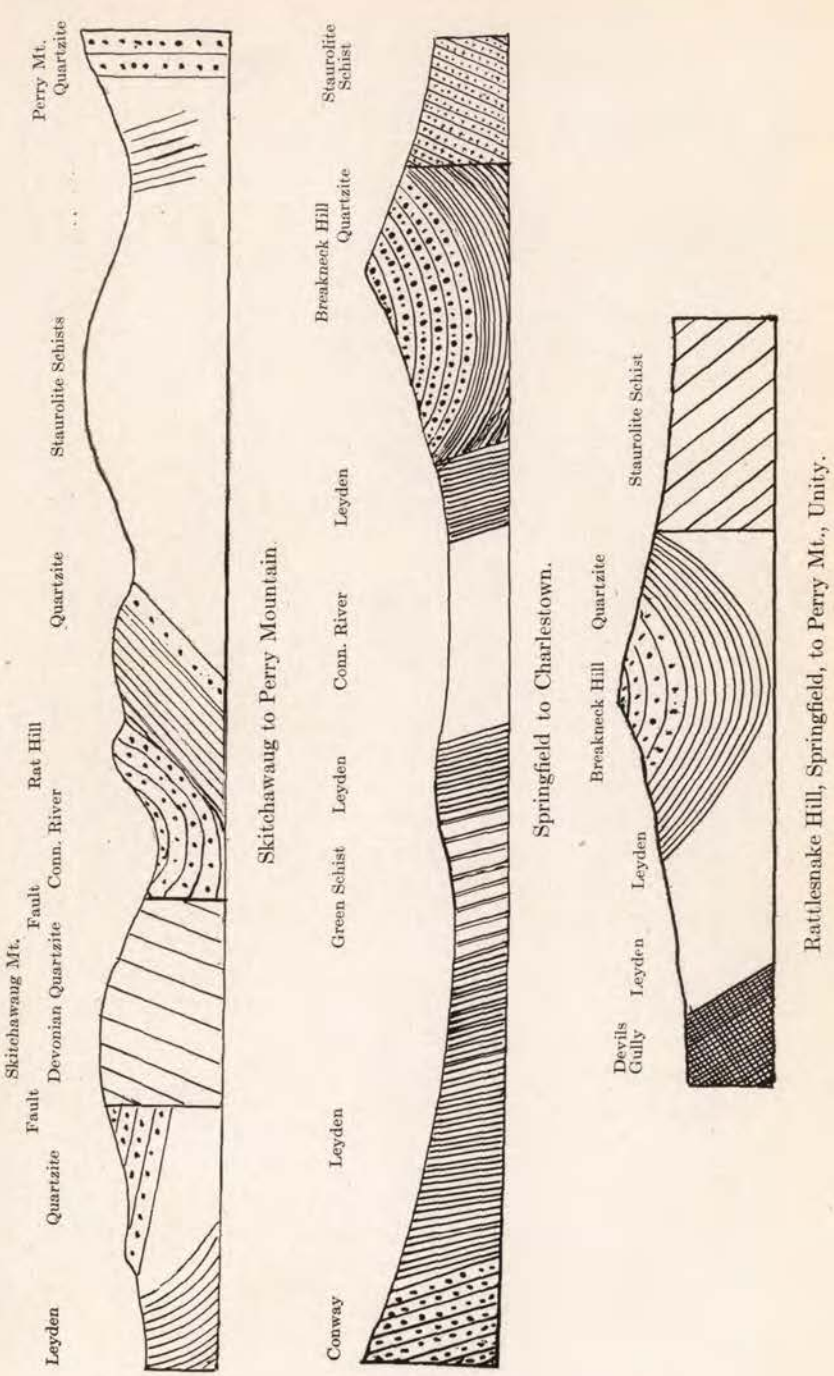
As nearly as can be stated at the present time the following are the rocks here represented: Conway, Leyden, certainly three if not four quartzites, staurolite mica schist, amphibolite and granite. Plate LII shows their areal distribution.

The Conway is an easterly extension of the normal area occupied by it in Vermont—constituting a projection running northeasterly from Springfield and Claremont to Cornish Flats and probably to Meriden. Most of the rocks in the spur cannot be distinguished from those in the typical area and a similar anticlinal goes with it, seen best in Claremont.

The slates are believed to be equivalent of those called Leyden at Bernardston. Upon the map of 1861 it was traced clearly into Weathersfield and repeated in Hartland after a supposed bend in New Hampshire. In my later studies I thought its continuity had been interrupted in Rockingham, replaced chiefly by the green schists, then called Huronian. As at present advised it seems better to say that it is continuous and the band has been scarcely affected by a mass of granite just penetrating the State from New Hampshire at Bellows Falls. The Devonian stauroliferous mica schists and quartzites lie between the Leyden slate and the granite to South Charlestown. Another portion may be represented by the hard green more or less chloritic schists, recognized from the northeast part of Westminster to the Cheshire bridge in Springfield. For the present these indurated schists may be esteemed as an older section of the slates, and perhaps are the legitimate extension of the green schists from the west part of Claremont, at Barber's Hill. The slates remaining appear in the east parts of Rockingham and Springfield south of the bridge, in the west part of Charlestown, and interruptedly into Claremont. Also in Springfield to the west of and supposedly beneath the quartzites into Claremont. Owing to thermal and elevatory causes the original slaty structure has occasionally become schistose.

The four quartzite areas are first the somewhat interrupted patches from South Charlestown northeasterly, extending into two sections east and southeast from the village of Charlestown called Breakneck Hill by residents; and its northern extension at Oak Hill. Plate LIII section 5 illustrates the stratigraphy of Oak Hill. From here there is a change in the topography; the hill becomes depressed, but the rock is continuous to the Rattlesnake Hill scratched by the railroad upon its western side about a mile south of North Charlestown. Its course is most likely interrupted by a cross fault along this line. A second area of a similar quartzite and conglomerate is to be seen in Springfield in the old School District No. 6, up Button Brook with a moderate dip south 60° east; and it is developed into a hill. The lower fertile ground to the north is occupied by slate till obstructed by another and much more impressive eminence—Rattlesnake Hill—the highest land in the neighborhood. This seems like the continuation of the one just named, and is a combination of quartz schists and conglomerate—the last having flattened pebbles of quartz, and also of slate. The dip is 50°-60° south 60° east and thickness estimated at 300 feet. This is the most western of these Devonian conglomerates, about

PLATE LIII.



Sections in Charlestown and Springfield.

a mile east on the edge of the Conway schist. There is also an exposure of a white quartzite just within the limits of Weathersfield, a mile back from the river.

The third area is that of Skitchawaug Mountain in the east part of Springfield presenting on the east side cliffs 300-400 feet high facing the Connecticut, as seen from the trains on the railroad. It is unique topographically, being a rough mountain three miles long, superposed upon the lower hills just north of the Cheshire bridge and the old military road. Mr. Hull has been all over it and thinks the general structure is monoclinal, dipping about 75° north 60° west. It adjoins the vertical indurated slates of the Black River valley. The rock is both a quartzite with saffron-like tint and conglomerate, and with it are indurated clays, sometimes calcareous. Near the military road upon the south-west side is a large outcrop of conglomerate with flattened pebbles dipping northerly, and underlying the other rocks.

Because of the infelicitous character of the hill—a heavily wooded surface with thorny shrubbery—it is not easy to examine it carefully. I am disposed to place a portion of it with the green schists such as occur along its strike upon Barbers Hill in Claremont. Several outcrops of it along the river road in Springfield adjoining Skitchawaug Mountain bear resemblances to that group of rocks. There is evidently a development both of the underlying schists and an overlying quartzite and conglomerate; besides hill higher beds of gray and saffron sandstones.

It has been a question whether the Charlestown Rattlesnake Hill quartzite makes a synclinal with Skitchawaug. Mr. Huntington takes that ground, while Mr. Hull thinks the general S. W. attitude of the mountain is against it. Mr. Hull says: 'I have passed over the ridge of the mountain and travelled around its base, and from twenty observations taken at different points along the ridge and varying but little, the average strike is about north 30° east, dip 75° west, but a large area near S. H. No. 6—the western part of the north end of the mountain—dips east—*as well as smaller areas along the eastern base.* The mountain is bounded on the west by slate having the same dip as the quartzite. Only the southern end of the mountain comes in contact with the Huronian rocks.' I have italicised that part of the quotation which proves that Mr. Hull was familiar with the phenomena about to be mentioned. Upon a reexamination of the ground I find first an easterly dip of the quartzite at the base of the cliff, directly opposite Rattlesnake Hill and secondly farther south, near the Montvale farm the ledge is unmistakably a coarse conglomerate of quartz pebbles dipping about ten degrees to the east. It is the west flank of the Oak Hill synclinal continued northerly. There may be a fault between it and the cliff behind, but that would not militate against the reality of the easterly dip. I regard the coarse conglomerate on the southwest side as the same formation.

There is also a mass of quartzite to the east of the Charlestown Rattlesnake Hill near the Town Farm with a westerly dip, discovered by Mr. Hull, causing him to believe in the existence of another band of this rock. He saw the same band a mile farther south; and I think I have identified it still another mile away. There is a possibility of its repetition by a fault; so I have not insisted upon its being a distinct band from the other.

The fourth range of quartzite is what was called the "Eastern Band" in the N. H. Report; a more pronounced formation than any of the others. It constitutes the long wall of Perry Mountain on the latitude of Rattlesnake, and the boundary between Charlestown and Unity. It seems to belong to the eastern outcrop of this rock in Claremont and as such to belong to the Grantham and Croydon Mountain range and so presumably to the Moose Mountain development in Hanover and so on up to Lisbon, with some interruptions. Going south, it may include the fragment in the northwest part of Acworth East of Prospect Hill and thus the triangular outcrop of Sam's Hill in Charlestown, which is supposed to be a sharp angle in its course. To the southeast it is recognizable in several outcrops all the way to the village of Langdon. To attempt to trace it farther is impracticable. Its magnitude induces one to believe it a more important stratigraphical line than any that has been mentioned. One might draw a problematical section across the two Rattlesnakes that will include all four of the quartzite areas that have been described. Plate, LIII Section 6.

It required the skill of Mr. Hull to develop the structure of the quartzite in the hill southeast of the village of Charlestown which happens to cross our general section IV, and figured in Plate LIII, Section 4. Ambush brook has eroded the overlying quartzite, so that it passes between two areas of the harder rock on the crests of Breakneck Hill, each of which is a synclinal outlier. The slate has the same synclinal disposition beneath, and it is so represented. It does not extend far to the east for at the top of the hill its place has been taken by a mass of staurolite schist in

which the position of the true dip is not clear. There is evidently a N. S. fault line, whose presence is seen for a couple of miles. The schist is the one containing the famous Staurolites of Charlestown. It extends to the north through the township and Acworth on the east. It makes the large Perry's Hill on the other section and must be the equivalent of one of the rocks of the same name at Bernardston and of later age than the Leyden slates.

The section is continued west across into Vermont along the line of the trolley, showing the slates under the quartzite and in the Devil's gully and on Mill Brook. Veins of quartz abound and the slates show that some metamorphic influences hâve been at work. The first ledges on the Vermont side are the same slates, followed by a mile width of the chloritic argillite schists, formerly called Huronian. The slates are repeated, extending beyond Black River Village along the section, and also north to Rattle-Snake Hill. They dip easterly, and apparently overlie the Conway series which succeeds, and is exposed in the village of Springfield and further west and north.

The investigation of the Oak Hill quartzite shows the plain continuation of the western flank of the synclinal in the part that rises above the sandy plain. The eastern flank has also been discovered in a series of ledges with a dip of 20° W., just peering through the sand, showing themselves all the way to Rattlesnake Hill where the synclinal structure develops its whole extent and crosses the river to the Springfield side, as has been stated previously.

STAUROLITE MICA SCHISTS.

The Staurolite mica schist has been elaborately described by Prof. W. S. Bagley in Bulletin 150 of the U. S. Geological Survey, from specimens furnished by the writer. The rock is dark gray in color and of crystalline texture. It is typically schistose, but the schistosity is not developed in parallel directions. There are large irregular lumps having a nucleus of fresh staurolite surrounded by alteration products. This is made up of slates of chlorite and small carbonaceous grains with micaous material. The ground mass consists of brown biotite, green chlorite, quartz, sericite, and occasional grains of zircon, rutile, magnetite, tourmaline and carbon. Garnet has been altered into chlorite and must have been the oldest of the present constituents since they are devoid of the black particles thickly strewn elsewhere. The quartz and sericite have been crystallised in situ. The schistosity is due to the elongation of the quartz grains and the induced arrangement of the sericite.

Nothing in the microscopic structure of the rock suggests its original fragmental character. It has been derived from sediments allied to shale. Technically it is a mica schist containing altered straurolities and garnets. The foliation is supposed to have been due to crystallization under pressure, attended by motion in the plastic crystallising mass. It is a good example of a schist formed from fragments through the metasomatic agencies accompanying dynamic action. The descriptions of the staurolite mica slates of Bernardston by Emerson and Julien agree with that given by Bagley.

This rock occupies most of the area of Charlestown between the Oak Hill and the eastern border ranges of quartzite. It is massive without decided planes of stratigraphic structure, though we usually refer to the best marked divisional lines as indications of strata. The staurolites are scattered irregularly through the rock without arrangement. Between Rattlesnake Hill and the quartzite of Perry Mountain it has an anticlinal attitude. Upon Breakneck Hill the mass seems to incline northerly with planes at right angles to the slates: so that there is the appearance of a fault running north and south perceptible for a couple of miles before concealment beneath sand. North from Sam's Hill to North Charlestown this rock must be disposed of blocks of large size separated by faults. No attempt has been made to align these rock masses to their original positions.

MICA SCHISTS.

Besides the area of the staurolite schists stated above, there are limited outcrops of a similar schist south east from Oak Hill and on Sam's Hill. Mr. Hull says: "A small area of mica schist has been found resting uncomformably on the quartzite southeast of Oak Hill. The exact locality is at the little pond a few rods north of Mr. Cummings' barn where the road passes between the outcropping ledges. It is readily distinguished from the older schists by its glistening rusty appearance and the smaller size of its constituents. A macroscopic examination reveals occasional garnets, biotite scales set transversely to the bedding, and staurolites seldom exceeding an inch in length. The rock is harder than the older schists, much wrinkled and somewhat broken. Average strike N. 55° W., dip 30° N., 35 ° E. Both macroscopic and microscopic examinations identify it with the mica schist of Sam's Hill, which rests unconformably on the quartzite of the so-called eastern band."

There are outcrops of a schist more widely spread on the east (as in Acworth) than that common in Charlestown. It makes up the bulk of the Coos schist as colored upon the geological map of New Hampshire. Mr. Huntington who was responsible for this section of the published New Hampshire map divided the Coos rocks there into the Argillaceous mica schists and the Mica schists, and recognized the fact that what I have called the Leyden slate was also different from them,though all of them were grouped as one upon the map. Our present delineation separates only the Leyden slate as distinct from the earlier area of coloration.

THE IGNEOUS ROCKS.

Amphibolite of an igneous cast is found in a triangular area east fron South Charlestown and at the North West corner of Langdon, perhaps three-fourths of a mile in length. That it was capable of altering sediments is demonstrated by the aspect of the mica schists adjacent upon the west side, and east of the quartzite. They are the Leyden slate altered to resemble part of the Goshen Conway group. They have the right position for the slates as they dip beneath the Devonian quartzite. Upon the east side at Page Hill the mica schists have been squeezed into zig-zag arrangements and have been indurated so much as to be hardly recognizable. Jointed planes dipping south were noted in this amphibolite.

A specimen of hornblende schist comes from the north end of Oak Hill and I do not recall any other ledge of this rock in Charlestown. Hence it is clear that amphibolite is not to be considered even as an altered sediment of the Devonian in this district. It was purely igneous capable of producing contact phenomena like the similar bunches in the Hanover quadrangle.

A typical elongated mass of granite lies between South Charlestown and Bellows Falls. Its place is easily recognized by the white conical hills made conspicuous since the removal of the trees. Where it has come in contact with slaty rocks in the south part of

Charlestown and the north corner of Walpole by the roadside, staurolite crystals have been formed—believed now to be the upper member of the Devonian series. The supposed gap in the Leyden phyllite of the earlier maps no longer exists.

To the south of the true granite at the Falls and farther south a related rock appears, which is more or less foliated. It is connected with the foundations of Kilburn Peak and is coincident with the elevated land to the north east in New Hampshire. It has a general northeasterly dip and carries fine specimens of wavellite, prehnite and fibrolite besides pegmatite veins. At the mouth of Saxton's River some of it is a red granite carrying inclusions of slate, showing that the latter rock was in existence before the igneous intrusions. Half a mile above the mouth of Saxton's River the granite is distinctly foliated. It has not always been easy for the geologists to map the precise areas occupied by these granite rocks because the region is at the corner of three counties in two states, and the maps of the different civil areas do not match one another. Then the geologist employed by the one State may not consider it his duty to trace the rocks from his own into another's territory. Then attention is diverted by the covering of the ledges by drift and the problems suggested by the terraces. Upon the New Hampshire map, Mr. Huntington has colored an important area in Walpole, Langdon and Alstead as underlaid by Montalban schists and gneisses. Combined with the granite (which he called the older gneiss) it would make an oval area about five miles both north and south, and east and west. An examination of the specimens collected by that Survey satisfies me that the so-called Montalban rocks are not necessarily the same with those so termed in other parts of the State. Among them are many ledges of the easily recognizable Devonian strata, and the degree of alteration is not as great as what is regarded as typical in the other regions. Hence this whole gneissic area may be regarded as partially altered Devonian.

The Devonian rocks are clearly recognizable in Westminster, occupying the east part of the town. Staurolite mica schist lies to the west of the quartzite, probably continuous from the south up to the sharp southerly bend in Saxton's River, and the ridge east of it towards Connecticut River is made up of a rock with a breeciated aspect, recalling certain features of the Skitchawaug conglomerate. These rocks have a width of two miles along the south line of Rockingham, and extend more than three miles directly north. A fine exposure of the staurolites may be seen upon the west side for a reservoir or ice-pond two miles north west of Bellows Falls, with quartzite beyond upon several ledges the dip of the strata is north 15° east, while the direction of the vertical cleavage planes is at right angles to this. Hence there is reason to connect these Devonian ledges with the staurolite rocks on the east side of the valley adjacent to the granite near South Charlestown. This reduces the width of the Leyden slope fully one-half of what it had been previously mapped, extending to Saxton's River Village. Other Devonian conglomerates occur plentifully in the lower part of Cold River in Walpole, which have not been indicated upon the maps. The very large area of quartzite in the central part of the town has the low dips characterizing the Devonian further south.

THE ROCKS NORTH OF CHARLESTOWN.

In regard to the farther northerly extension of the Devonian rocks, several points may be noted.

1. There is somewhat of a change beyond Charlestown. Between North Charlestown and Sugar River the quartzites are absent. The Conway group on the west enters New Hampshire from Weathersfield and has the Leyden phyllite and the mica schists between it and a large development of granite extending from Quaker city to Green Mountain. At the North Charlestown station the rock is slaty with quartz ledges dipping 75° southeast—so different from the Rattlesnake Hill exposures as to suggest a cross fault. The quartzite has been shifted to the east of the granite and in the natural place for its continuation it is well developed in Claremont, where there seems to be the extension of the eastern range, curving around the granite.

2. Barbers Mountain in the west part of Claremont has been mapped as a part of the green sericite schists. It has resemblances to the chloritic part of the Goshen.

3. The Leyden phyllite has been found occupying both sides of the green schists in Springfield, occupies much space in the northeast part of the town and connects directly with slates in Claremont so that the gap in its continuation on previous maps has been filled; and that rock can be traced without a break from Massachusetts to Claremont.

4. The Conway schists are also continuous from Massachusetts to Claremont, being the foundation for the Devonian column.

5. The phyllite is doubled in area in the north part of Claremont. In the midst of it are three bands of quartzite upon Bald mountain, one of them a beautifully spotted rock with white flattened pebbles in a dark argillaceous paste. This we correlate with the lowest Springfield conglomerate carrying slate pebbles. It lies near the west side of the phyllite, like that in Springfield.

6. This slate range includes the so-called Coos slates of the New Hampshire report. That report was based upon the assumption that the slates with staurolite belonged to a different age from those that were devoid of them. Hence there were proposed adjustments of structure separating the two slates in Bernardston by a fault, which were not favorably received by geologists. Therefore that view is no longer maintained, and the two slates are now regarded as one and the same; and it will be seen presently that a large area of slate carrying small crystals of staurolite farther north is to be added to the Leyden phyllite, and though older than the proper Coos it was included with that series in the statement that the Coos group is the equivalent of the Bernardston rocks in their northward extension.

7. This slate connects with the band originally termed Coos slate north of Sullivan county in Lebanon, Hanover, and Lyme into Orford if not beyond; and it is the oldest of the rocks north from Springfield, being separated from association with the Conway rocks in the east part of Cornish. From Cornish northwards it must be an anticlinal flanked by the newer Coos schists and quartzites.

8. The Bald Mountain conglomerates correspond with those of the west belt in Grafton County. The difficulty of always recognizing the dip of the strata in distinction from its cleavage in this State will render useless the attempt to harmonize the observations of position that have been recorded upon this terrace. The distribution of conglomerate bands adjacent to it will be a satisfactory guide.

The application of these new views to the rocks in Grafton County will work a revolution in our ideas of the true order in Hanover and Lebanon. Upon the first day of field work in New Hampshire I saw the quartzite of Moose Mountain; and said to my companion, "there is the key to the geology of this region." It led first to the inauguration of the Coos theory; but the details have not been understood. When charged with the exploration of New Hampshire geology I neglected this field, expecting to be able to work it up later, because of residence close at hand, and for all the intervening years I have been patiently collecting the facts of distribution and position without understanding them. Today I think the mystery is solved. The phyllite is the central underlying rock, flanked upon both sides by Devonian formations analogous to those first studied in Bernardston. I will now offer a description of these rocks in Hanover and Lebanon.

Geology of Hanover and Lebanon.

Owing to the difficulty of discovering the true dips of the slate, our observations upon the structure of this formation as it passes through this area are unsatisfactory. Almost everywhere the cleavage planes are nearly vertical. The belt is wider near the north line of Hanover than it is farther south, as if it may have crowded out the overlying quartzite north of the center. The valley of Mink Brook shows the rock in abundance, also on Hayes Hill. Early observations suggested an anticlinal in the west part of this section. In the valley of Mascoma River the anticlinal structure has always been reported; also upon the mountain west of the lake. The slate is well shown from Ruddsboro down to East Lebanon, Enfield on Mount Tug and the hill west of Mascoma Lake. Its place is taken by the staurolite schists towards Lily pond. The slate is narrowed almost to extinction in the south corner of the town.

The quartzites and conglomerates give character to the geology of this district and their occurrences will be given in some detail. They crop out upon both sides of the slate. They are so narrow that only lines can represent them upon the map, and I have taken pains to show them as accurately as possible with their breaks and curvatures. The names of the residents are taken from the atlas of D. H. Hurd & Co., 1892.

Upon my published map I have indicated the presence of interrupted outcrops of quartzite upon the western side of Hanover, near the Connecticut. It is likely that this horizon will be demonstrated to exist, chiefly because of its better development farther north in Lyme and Orford.

Upon the west side of the main area the most northerly outcrop of the quartzite is about half a mile southeast from the church at Hanover Center, near the site of a house once occupied by O. Woodward. The ledges may be followed an eighth of a mile northeasterly up the steep hill. There are two bands here—one of them with chloritic cement. Some of the quartz pebbles have flattened. The most interesting feature is the presence of pebbles and irregular included patches of the slate; also a mass of the slate five feet thick folded into it from below. The slate is unusually black. The presence of the fragments suggests the correlation of this conglomerate with the basal member of the Devonian in Springfield.

To the south the conglomerate crops out on the hill by H. Chandler and C. H. Camp, dip 80° N., 60° W., and this line should cross Mink Brook at the fork in the road east of F. G. Emerson's. It appears next at L. Merrill's 100 feet thick with high north west dip. Soft schists and chloritic layers adjoin it on the west. The next outcrop is at the angle in the road east of D. W. Miller's, half a mile east of the Town House. Next it is to be found nearly to the top of the hill south from R. W. Hayes', dipping N. 10° W. A similar range appears to the east from Hayes, south from D. C. Hoyt. Coarse mica schist lies between them. What seems to correspond to one or both of these outcrops is in the edge of Lebanon, near D. Paddleford's, 50°—60° N., 20° W. And the last seen along the line is about a quarter of a mile to the S. W. of C. P. Freeman's. The ledge is thirty feet square, and was at first thought to be a boulder.

Upon Hayes Hill upon the Portsmouth road near the site of an old school house, G. B. Davis, are two or three narrower layers of quartzite,interspersed with a conglomerate of different character. This rock is a slate with numerous pebbles, some a foot in length, very much compressed. The conglomerate has a chloritic pastein in thus corresponding to those already mentioned along this line.

Passing southerly from Hayes Hill the quartzite appears in the valley of Hardy Brook in Lebanon. Upon the hill above Mrs. E. Loomis' are some remarkable curves in the course of the formation not yet understood. Certainly two possibly three bands of the rock are indicated, separated by mica schist. Another outcrop is at the angle in the road south from W. G. Walker's. This ledge shows the strikes of N. 20° E., and N. 40° W., with a doubling up of the strata. A few rods north of the road the rock has been made uniform in its texture and cleavage by pressure.

Probably there has been a lateral shift from the Walker ledge to two bands of the rock not far apart, near the locality of the celebrated pot holes in East Lebanon. One of these bands contains fragments of Lyndon slate.

Upon the west slope of Methodist Hill, Lebanon, south from the railroad, two or three exposures may be seen. At G. B. Eastman's the slates stand vertically, not far from the ledge that has furnished excellent specimens of distorted pebbles, one of them an inch in diameter having been drawn out seven inches in length. The strata dip 75° northwesterly, succeeded by a dark schist, and then by a conglomerate with black cement. After nearly a mile of slaty layers comes in the Stony brook range in which there is a notable amount of argillaceous and chloritic cement. At the crossing of the east line of Lebanon by the road, a section similar to the one just described may be seen—two bands of quartzite separated by slate, and the lower one gracefully curving down to Stony Brook. In the curve are conspicuous veins of white quartz filling the rents made in the strata by the bending of the strata.

There are two more conspicuous outcrops in Enfield—one just upon the south side of Stony brook by B. M. McCollister's and the other near the southwest corner of the town.

When driving along Fairfield Brook, just to the north of Moose mountain, the quartzite may be seen part way up the northern slope. There are certainly two ranges of it by the Signal Station. At the Wolfborough road there is an outcrop of quartzite just as the steep ascent commences, dipping 50° N., 50° W.; but the principal mass of it lies just on the summit of the divide.

To the south for about two miles the ledges are concealed. At the place of an ancient road over the mountain where the remains of houses may still be seen, two bands of the quartzite are visible, the first about 50 feet thick holding constituent fragments of slate. These are near the granite. Passing up the mountain from a cemetery near J. W. Dana's, above various schists dipping into the mountain, the first quartzite is 200 to 300 feet thick, uniformly vitreous in character, as if used, and some of the original fragments are visible. Passing some hard schists the second quartzite is apparent; and also other quartzite schists, before reaching the granite at the very summit.

From Ruddsboro one can climb to the summit and observe three parallel ranges of the quartzite. East from Walker's the crest has been cut by a broad dyke of anorthite diabase. The three ranges extend to the south town line. Beyond this line there are only two—and these come to an abrupt end in the northwest corner of Enfield. It is an interesting walk along the ridge, well described as a knife edge, as much as ten miles, from Enfield to Lyme, and quartzite is visible nearly all the way.

From the south end of the Moose Mountain one can look across the lower land about Mascoma Lake and discern the hill by the lily ponds, six miles distant, where are two and perhaps more of the quartzite ranges. These are conceived to represent the same line of outcrops. Both the east and west lines can be followed still farther south; the first reappearing in the northwest part of Grantham, by another lily pond and a Methodist church; the second near schoolhouse No. 14 in Plainfield. The two are imagined to unite in Grantham Mountain. Thus there are two well defined conglomerates close to the west side of the slates, one of them characterized by the presence of chlorite. The first of the two or three bands on the east side is contiguous with the slate; besides carrying pieces of it so that the two series of quartzites are apparently identical. The highest Moose Mountain quartzite may correspond to the eastern range described in Northfield, Mass. and Charlestown, N. H.

Between the slate and Moose Mountain is a development of the Coos schists, quite variable in character. They are mica schists, staurolite mica schists, wrinkled phyllites, very quartose schists, chloritic and hornblende schists. The area broadens very much in the south part of Enfield.

It is easy to recognize the staurolites of Charlestown at West Enfield, otherwise known as Fox Hollow and Montcalm P. O. I have never seen any area where these minerals are more abundant. They extend two miles north, nearly to the Shaker settlement on the east and near to the south line of the town. So the two horizons of the mica schists described in Charlestown can be identified in Enfield.

Similar rocks are found upon the west side of the Leyden slate and associated quartzites, extending to the Connecticut. The staurolites are not very abundant, but are present. Two additional elements are to be noticed. The first is the conglomeritic character of a considerable area, noticed in my previous report, page 157. It is made up of fragments of the country rocks in a chloritic paste and is so much like the schists that its sedimentary character is not noticed at first. Ledges of it occur on Mink Brook to the west of F. G. Emerson's, and upon Hayes Hill, already mentioned. The west border of the slate just above Emerson's consists of a slate conglomerate—and precisely the same rock is abundant about a mile east of Lebanon P. O. and at a dam across Mascoma River used to acquire power to elevate water into a reservoir. Both these conglomerates must be newer than the rock fragments of which they are composed. Whether there can be any correlation between them and the quartzites is unknown—but both must be Devonian. The second element of unusual character in these schists is the fact of their alteration by the heated influences emanating from the granite batholith. Plate XLVI shows the whole of this area, which has been referred to in the sections, Plates XLIV, XLV, and upon page 165 of the previous report. The granite mass on the acidic portion of the magma was early seen to have a nucleus of porphyritic character encircled by the granite proper, and this with a basic element wrapped about it. The part which strictly belongs to the batholith is included in the area represented upon the map. But outside of that the influence of the heated magma can be seen in the schists for a great distance in the production of gneisses, feldspathic mica schists, mica, staurolite and chloritic schists, and of many crystals of hornblende. The metamorphism that has produced these alterations is both that of contact and regional. Veins of aplite are common in the granite—usually of small dimensions.

AMPHIBOLITES AND BASIC DIKES.

It is easy to decide upon the igneous character of the amphibolites in the Hanover area, as has been shown in the previous report. Neglecting the surface deposits, these rocks are represented as occupying a continuous space near the Connecticut river. They are given more accurately upon Plate XLIII. They were regarded as a stratified formation in our earlier studies—an impression heightened by the fact that much of the amphibolite is only mica schist impregnated with hornblende. The magma was evidently poured out at certain vents and mixed with the schists in fissures and cavities, and so assumed the appearance of stratification. It has been thrust into cavities and between the layers of the mica schist, sometimes at its border; but so far as known it has not penetrated the green schists, though it has occasionally come in contact with and altered it, as on the west side of the river in Norwich. The foliation of the amphibolite comes partly from its interpenetration of the mica schist, and partly from the pressure exerted by the igneous matter against its confining walls. Sometimes it had a laccolithic origin, though commonly it is described like a sill, and more rarely as a neck.

The mineral hornblende is scattered through many of the schists where it cannot be called amphibolite. In such cases it may merge into sediments, especially limestone. Such is the character of the hornblende mentioned upon page 149 of the previous report. So the hornblende rocks in the Connecticut valley Devonian areas are both igneous and metamorphic.

Quite a number of basic dikes are found cutting our Devonian strata. There is the diabase in which chlorite has been developed in the valley of Mink Brook east of Etna; a beautiful dike upon Crafts Hill in which one can see the effect of the cool wall upon the interior igneous mass; a very large mass east of the Hanover reservoir in quantity sufficient to supply road-metal to highway surveyors; and several dikes of anorthite diabase already referred to. In this vicinity Camptonites and olivine diabases have been found. These dikes are supposed to be connected with the granite—there was first the production of the great batholith of granite with its veins of aplite and various branches; secondly the protrusion of the amphibolites; third the injection of the diabases into fissures; fourth the formation of large veins of quartz and pigmatites. The Connecticut valley Devonian rocks abound in illustrations of the later theories of igneous development, which await investigation. The establishment of the Devonian age of the rocks opens the way to a revival of the theory of the metamorphism of the New England crystallines at the close of the Carboniferous.

CORRELATION OF THE DEVONIAN IN THE THREE DISTRICTS WHICH HAVE BEEN DISCUSSED.

Bernardston—quartzite east of the Connecticut; amphibolite and staurolite schists; upper quartzite; limestone; lower quartzite; leyden phyllite.

Springfield and Charlestown—Sam's Hill on the eastern range; mica schist; staurolite schist; Skitchawaug quartzite; Rattlesnake conglomerates; lower quartzite; leyden phyllite.

Hanover and Lebanon—slate conglomerate; mica schist; staurolite schist; amphibolites; chlorite schists; three quartzites; lowest with slate inclusions; leyden phyllite.

In Hanover and Lebanon the series is duplicated upon the east flank of the phyllite. Three quartzites are found, of which the lowest carries slate inclusions and the highest forms the ridge of Moose Mountain.

Much is yet to be learned about this locality. Granite borders Moose Mountain on the east.

THE TERRANES OF IRASBURG, VERMONT.

C. H. Richardson and E. F. Conway, Syracuse University.

INTRODUCTION.

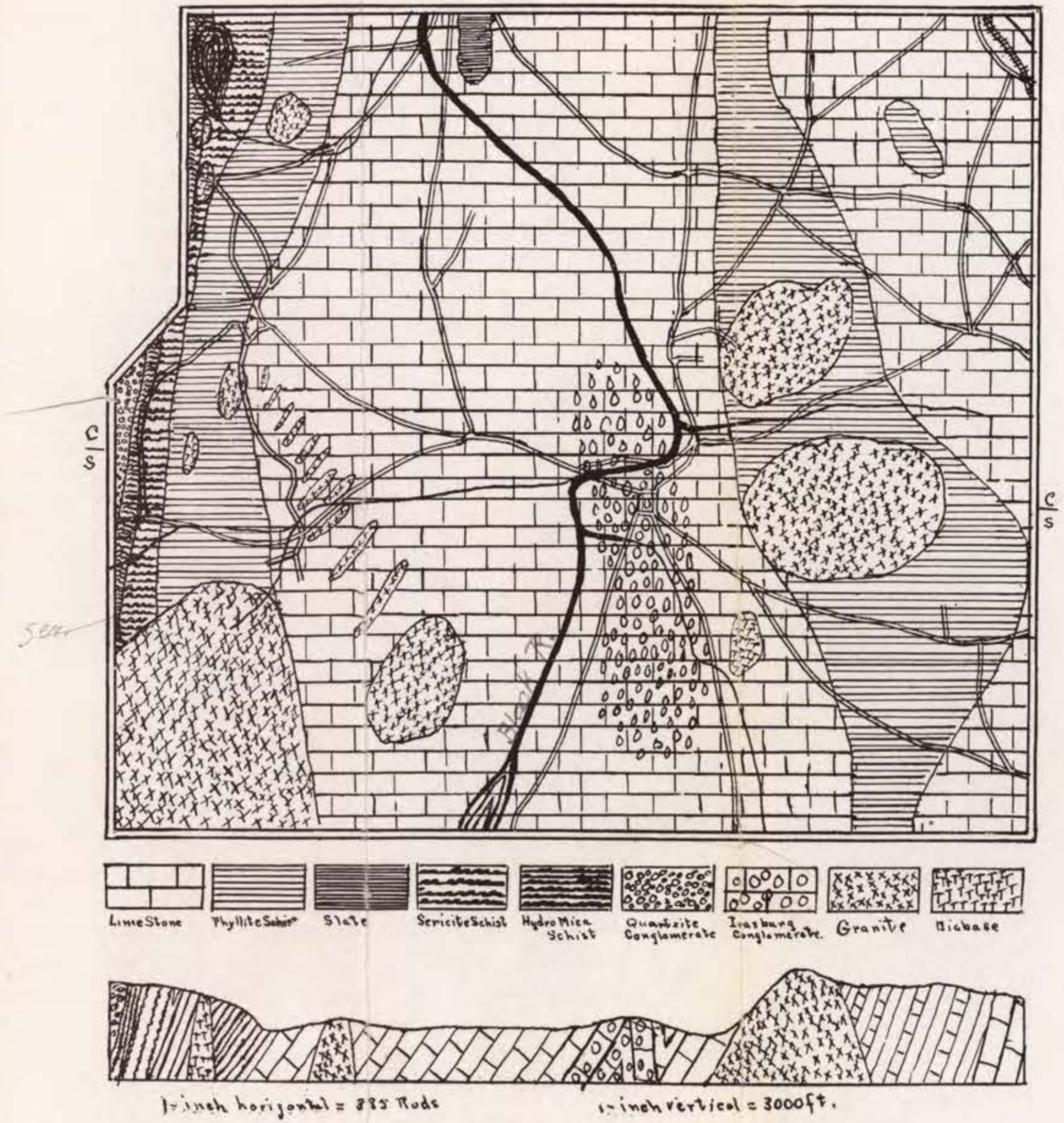
In the summer of 1895, the senior author of this report while making a detailed study of the terranes of eastern Vermont traversed this area to trace if possible the geological formation of Orange County northward to Lake Memphremagog. In 1907, 1908 and 1909, while completing the work in Newport, Troy and Coventry, this field was invaded anew. Under the courtesy of the Canadian Geological Survey, Prof. J. A. Dresser also visited this area as the guest of C. H. Richardson, and to him we acknowledge our indebtedness for his timely suggestions.

The detailed study of Irasburg was taken up by the authors conjointly during the summer of 1911. The area is situated just south of that covered in the report on the geology of Newport, Troy and Coventry published in the Annual Report of the State Geologist 1907-1908. About seventy rock specimens were collected for the State museum. These have been examined in the laboratory and labeled. Two maps were made, Plate LIV, one stratigraphic, representing a section across the township, passing just north of the village of Irasburg over Allen Mountain on the east and Kidder Hill on the west. The other an areal map showing the geographical distribution of the terranes. Several photographs were taken which illustrate this article.

WORK UNDERTAKEN.

It has been the purpose of the authors to determine the kind and extent of the rock formations underlying the township; to determine, if possible, their age by fossil content, stratigraphical position and lithological similarity to contiguous areas; to map the section showing the kind and extent of the terranes; to show by a cross section the dip of the strata and the relation of the different formations; to make a careful study of the mineral resources of the region as would be shown by the ordinary mineralogical field and laboratory tests.

Plate LIV.



Geological Map of Irasburg.

TOPOGRAPHY.

Irasburg lies between north latitude 44° 45′ and 44° 57′ and west longitude 75° 15′, 75° 22′. It contains approximately forty square miles. The township is traversed by three great ridges extending in a north easterly and south westerly direction. Rounded hills are located on these ridges. The ridge on the west is the highest, having an average elevation of over 1,900 feet. The ridge on the east has an elevation of about 1,400 feet. The central ridge is not more than 1,100 feet high and is unlike the others in that its sides slope gently to the adjacent valleys and its crest is well rounded.

The village of Irasburg is situated on this central ridge in the middle of the township. These ridges are intersected in many places by streams and narrow V-shaped valleys. The Black River and its tributary, Lords Creek, cut the central ridge at three different points. The western ridge is cut at two points, in the central part by a western tributary of Black River and in the northern part by Kidder Brook, the outlet of Kidder Pond. The eastern ridge is cut by many narrow ravines and intermittent stream valleys. The highest elevation is in the southwest corner of the town where Lowell Mountain reaches a height of 2,600 feet. From this mountain to the north town line the altitude varies but little from 1,600 feet. Just east of Irasburg Village is Allen Mountain with an elevation of 1,800 feet, and directly north of Allen Mountain is Knights Hill with an elevation of 1,600 feet. West of the village of Irasburg is Long Mountain with an elevation of 1,600 feet.

Between each pair of ridges there are very fertile U-shaped valleys. The western contains the Black River, except where the stream cuts a post glacial V-shaped valley thru the central ridge near Irasburg. East of the central ridge there is a narrow valley carrying Lords Creek in its southern part. On the eastern side there is a wide valley in the northern part. A spur of the eastern ridge extends out into the valley nearly to the town line near the center. The valley widens again to the southward. The central part of this township affords excellent illustrations of the formation thru stream action of valleys, deltas and river plains.

DRAINAGE.

The Black River, which rises in the town of Craftsbury in the southern part of Orleans County, flows in a northerly direction into Lake Memphremagog. It passes thru the central part of Irasburg from south to north. A tributary to this stream, Lords Creek, flows into Black River just south of the village of Irasburg. This stream drains the valley to the east of the central ridge. A small stream having its source in the springs at the base of Knights Mountain also empties into Black River from the east just north of the village. Another small stream, rising in the valley between Lowell and Kidder mountains, flows thru Long Mountain and empties into Black River from the west. This stream drains the western part of the township.

In the extreme north western corner of the township is a pond covering about five hundred acres with an outlet flowing easterly over the slate belts, then northerly parallel to the Black River and finally emptying into the Black River in the township of Coventry. With the exception of Barton River, which flows across a small corner of the town in the northeast the above named streams drain the entire section.

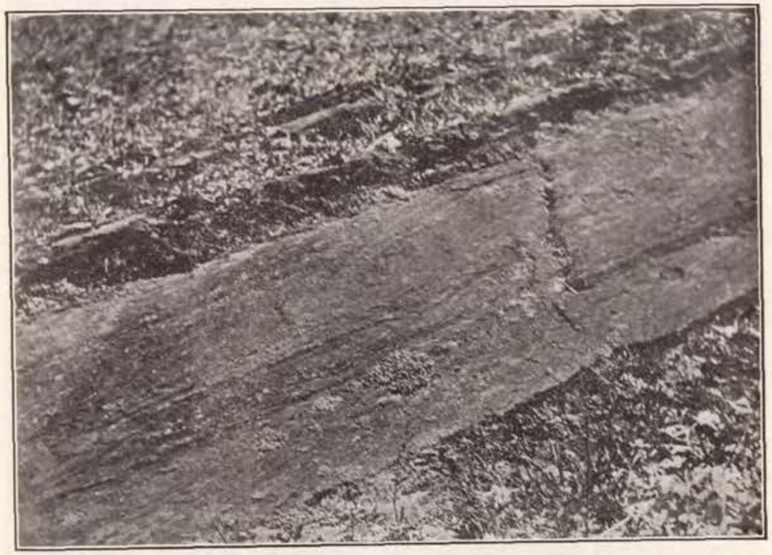
GLACIATION.

The town of Irasburg lies in the old Memphremagog basin with the western slope of Glacial Memphremagog on the east side of the western ridge containing Lowell Mountain and Kidder Hill. On every ridge and elevation with the exception of those in the central part there are great angular boulders strewn along the mountain sides. These boulders are of granite, diabase, peridotite, quartzite and limestone.

The whole central portion between the eastern and western ridge is covered with a thick mantle of glacial drift, in the form of kames, eskers and ground moraines. Many of the transverse valleys in the main ridges have been completely filled with this material.

On many of the outcrops of rock, glacial striae were seen and in several cases the direction was recorded. These were not always in the same direction. On the east side of Kidder Hill an outcrop of slate scorings were found which extend in two directions. These were probably made during two different glacial periods.

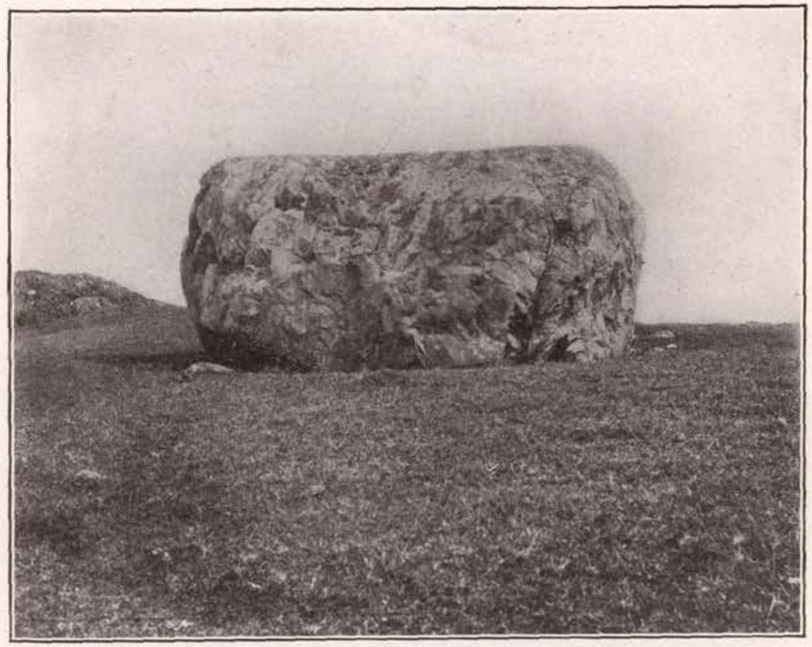
PLATE LV.



A. Post Glacial Fault, Irasburg.

B. Long Mountain, Irasburg.

PLATE LVI.



Diabase Boulder, Irasburg.

QUARTZITE CONGLOMERATE.

This peculiar formation, consists of a mass of small, white quartzite pebbles encased in fine grained quartzitic material.

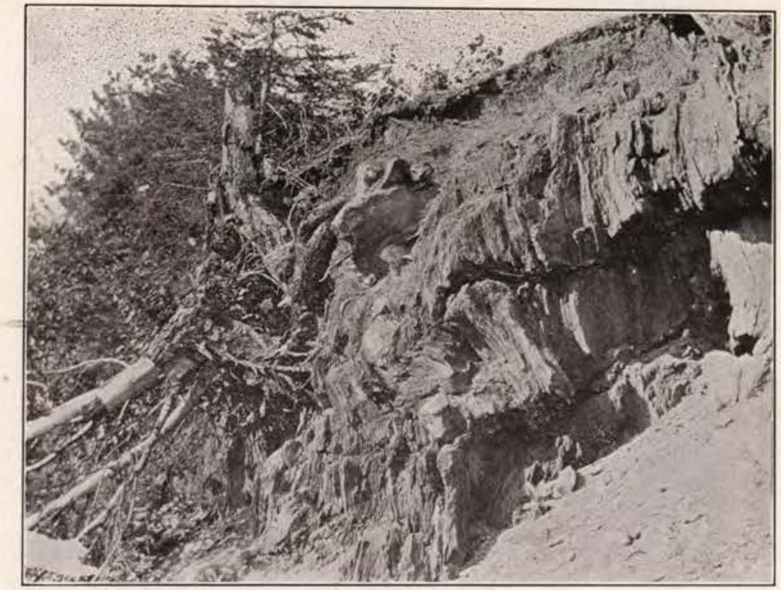
This formation crosses the road leading over Kidder Hill near the Newport line. It is about one mile long in the township and not more than one-half mile wide at the widest part. The strike varies from north 40° east to north 42° east and the dip from 78° west to 82° west.

HYDROMICA SCHIST.

The hydromica schist is dark in color, greasy in feel, rich in cubes of iron pyrite, and of a somewhat slaty texture. When the layers are split parallel with the planes of foliation oxide of iron covers the surface. This will hold true to the depth of the complete breaking down of the pyrite. In many cases small grains of quartz were found embedded in this rock. The formation may be traced from the north western part of the township north of Kidder Pond, southward to the granite in Lowell mountain. It is only a few rods in width in the southern part but widens gradually toward the north. The greater part of Kidder Pond lies in this formation. The strike seems uniformly north 40° east while the dip varies from 75° west to 80° west.

SERICITE SCHIST.

The sericite schist comprises a band of fine grained, light colored micaceous rocks lying directly to the east of the hydromica schist. No large crystals of pyrite were found in this terrane altho there are some small crystals of the mineral in several localities. In the southern part of the belt the rock has a slaty appearance but it is far lighter in color than the slate. To the north the rock is more massive but still retains the characteristics of a mica schist. Still further to the north in Troy the cleavage is so highly perfect that it readily splits into slabs three-sixteenths of an inch in thickness. A vein of quartz, locally thought to contain gold, silver, nickle and copper, is found in this terrane near Kidder Pond. In some places prospectors have opened up the vein to determine its width and value. It is, however, only



A. Abnormal Dip of Limestone, Irasburg.

B. Limestone Quarry, Irasburg.

a few feet in width and extends northward into the township of Newport. Several assays have made from similar quartz veins in northern Vermont and in no instance has gold been found in commercial quantities. This belt of sericite schist is about one mile in width and extends from the north town line to Lowell Mountain on the south. The strike is uniformly north 40° east and the dip varies from 75° west to 80° west.

ORDOVICIAN.

Parallel to the Cambrian group of terranes and flanking them on the east is the Waits River limestone and the Memphremagog slate. They consist of interstratified silicious limestones and slate or phyllite. They have a general dip to the west of about 60° and a strike of about north 40° east. The slate being less effected by erosion and solution stands in the form of long parallel ridges extending northeast and southwest across the township. The softer limestone has been worn down many feet below the surface of the slate forming broad U-shaped fertile valleys between the ridges of the slate. The central belt of slate mapped in the report on Newport, Troy and Coventry and published as a chapter of the State report 1907-1908, dies out just across the line in Irasburg, leaving only two belts of slate to cross the entire township, the eastern and the western. These Ordovician terranes will be taken up separately in the further discussion.

IRASBURG CONGLOMERATE.

Extending thru the central part of the township in a direction of approximately north 40° east, there is a limestone conglomerate. It carries pebbles of diabase, granite, porphyrite, quartzite, and sericite schist. It was discovered by the first named author of this article in 1904 and named by him at that time the Irasburg conglomerate. As the work assigned at that time lay in the northern townships there was not given an opportunity to trace out in detail the extent of the formation. In some parts the pebbles are small, well water worn, while the entire conglomerate is highly crumpled and folded away very much as seen in Plate LVII A. In other parts the conglomerate contains large boulders of diabase, porphyrite and quartzite. Some of these are from two to four feet in diameter. Plate LVII B shows this conglomerate as it appears in the bed of Lords Creek just south of Irasburg village. Another excellent exposure of the conglomerate is about one-fourth mile south of the village of Irasburg on the east side of the road to Albany. The site is further located by the large isolated pre-Ordovician boulder, a cut of which appears in an earlier report.

This conglomerate can be traced for two miles north of the village of Irasburg and for an equal distance to the south of the same village. In each direction the pebbles become smaller and less numerous. This may simply imply that the outcrops lie higher up in the conglomerate. The area exposed is about four miles long and one-half mile wide in the widest part which is near the village of Irasburg.

Accurate measurements of the dip and strike of this terrane are attended with difficulty for the strike sometimes changes 90° within ten feet. The dip thru the complex folding appears in all directions and at all angles. This conglomerate is considered to represent the base of the Ordovician series of rocks in eastern Vermont. The pebbles are all pre-Ordovician and the matrix is limestone. The size of the encased boulders implies that it marks a shore line at one time in the Ordovician sea and establishes an erosional unconformity between the Ordovician and the pre-Ordovician terranes. That it is not the conglomerate found in the western part of Coventry and previously reported is proved by the fact that the Coventry conglomerate carries pebbles of both limestone and slate of Ordovician age and these are entirely wanting in the Irasburg terrane. This conglomerate reappears in Albany and will be discussed in the report upon that township.

WAITS RIVER LIMESTONE.

There are three phases of the Waits River limestone in Irasburg. The first of these represents the Coventry phase. It is a dark gray pyritiferous silicious limestone. The coloring matter is largely due to carbon. It is locally burned for its lime content. It underlies about one-half of the township which occupies the U-shaped fertile valley between the slate belt on the west and the one on the east. It extends across the entire township form north to south, and is about three miles in width. The strike varies from north 10° east to north 20° east and the dip from 55° west to 60° west.

A. Conglomerate, Irasburg.

B. Conglomerate in Bed of Lords Brook, Irasburg.

In the central part of the township the limestone is much more compact and of steel gray color. The cubes of pyrite when present are very small. Large veins of secondary quartz traverse this phase of the limestone. In some instances they are reported as auriferous but the gold content is never a commercial factor. This represents the Washington phase where it was worked for several years as a marble.

In the eastern part of the township the limestone is lighter in color than either of the other phases and in some instances variegated. On its western border it was found to be in contact with the dark Washington phase. It is interstratified more or less with the eastern belt of slate. In many places covered by the limestone on the areal map there are small beds of slate or phyllite but the limestone predominates. It is due in part to these narrow beds of slate and phyllite that the eastern part of the town has a higher altitude than the western valley. This limestone represents the Waits River phase from the village of Waits River in Orange County near which it was quarried for several years and named by the manufacturer a "Variegated Imperial Granite" altho it contains no feldspar. The strike varies from east and west to north 70° east and the dip from 55° west to 80° west.

SLATE AND PHYLLITE.

Flanking the sericite schist of Cambrian age on the east is a belt of slate and phyllite schist. It extends from Lowell Mountain on the south northward across the entire township and represents the same belt of slate that traverses both Newport and Coventry to Lake Memphremagog. It is styled in the report on Newport, Troy and Coventry the western belt of the Memphremagog slates. In the northern part it has a more slaty texture. The rift and grain is sufficiently perfect to permit the quarrying and splitting for flagging purposes blocks of considerable size. It has been utilized locally in the northern section for this purpose.

This terrane has a decidedly western dip but not nearly as vertical as the Cambrian rocks which it borders. It is about one mile wide in the northern part of the township but gradually narrows toward Lowell Mountain.

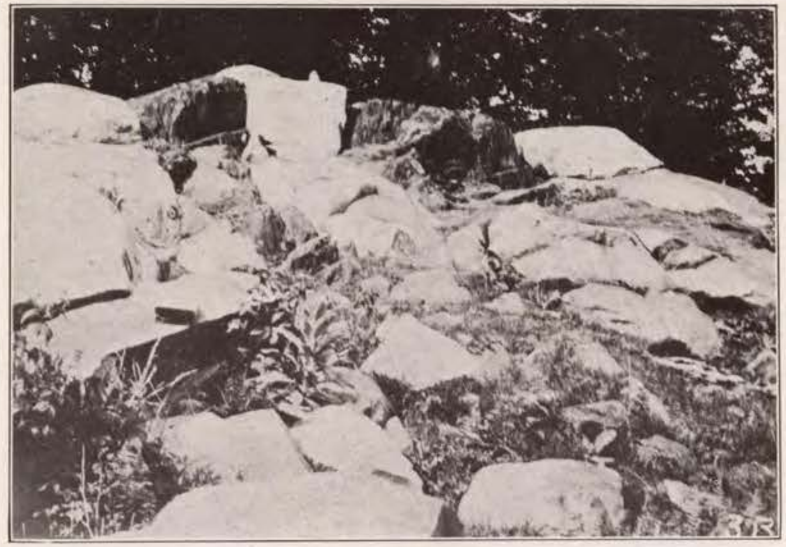
In the central part of the township from north to south there is a somewhat peculiar condition. The slate has been metamorphosed by acid intrusives into an ottrelite schist, or a phyllite schist with many crystals of ottrelite set transverse to the planes of foliation. The schist has no regular strike and the dip is nearly vertical. Excellent laboratory samples of anticlines and synclines can here be secured. In the vicinity of this abnormal condition are large granite intrusions with inclusions of phyllite in the granite. One of these is shown in Plate LVIII A.

This formation contains crystals of pyrite in the form of cubes. In many instances the sulfide of iron has dissolved out leaving hexagonal holes in the phyllite. The entire surface is more or less covered with the oxide of iron caused by the decomposition of the pyrite. The strike varies from east and west to north 55° east and the dip from 55° west to 90°.

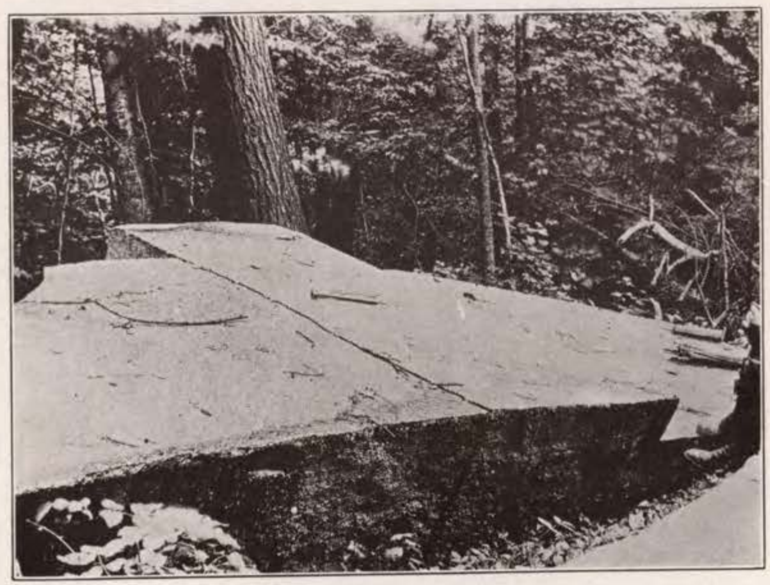
In the eastern part of the township there is another large belt of slate together with a small bed in the northeastern part having the same dip and strike as the continuous belt. The smaller bed may be the last remains of an old ridge of slate that has suffered disintregation and erosion until it has nearly disappeared. To the southward the main belt extends to the extreme eastern edge of the township. Its strike has changed from north 40° east to east and west. This area is southeast of the large granitic intrusives of Allen Mountain and Knights Hill which is undoubtedly the cause of the abnormal trend of the eastern belt of phyllite in the south central part of the township. This belt is interstratified with the limestone far more than the western belt. The encased limestone beds are from a few feet to many rods in width. The phyllite is more crumpled and metamorphosed in the southern part of the township than in the northern. In some instances in the northern section the slate would make a very satisfactory roofing material were it not for the crystals of pyrite which it contains,

INTRUSIVES.

Acid intrusives: The term acid intrusives in this discussion is used to designate a series of intrusive rocks which are light in color, light in specific gravity, holocrystalline and high in their point of fusion. In this respect they bear a striking contrast with the basic irruptives which will be mentioned later in this article.



A. Phyllite Inclusions in Granite, Irasburg.



B. Top of Granite Block, Irasburg.

GRANITE.

Much of the surface of the township is covered with rounded, densely wooded elevations. In the western ridge there are three of these elevations. At the extreme north the large granite area covering many acres outcrops just north of the outlet of Kidder pond. This appears as a large dome pushed up thru the slate. This granite contains a considerable amount of iron as shown in the sap. The stone does not split well.

About three miles south of this area there is another large intrusive consisting of both acid and basic rocks. Here the granite also contains iron and is otherwise of an inferior quality.

The largest field of granite in this section is situated on the eastern slope of Lowell Mountain. It covers the whole southern corner of the township. At the base of the mountain the granite is of very good quality. The rift and grain are perfect. It is an excellent working stone and free from iron. The prevailing ferro-magnesian silicate is the black mica, biotite. Plate LVIII shows the top of a block of this granite measuring 22 by 14 feet by 8 feet.

This outcrop is on the farm of R. G. Phillips and has been worked to some extent. It is an excellent stone for bridges and underpinning, the two uses to which it is locally adapted, but it appears equally valuable for structural and monumental work.

To the north of this point there is another good outcrop on the farm of Arthur Clough. It belongs to the same area but lies a little nearer the northern border of the intrusive. This granite also has good rift and grain and has been worked to some extent. It contains more of the biotite and is therefore a little darker in color than the granite on the Phillips farm. It is also a little tougher than the Phillips granite.

The nearest railroad is the Boston and Maine. The nearest station is Orleans some eleven miles distant. If one of the numerous "Granite Railroads" of Vermont passed thru the Black River valley this granite would be extensively worked for it can easily compete in open market with the other granites of the State.

A few hundred feet higher up on the eastern slope of Lowell Mountain there is a granite containing much pyrite and the stone is without perfect rift or grain. The slate which is cut by this granite is highly pyritiferous far more so than the adjacent limestones on the east. It may be that the slate furnished a part at least of the iron now found in the outer and higher portions of this large granite area. Moreover erosion and solution have both been more active on the eastern side and therefore the exposure of the granite on the Phillips and Clough farms is hundreds of feet lower on the granite formation.

Beginning at the place where the central granite area of the western belt is found, extending to the south at irregular intervals from each other there is a series of pegmatite dikes parallel to each other with strike east and west. They form with the limestone a prominent ridge which is about four miles long and quite narrow. The slopes upon either side are precipitous. Some of these dikes are only a few feet in width, others are twenty feet wide. In some instances thay appear as veins of pegmatite in the limestone, always crossing it at a high angle. Plate LIX illustrates the nature of these dikes. A wide dike is seen at the left of the photograph. The narrower ones at the right.

A U-shaped valley has been excavated between the western main ridge and this secondary ridge. The dikes do not appear to extend further in either direction than the foot of the ridge. At the southern extremity of this long ridge there is a round mountain having an elevation of 1,600 feet. It consists of granite of inferior quality.

The formation between the pegmatite dikes is the black shaly limestone which would easily suffer solution and erosion. These intrusives have withstood the influences of corrosion and corrasion thus forming this long narrow ridge terminated at the south by Round mountain. It is not impossible that these pegmatite dikes represent the more acid phase of the same magma as furnished the granites for Lowell Mountain and that this intrusive worked its way into the fissures in the limestone. The ridge as a whole presents an intensely interesting spectacle with its wooded crest, bare, weathered limestone sides, banded frequently with the whiter pegmatite dikes transverse to the strike of the ridge and the limestones.

The Irasburg conglomerate and the western valley of the limestone do not apppear to be traversed by any granite outcrops. The eastern slate belt however has been intruded. One-half mile east of Irasburg Village is Allen Mountain which consists of granite. Near the borders of this dome-like structure there is a brecciated granite containing fragments of the limestone, slate

PLATE LVIX.

Pegmatite Dikes, Irasburg.

and quartzite which it cuts. The flowage zone is in many instances clearly marked. This granite also contains much iron which gives it a rusty appearance, especially at the surface and on samples that have stood exposed to the oxidizing agents of the atmosphere for a considerable period of time.

Knights Hill, situated just north of Allen Mountain, is composed of both acid and basic intrusives. This granite also contains pyrite but the rock is quarried to some extent and utilized for foundation purposes.

Basic intrusives: The term basic irruptives as here used includes a series of intrusives that are basic in their nature and therefore more easily fusible than the acid, holocrystalline rocks just described. As these basic members are dark in color, high in specific gravity, often micro-crystalline, they form a striking contrast with the granites.

DIABASE.

The term diabase includes the heavy, basic intrusives consisting of plagioclase, augite and magnetite. Olivine may, or may not, be present. The rocks forming this class are mostly in the western part of the township cutting the sericite and hydromica schists. In the region of Kidder Pond many of the rounded igneous outcrops appear. Also south of this area and west of the central granite mass there are large domes of diabase.

About one-half mile south of Irasburg on the road to East Albany on the east side of the ridge just west of the covered bridge over Lords Creek, there is an outcrop of basic material with bright, shining crystals of hornblende. This ledge is about one hundred feet long and seven feet high extending in a westerly direction into the ridge.

In the igneous masses on Allen Mountain and Knights Hill much basic material is found. On the west side of the hill there is a ledge about one hundred yards long and several wide consisting of a tough, black, ferro-magnesian rock. Samples of it were not easily procured even with a two-pound hammer. This rock appears to consist of phenocrysts of biotite, a little quartz, and no phenocrysts of feldspar.

On this hill there are several outcrops of brecciated material. In some instances the main mass is granite containing fragments of diabase and other material, highly metamorphosed slates and phyllites apparently, but in other instances the main mass is diabase and the inclusions are granite. Two igneous irruptions must have occurred here with some little period if time intervening.

ECONOMICS.

The economic products of this area deserve special mention in this article altho their value is very much lessened by the great cost of marketing the products.

The first product of importance in the township is the great quantity of granite which is widely distributed thruout the area. The granite in the eastern part might easily be placed on the market by a short haul to Orleans but the quality of the rock is of such a nature as to bar it commercially. It is so full of pyrite that it can not be used for architectural purposes. It may be used, however, for underpinning and in other places where the iron rust would not tend to lessen the value of the stone.

The granite on Lowell Mountain in the southwestern corner of the town is of good grade as already noted. It is well suited for massive construction and monumental work. It is easily quarried and can be manufactured into any form to suit one's purpose. The distance from a point of shipment is the one disadvantage. Should a railroad ever be constructed from Newport southward thru the Black River valley this granite will be a valuable asset to the town.

The basic irruptives may be utilized for road material. In many places permanent roads are in the process of construction. The diabase such as is found on the East Albany road or on Knight Hill would give a much better road than the field boulders that are crushed and used for this purpose at the present time. Many of these limestones, slates and schists that are not so permanent in the wearing qualities with heavy traffic. However the lime may serve as a cement to bind the other fragments together.

The limestone found in the central section would make good abutments for bridges, and walls for houses and barns. It is so used locally.

Good samples of bog manganese, or wad, occur in the densely wooded sections in the western part of the township but the extent of the ore is unknown. Pyrolusite, the dioxide of manganese,

has also been reported from this area. Rhodonite, a silicate of manganese, occurs here also and may have been the progenitor of the pyrolusite.

Many auriferous quartz veins have been discovered in this territory and several attempts have been made from time to time to find gold in commercial quantity but these efforts have proved futile. The largest value obtained from any of these veins was gold $3.61 per ton.

HISTORICAL GEOLOGY.

There is no paleontological evidence yet discovered in Irasburg to prove the age of the Memphremagog slates and the Waits River limestone in this territory.

The first named author, however, after diligent search succeeded in finding evidences of crushed graptolites in the Waits River limestone, in the town of Coventry just north of the Irasburg line, and in the town of Brownington, some five miles east of the first locality. The same author had collected and described in an earlier report fifteen species of graptolites from Castle Brook Magog, Quebec, as bearing evidence of the age of the Memphremagog slates in northern Vermont. Samples of the crushed graptolites from the Vermont localities were submitted to Dr. J. A. Dresser, who pronounced the graptolites undoubtedly genuine. Samples of these graptolites have recently been submitted to Dr. Rudolph Ruedemann, State Paleontologist, Albany, N. Y., who likewise declares them genuine.

If we accept the records of the Canadian graptolites, the new record of the Vermont graptolites, the lithological similarity of the formations in contiguous areas, and the crinoidal stems in two phases of the Waits River limestone we are compelled, knowing the stratigraphical position of these terranes, to locate the slate, phyllite schist, and Waits River limestone as Ordovician, and more specifically, the upper portion as Lower Trenton.

The lithological similarity of the non-calcareous terranes in the western part of the township to the bands of quartzite on western side of the Green Mountains and their continuous extension into Canadian territory where they have been recognized as Cambrian terranes has led the authors to catalog these western members of Irasburg as Cambrian.

These Cambrian rocks furnished the finer sediments for the slates and phyllite schists of Ordovician age and the free silica of the Cambrian Quartzite may have been the source of the free silica of these silicious limestone belts in Irasburg.

That Irasburg was the first of these terranes to be laid down, or at least the earliest Ordovician terrane to be brought into view by subsequent erosion, for it is the most twisted and distorted of any of the members of this series. The numerous pebbles and large boulders so abundant in the conglomerate would indicate that this outcrop was formed in close proximity to the shore line.

The greater amount of crumpling in certain areas was undoubtedly due to igneous intrusions of Devonian age. Plate LXI, shows a portion of the limestone which illustrates this greater folding. To the east of this area is the great granite intrusion of Allen Mountain and just west is the large igneous mass of Long Mountain Plate LV. Directly to the east of this is a great mass of igneous material carrying hornblende crystals. In all cases where this abnormal folding and plication occurs intrusives are found in the immediate neighborhood.

SUMMARY.

The authors have made a more detailed study of the terranes of Irasburg than has hitherto been undertaken; (1) mapped as accurately as time would permit the underlying strata; (2) shown the stratigraphical relation of the terranes to each other; (3) given new paleontological evidence of their age; (4) proved that only two of the slate belts of Coventry and Newport extend across Irasburg; (5) proved the Irasburg conglomerate to be at the base of the Ordovician series in Vermont; (6) proven an erosional unconformity to exist between the upper Cambrian and the earliest of the Ordovician series; (7) shown the economic possibilities of the area involved.

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PLATE LXI.

B Abnormal Dip of Strata, Irasburg.

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1905–6. Annual Report of the State Geologist, The Areal and Economic Geology of Northeastern Vermont. C. H. Richardson.

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THE TERRANES OF ~~IRASBURG~~ Craftsbury, VERMONT.

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SECOND REPORT.

INTRODUCTION.

The present report upon the terranes of ~~Irasburg~~ Craftsbury is necessarily brief. It must be considered only as one of progress in the solution of the intricate geological problems of northern Vermont. The author first traversed this area in reconnaissance work in 1895 and again in 1905, but it was not until the summer of 1912 that detailed study could be given to the field. The reasons for selecting this area are that it lies in the line of the erosional unconformity between the Upper Cambrian and the lowest of the Ordovician series represented in the eastern half of the State; furthermore it forms with Irasburg and Albany whose geology is already written for the 1912 State Report a definite geological unit. It carries the work from the International boundary thru Orleans County to Wolcott in Lamoille County and Hardwick in Washington County.

Some little work has already been accomplished in Greensboro but the data obtained has not been sufficiently correlated to be embodied in the present report. It will however be available for the report of 1914. It is the authors desire to include with Greensboro in the next report at least Hardwick and Woodbury for two reasons. First, the large economic possibilities in the granite industry they represent; and second, the break they record in the geological record in eastern Vermont.

Forty-one new rock specimens have been collected in Craftsbury and carefully trimmed to the standard uniform size, three by four inches, for laboratory study and exhibition in the State Museum at Montpelier. This brings the total number thus collected, exclusive of those in Greensboro to four hunderd and fifty-one. The specimens represent a very important series of rocks of widely different ages, mode of origin, and chemical composition.

Two maps accompany this report. One, Figure 1, is stratigraphical, representing a protracted section across the township from east to west near the center of the town. The other, Plate LXII, an areal map, showing the geographical distribution of the terranes within the area involved. A map cannot be accurate until a

topographic survey of the eastern half of the State has been made. Then it will be a pleasure to map with accuracy the geological formations represented. None can deplore more than the author of this report the utter absence of this most necessary and valuable assistance in the field.

I wish also to recognize herewith my great indebtedness to Dr. Rudolph Ruedemann, State Paleontologist, Albany, N. Y., for his services in the identification of crushed graptolites from Coventry and Brownington and for his examination of the badly weathered and crushed material, strikingly suggestive of fossils from Irasburg and Albany. Furthermore to Homer G. Turner, a graduate student in Syracuse University, for his companionship and aid in working out the numerous details involved in this problem. Mr. Turner is also aiding in the study of the terranes in Greensboro.

DRAINAGE.

The drainage of the area involved in intensely interesting. The height of land separating the waters flowing north into Lake Memphremagog from those flowing south into the Lamoille River is normally parallel with the north town line of Craftsbury. It would be expected then that the drainage would be in a southerly direction into the Lamoille Valley. The largest river or stream of water is Black River which rises in Eligo Pond in the extreme southeastern part of the township and flows in a northeasterly direction across the entire town, ultimately emptying into Lake Memphremagog at Newport. Its main eastern branches, Eligo Creek and Whetstone Brook, have their sources in the northeastern part of the township and flow in a southerly direction nearly the length of the township. About one mile south of Craftsbury they encounter the waters from Eligo Pond and abruptly change their course to the northward. One small stream flows from the north into the northeast corner of Elig Poond and flows out again at northwest corner of the same pond as Black River. The entire southern section is drained by Wild branch and its tributaries which empty into the Lamoille River about two miles west of Wolcott Village. This drainage is entirely to the south.

It is possible that the original drainage of Eligo Pond which lies mostly in Greensboro was to the south into the Lamoille River at Hardwick and that Eligo Creek and Whetstone Brook were the head waters for this supply. If so, we have here an excellent illustration of the migration of a divide and the beheading of a stream. How much of this work may have been accomplished by the ice when it moved to the south broadening and deepening the U-shaped valley of the Black River I cannot say.

These streams are not all sluggish. The Black River is especially sluggish and furnishes here no water power of commercial significance. This does not hold true of Eligo Creek or Whetstone Brook. The former has an excellent water power at Mill Village which is now utilized, the latter falls over two hundred feet in less than half a mile. Vertical falls of from fifteen to twenty feet are not uncommon in this stream.

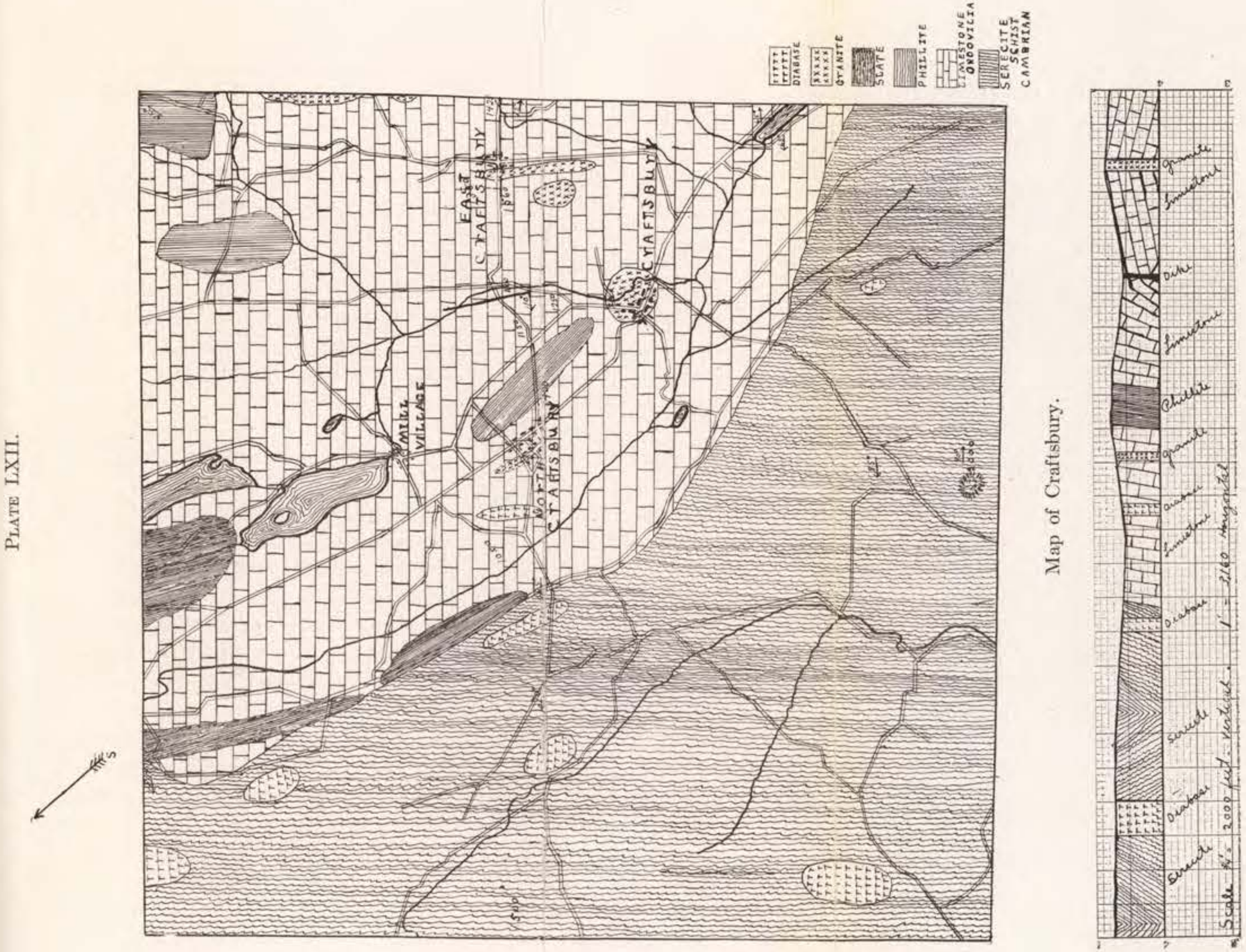
TOPOGRAPHY.

The area traversed lies almost due southwest of Albany. Their east and west town lines are parallel in their extension, north 40° east or south 40° west. It covers an area of approximately forty square miles.

The valley of the Black River is longitudinal with its course determined somewhat by the softer and less resistant western belt of limestone over which it flows. It is nearly parallel with the strike of the limestone. In general the longitudinal character holds true of the north and south depressions. However, Whetstone Brook flows directly across the strata which it cuts. It presents a beautiful winding gorge in the wooded area thru which it flows. The time of this gorge is post-glacial. The original course of this stream was not determined.

The eastern ridge of resistant slates and phillites that has been nearly continuous thru Albany and Craftsbury has passed to the southeast into Greensboro near the center of the eastern town line. The altitudes have varied from 1,000 to 1,800 feet. The central ridge of slate which has been continuous northward to Lake Memphremagog dies out near the village of Craftsbury. Here the U-shaped valley of the Black River becomes quite broad and in it the slates and phyllites do not appear. The valley is from 250 to 300 feet lower in altitude than the central ridge. The western ridge which persistently maintains its higher altitude to the northward even into Canadian territory extends in a southerly direction across the entire township. The highest altitude is found in West Hill which reaches a height of 2,000 feet. With

Plate LXII.



Map of Craftsbury.

Section across Craftsbury.

West Hill in Craftsbury, Sarah Mountain in Greensboro, Black Hills in Glover, Lowell Mountain in Lowell and Black Hills in Newport all around 2,000 feet in altitude, the area traversed presents the appearance of a dissected pene-plain with these crests standing out as monadnocks.

GLACIATION.

The town of Craftsbury is mantled with morainic material to such an extent that the geologist may travel many miles in the direction of the ice movement without finding a single outcrop for the study of field relations. This holds especially true in the southwestern part of the township in the valley of the Wild branch where pre-Cambrian terranes are completely obscure and in the Black River valley where Ordovician terranes are buried to such a depth that few rock exposures could be found. These deeply buried portions may carry the true diognastic features of age.

Another interesting feature of the ice movement is that it has not all been in the same direction. The general movement is accepted to have been in a southerly or southeasterly direction. This is proven by the many boulders of the old Lawrentian gneiss from the north side of the St. Lawrence River strewn along the pathway of the moving ice. Evidences of a different direction of ice movement are very marked on the resistant outcrop of phyllite just east of Craftsbury Common. Here excellent exposures of glacial striae can be observed. One set of markings are recorded south 20° west and the other south 40° west. The lower portion of the ice may have conformed somewhat to the broad U-shaped valley of the Black River and moved in a southeasterly direction. The two different directions recorded on Prospect hill can be duplicated in other high altitudes in the township.

Several small valleys have been partially filled with morainal material thereby giving rise to small lakes or ponds. Two of these are in the northern part of the township and are known as Hosmer Ponds. One of these lies entirely in Craftsbury and the other extends northward into Albany. Each of these has its longer diameter in the direction of the moving ice a little to the southeast as if the valleys were deepened by the erosive action of the ice. One small pond is found northeast of Mill Village and another west of Craftsbury Village.

GEOLOGY.

The geology of Craftsbury is intricate and complex. The terranes consist largely of a series of crumpled, folded, faulted, metamorphic rocks, dipping always at high angles, and often cut by both acid and basic intrusives. In the western part of the area covered in this report the stratigraphy must be determined by field relations, and even here there is a wide chance for error. In the eastern part the problem is rendered less difficult by the erosional unconformity between the older terranes on the west and the younger rocks on the east, and by the discovery of crushed graptolites in the northern extension of these limestones in Coventry and Brownington.

CAMBRIAN.

The term as here used comprises an undivided group of highly metamorphosed sedimentary, or meta-sedimentary, rocks lying between the eastern foothills of the Green Mountains on the west and the valley of the Black River on the east. They consist of pyritiferous mica schists, sericite schists, quartzites and conglomerates. In their northern extension thru Newport they embrace slates and gneisses. Their general strike is north 40° east. In the southern part of the township the strike in some instances became north 10° east. The dip varies from 65° west on the east to 80° east on the west. In them therefore there are two synclinal troughs and one anticlinal axis not comparable to the major axis of the Green Mountains.

These terranes were considered by Prof. C. H. Hitchcock as pre-Cambrian. The finding in this series of undivided metamorphics of many beds of Upper Cambrian quartzite has led the author to place this group definitely as Cambrian. They can best be divided when the study of the Lamoille valley, as it cuts the Green Mountain axis is taken up.

MICA SCHISTS.

The pyritiferous mica schist is best observed in the extreme western part of the township. Cubical crystals of the sulfide of iron FeS_2 have dissolved out leaving many cavities in the decomposing schist. These cavities are not as large and numerous

as in Troy just west of the village of South Troy where single specimens show a score or more of square holes formed by the complete washing away of these secondary products. These cavities are square because the geometrical form of the associated pyrite is that of the cube. Some of these chambers are now filled with the oxide of iron which has not yet leached out and it is only in the less decomposed material that the original pyrites are found.

This terrane has been traced continuously from the International boundary on the north southward thru Troy, Newport, Irasburg, Albany and Craftsbury. This schist is marked by its black or greenish black color, the presence of beds of bluish quartzite often rounded and embossed by the action of the ice, and by the slippery hydromica of Hitchcock. In certain local areas to the northward this terrane has almost the fissility of slate.

SERICITE SCHISTS.

The sericite schists flank the pyritiferous, hydromica schists on the east, and the youngest Ordovician slate on the west. They have been traced continuously from the International boundary on the north southward thru Troy, Newport, Irasburg, Albany and Craftsbury. Their best development is in Troy where they are so fine grained that they have been quarried to some extent and used locally for building purposes. The same use has been made of a little of this rock in the northern part of Craftsbury. Here the terrane becomes quite narrow, only about a mile in width while in the southern part of Craftsbury it stretches nearly across the entire township.

These schists are light in color and at a distance somewhat resemble a badly weathered and sheared diabase. They consist mainly of minute grains of silica and plates of an altered mica now classified as sericite, a hydrated variety of muscovite. In some instances these schists approach a quartzite and might be cataloged as a quartz schist. In such cases the parallelism of the minute scales of sericite is perfect and the whole mass seems to be made up of but little more than minute quartz grains held together by an original cement of clayey matter and iron. No attempt has been made to separate this highly silicious area from the more sericitic phases of the schist. They are simply regarded as representing the more silicious phases of the sediments laid down on the floor of the ancient seas. Their meaning however may be far deeper.

The high degree of metamorphism that characterizes these schists is not only due to changes that took place during the Cambrian Revolution of early geological times, but to intrusive masses of diabase introduced at some later time, possibly Devonian. These diabases will be discussed under the caption of intrusives.

In the western part of Craftsbury these schists are traversed by numerours quartz veins which have given rise to an active quest for gold. The amount of gold reported from samples sent away for assay has varied from a mere trace to $4.50 per ton. There is no evidence that any of these veins are commercial propositions.

The southeastern part of the township was considered by Prof. C. H. Hitchcock in his Geology of Northern New England, 1870-1882. to consist of the calciferous mica schist and clay slates of Upper Silurian age. The break between the older and the younger formations was carried some four miles too far to the west. It even embraced some area to the west of Wild branch, a tributary of the Lamoille River.

A diligent search was made in the southern part of the township for outcrops of either the limestones or the slates now recognized as Ordovician but none could be found. Wherever the rocks are exposed thay are distinctly Cambrian sericite schists and quartzites. These can be seen abundantly on West Hill in the extreme southern part of the township and embraced in the younger fo rmations of Hitchcock. The sericite schists also found in numerous outcrops on the hill beyond the end of the road that leads in a southerly direction about one-half mile west of the northern part of Eligo Pond. That this material is sericite schist and not Ordovician limestone is very apparent to the observer in the field.

This condition brings the Cambrian terranes somewhat abruptly to the east a far greater distance than was expected. In fact, the Cambrian sericites and quartzites appear to pass out of Craftsbury into Greensboro on the east and at this point the formation becomes about five miles in width.

According to the earlier maps of Hitchcock the Ordovician terranes should extend westward about three miles in the northern part of Wolcott.

According to the results obtained this summer the Cambrian terranes should be carried four miles further to the east so that the Ordovician limestones and slates would not appear in Wolcott at all. This abrupt easterly extension of the sericite schist from

field investigations I admit was quite unexpected. Whether they turn abruptly to the west in Hardwick and Wolcott and so conform more nearly to the earlier reports of Hitchcock is a matter of considerable interest and one that the author hopes to settle in season for the next State Report.

CAMBRIAN CONGLOMERATES.

The adjective Cambrian is here used that these outcrops of conglomeratic material may in no way be confused with the Irasburg conglomerate which lies at the base of the Ordovician. Quartz pebbles were found in great abundance in the northwestern part of Irasburg in the Cambrian terranes, but this terrane, if it be a separate one, passes so far to the west that it would not enter Craftsbury at all, unless there be a change in its strike in Eden to about north 10° west. The conglomerate phase in the sericite schist is well marked about one mile east of the western town line on the north road to Eden Mills. Here the strike is about north 40° east and the dip nearly verticle. This condition appears again locally in the southern part of the township in the vicinity of West Hill. It occurs also in a locality far easier of access in the eastern part of the sericite schist just south of the direct road to Eden Mills and about two miles west of Craftsbury Common. These areas may simply imply that erosion has been carried deeper or nearer the lowest beds of the Upper Cambrian. It may imply more. This question can not be settled until time permits the larger work in the separation of the Cambrian sedimentaries that flank the Green Mountains on the east. It would be settled when the geology of Lowell, Eden and Wolcott was worked out in detail. It is a stratigraphical problem of interest.

ORDOVICIAN TERRANES.

The Ordovician terranes in Craftsbury comprise a series of limestones, slates and phyllites, occupying the eastern half of the township. They are interstratified more or less with each other and the limestone predominates. These formations will be taken up separately in the discussion which follows.

WAITS RIVER LIMESTONE.

The Waits River limestone as described in the Annual Report of 1906 in The Areal and Economic Geology of Northeastern Vermont falls into three distinct phases. The first of these, the beautifully banded variety, so closely resembling some varieties of the Columbian marble of Proctor, Vt., does not occur within the area covered in this report. Isolated areas may appear in the towns north of Craftsbury in their extreme eastern portion but even here the characteristics of the type locality are largely wanting. It does appear however in its banded phase in the eastern part of Orleans County.

The major part of the limestone in Craftsbury belongs to the Washington phase of the Waits River series. It is a steel gray silicious limestone bearing about thirty-five per cent silica. It is usually quite free from pyrite save where it has been effected by intrusives. It is here much lighter in color than the dark steel gray limestones of Danville and Washington. A minor anticline appears in the eastern part of the township in this formation. The major anticline lies several miles further to the east. The dip of the limestone in the eastern part of Craftsbury is from 10° to 15° east and on the western side of the anticline the dip is 12° west. The eastern high altitudes lie partly in this anticline in the limestone and partly in the phyllite. The low dip is easily found one half mile south of East Craftsbury also in the gorge in Whetstone brook.

Whetstone Brook derives its name from the early use of this material as scythestones. The fine jointing and the perfect rift of this rock enabled the farmers to manufacture easily their own abrasives. The stone is of good grit and wears well. If this characteristic predominated over any considerable area I would choose to catalog the terrane a calcareous quartzite. Another similar area is found some twenty-five miles to the northeast near Evansville. The same highly silicious material appears in Marshfield in Washington County.

It is in the Washington phase of the limestone series that the crinoidal stems cited in Hitchcock's Final Report on the Geology of Vermont, 1861, were found. It is this phase also that carries the crushed graptolites in Coventry and Brownington and cited by the author of his article on the Terranes of Newport, Troy and

Coventry in the State Report of 1908. It is this phase furthermore that was mapped by Prof. C. H. Hitchcock in his Geology of Northern New England 1870-1882 as extending thru the southeastern part of Craftsbury where the terranes are found to be sericite schists and quartzites of Cambrian age.

In the northern part of the township the Washington phase of the limestone series is flanked on the east by a highly folded and much indurated belt of phyllite and on the west by the central belt of slate which further to the south passes also into a phyllite schist.

The Coventry phase of the Waits River limestone lies between the central and western belt of slates. It is a dark steel gray rock studded with pyrite. In the type locality in Coventry it is massive. In other localities it is more shaly and found in thin layers. It is in this phase that some true diognostic feature of age should be found. The stone weathers rapidly on exposure to the corrosive agents of the atmosphere on account of its iron content. This characteristic may be seen near the base of the hill on the road from North Craftsbury to West Albany.

IRASBURG CONGLOMERATE.

The Irasburg conglomerate was discovered by the author of this report just south of the village of Irasburg in the summer of 1904. The extent was then unknown altho it was ascertained to cover a considerable area. It was deemed of sufficient importance to give this formation a distinct geological name and therefore it was named from the town in which it was discovered. As already described it contains boulders of diabase, granite, porphyrite, quartzite, and sericite schist, all pre-Ordovician in a cement of Ordovician material, essentially limestone. No analysis has been made to show how silicious this cement may be.

In Albany this conglomerate was found again but the boulders of diabase and granite are absent. A diligent search was made for outcrops of this conglomerate in Craftsbury and the search was rewarded with small outcrops near the road leading from West Albany to Craftsbury Common. The pebbles here are not so numerous nor are they so large as they are in the northern exposures.

A few pebbles about two inches in diameter were found. These were porphyrites and quartzites. The southern extension of this conglomerate into Craftsbury is further marked by its highly folded and crumpled condition. The erosion here is not quite so low on the formation as it is in the more northern outcrops. It is the author's desire to find this conglomerate represented distinctly in the Lamoille valley in Hardwick where the altitude above sea level is much lower than in Craftsbury and where the erosion should also be lower on the formation.

This conglomerate distinctly marks the lowest of the Ordovician terranes in eastern Vermont, or east of the Green Mountain anticline. It lies in Craftsbury to the west of the central belt of slate and phyllite and to the east of the Black River. It is a true basal conglomerate as shown by the size of the boulders especially in Irasburg where some of them are from two to three feet in diameter. It marks furthermore an erosional unconformity.

SLATES AND PHYLLITE

The eastern belt of slate and phyllite that has characterized the high altitude from Newport southward thru Irasburg and Albany and ceases to appear in the extreme southeastern corner of Albany outcrops again in the extreme northeastern corner of Craftsbury. The phyllite here is highly metamorphosed. It often becomes exceedingly tough and loses much of its characteristic cleavage. Many crystals of ottrelite set transverse to plains of foliation are present. This phenomena is well represented in the samples collected for the State museum. The strike that would be expected for this terrane is north 40° east but the strike found in the area was north 40° west and the dip was at a high angle to the northeast. It perhaps might be better classified as an ottrelite schist. Its induration is in part due to the presence of the acid intrusives in the northeast corner of Greensboro.

About one mile to the southeast the phyllite assumes its normal slaty appearance. Many specimens could be obtained that would be classified in the field as a slate. It is so mapped in the areal map of Craftsbury. South of this outcrop the eastern belt of slates and phyllite do not appear in Craftsbury but pass out of the township to the southeast into Greensboro where on Calderwood Hill and Sarah Mountain, two high altitudes of approximately 2,000 feet the phyllite abounds. In this area scarcely an outcrop of limestone could be found. The exposures were phyllites and granites.

The central belt of slate that was continuous thru Newport, Coventry, Irasburg, and much of Albany, enters Craftsbury on the north and is continuous as far south as the larger Hosmer pond. Here it assumes the general appearance of slate. It is characterized by numerous small crystals of pyrite. These render it worthless for roofing purposes. In the northern sections as in Coventry it has been quarried in this same belt to some extent.

This belt of slate as it appears on Prospect Hill to the east of Craftsbury Common has suffered more metamorphism and passed into the characteristic phyllite again. This outcrop is especially characterized by a large vein of white quartz that is reported to be auriferous. This vein in about five feet in width and can be traced northward to the east of Hosmer Pond and southward for a mile or more. In the outcrops of this vein as far as examined there were no evidences of gold in commercial quantities. This belt terminates just north of Craftsbury village. South of the village no outcrops of either slate or phyllite belonging to the central belt was observed. The valley below this belt is some 300 feet lower in altitude than Prospect Hill and seems to be cut entirely in the limestones.

The western belt of slate which was mapped by Prof. C. H. Hitchcock as continuous across the entire township and extending into Wolcott on the south in his report on the Geology of Northern New England, 1870-1882, and also in his Geological Sections across Vermont and New Hampshire, 1884, does not appear to be continuous. It does not even extend more than half way across the township. It has been traced continuously from Lake Memphremagog on the north southward thru Newport, Coventry, Irasburg and Albany save where it is locally cut off by granite in the southwestern part of Irasburg and the northwestern part of Albany. It enters Craftsbury on the north and on the Whitcher and Wrenfrew farms it has been quarried to a considerable extent for structural purposes. Blocks six or eight feet in length and of any thickness desired can be easily obtained. The strike is north 40° east and the dip 80° west. This slate, which has been confined to the west of the Black River road from Irasburg southward, about two miles south of the northern town line passes to the east side of the road and if connected with the northern portion that connection is drift covered and was not observed. The strike is north 10° east and the dip still at a high angle to the west.

This slate was not found south of the school house about one mile west of Craftsbury Common. As it overlies the youngest of the limestones it may have once been continuous but if so it has since suffered a complete erosion. It does however appear again to the south for it is this belt that carries the roofing slates of Montpelier and Northfield. How long a gap there is can be determined only by subsequent field work.

DEVONIAN

From Lake Memphremagog on the north to Craftsbury no limestone has been found west of this belt of slate save in large erratic blocks in the northern part of Newport. It was the author's great surprise in the last days of his field work this summer to find directly west of the slate on the farm of C. H. Whitcher a belt of limestone. Its present position now is above the slate and to the west of the westernmost belt of slate in the township. It is more than a mile in length and several hundred feet in width. It is flanked on the west by the sericite schist and in the east by the slate. It is a silicious limestone like the shaly phases of the Ordovician. If it be Ordovician its position above and west of the youngest Ordovician terrane can be explained by a thrust fault with a considerable horizontal displacement and an inversion of the strata.

There is however another possible explanation of the appearance of a limestone west of the western belt of slate where it has not been supposed to exist. There is at Owl's Head in Canada some fifty miles to the north a small area of Devonian limestone. The strike of that outcrop would carry the formation if continuous into the towns west of Craftsbury. These terranes consist of Cambrian schists and not Devonian limestones. It is possible that this limestone is Devonian and comprises an area much larger than that at Owl's Head. The author regrets that there was no time left this summer while in the field to search this area diligently for Devonian fossils and gather the necessary data for the solution of this unexpected problem. The one outcrop of known Devonian rocks in eastern Vermont lies in the extreme southeastern corner of the State, a few miles north of the type locality at Bernardston, Mass.

INTRUSIVES.

The irruptives in Craftsbury comprise both the acid and the basic intrusives. The former are light in color, light in specific gravity and form a striking contrast with the latter rocks which are dark in color, high in specific gravity and often macrocrystalline.

GRANITES.

The granites in Craftsbury are confined to the eastern half of the township and everywhere associated with the Ordovician terranes. The most promising of these outcrops is situated in the eastern part of the town on the farm of E. A. Dutton. The strike of the outcrop is nearly parallel with the east town line which is approximately north 40° east. This belt is a little less than one mile in length and only a few rods in width. The boulders in the southern extremity of the outcrop were opened for building purposes but these were found to possess a gneissoid structure and the opening was abandoned. An opening was made then on the main body of the intrusive some fifty rods further to the north. Some blocks showing the same gneissoid structure were encountered which record a flowage in the periphery of the granite mass.

A considerable amount of development work has been done at this place. The granite is from fine to medium in texture and not as dark as the dark Barre or Hardwick granites. It possesses good rift and grain and can be cut to as fine an edge as required. It is well adapted for monumental work as shown in the bases and dies now in the process of completion at the quarries. The quarries are leased for a term of years by H. A. Jackson of Hardwick, Vt., who is now working them. The stone is said to take an excellent polish but no polished samples were seen by the writer.

Some fifty rods to the west of the quarries owned by E. A. Dutton another opening has been made on the farm of Robert Harper. A small amount of building stone has been obtained here. While the derrick was still standing no further development work was in progress. The sap here was a little deeper than on the Dutton quarry and the work executed was not so extensive.

A few rods east of this opening an outcrop of phyllite was found. As this terrane carries a considerable amount of iron a deeper sap in this granite might be expected. Blocks of considerable size can be obtained here but the development work is not yet extensive enough to state definitely what their character at the lower depths will be. The nearest sedimentary to the Dutton granite lay on the east side and was the Waits River limestone with a low dip of 12° to 15° to the east. This limestone here is compact and free from visible pyrites. Distance from the railroad increases the cost of production and lessens the output of both quarries.

The large granite outcrops of northeastern Greensboro appear to cross the town line into Craftsbury. There are no desirable places to open quarries in the latter town in this intrusive, but on the farm of E. W. Barclay in the edge of Greensboro four quarries have been opened and a considerable amount of good granite obtained.

ORBICULAR GRANITE.

In the village of Craftsbury and directly to the east there is a small area of granite that is worked locally for bridges and underpinnings. In the pasture of W. P. Kaiser the orbicular nature of this granite is best seen. Here the stone possesses good rift and grain and the quarring has been the most extensive. The spheroidal aggregations of the biotite and quartz prevents its commercial use in monumental and structural work. It has received many appellations. It was called by Hitchcock in his Geology of Vermont, pp. 363-365 "concretionary granite". It has likewise been termed "butternut granite" and "plum pudding stone" from the resemblance of the more basic aggregations to dried butternuts and the whole rock to a plum pudding. S. R. Hall on page 721 of the same report says "I regard the nodular granite as the greatest geological curiosity in New England."

Attention was later called to this granite by G. Hawes in 1878 in the Geology of New Hampshire by Hitchcock, by Chrusthov in 1885 and in 1894, by Forsterus in Finland in 1893, by C. H. Richardson in the Areal and Economic Geology of Northeastern Vermont im 1906, and by T. Nelson Dale in the Granite of Vermont pp. 94-95 in 1910, and by many others so that the literature is now voluminous. Before reading the conclusions of Forsterus as given by Dale for the orbicular granite the author

had concluded that the nodules represented the more basic segregations in the more basic part of the granite, and this particular granite was more basic than the other granites in eastern Vermont.

The uniform distribution of the nodules in this granite as well as the large number of these spheroidal aggregations can be seen in the plate in the authors report on the Areal and Economic Geology of Northeastern Vermont. In a block weighing approximately 400 pounds obtained for the museum at Syracuse University, a somewhat circular arrangement of these nodules themselves is very apparent. The cross section of the block shows these nodules in more or less of alignment as if there was a flowage of this more basic material.

Dale has cited a similar but somewhat different condition in the granite of Bethel, Vt., Ellis Quarry, Plate XXII, Granites of Vermont. The author of this article has seen a similar condition in the fine grained granite at Stanstead, Quebec, Northfield, Vt., and in the Dutton quarries in the eastern part of Craftsbury. In Irasburg he has found boulders well filled with nodules. This evidently came from the northern locality. But smaller boulders from Craftsbury have been found in several localities in both Orange and Washington Counties.

DIKES.

In the vicinity of Craftsbury Common there are several dikes. Two only of these are represented on the areal map. About 75 rods west of the Common there is a dike seven feet wide with strike north 40° east. It contains many crystals of hornblende. Some of these phenocrysts are long and acicular while others are short and stout.

The second dike represented on the map in the vicinity of the Common is fifteen feet wide with strike north 10° east. It bears no hornblende phenocrysts. It decomposes rapidly because of the oxidation of the iron content. Hitchcock cites three other dikes in the same vicinity with strikes as follows; north 9° west, north 10° west, north 20° west.

In the bed of Eligo Creek, where the road to East Craftsbury crosses it, there is another granite dike 10 feet wide with strike north 10° east. This dike is also represented on the areal map.

DIABASE.

The basic intrusives are confined to the western half of Craftsbury. Some of them are fairly fresh with a rind about one-fourth of inch in thickness. Others are more or less sheared and somewhat resemble the more highly altered sedimentaries. Three of these areas may be seen to the west of the road extending north and south on the west side of the Black River Valley. These areas are small in comparison with the great masses of diabase in the more northerly town in Orleans County. That is the amount of basic material cutting the Cambrian metamorphics has diminished continuously to the southward thruout the County. In the extreme northwestern and in the extreme southwestern corners of the township are two masses of this intrusive of little larger dimensions than those on the eastern slope of the sericite schist. A dike of diabase appears about one mile east of the west town line near where the road crosses Wild branch.

The larger outcrops of this area can well be utilized in the construction of permanent roads thruout the township.

AGE OF THE INTRUSIVES.

The intrusives of Orleans County as covered in this and the earlier reports are widely separated in age as are the great crustal movements that have affected the area involved.

The peridotite which is unquestionably the oldest of them all is definitely known to cut Cambrian terranes but nowhere does it cut the Ordovician.

The peridotites therefore could not have been introduced prior to the Cambrian sedimentaries which they cut, and as they do not appear anywhere in the Ordovician terranes they are regarded as being introduced at the close of the Cambrian.

Some of the granites like the gneissoid granite of Newport that cuts the Cambrian terranes is unlike in many respects the granites that were intruded into the Ordovician sedimentaries. This granite has been regarded as of the same age.

The granites that are important from a commercial standpoint have been regarded as introduced with the great crustal movement that occurred at the close of the Devonian. In the Province of Quebec they are known to cut Devonian strata. They therefore cannot be older than the Devonian. It is possible that these

granites are not all Devonian and that some of them are Carboniferous in point of age. Unfortunately for the establishment of this point there are no Carboniferous terranes in eastern Vermont. It was probably at the close of the Devonian that the earlier granites of Newport were rendered gneissoid. The Devonian granites soon after their crystallization were traversed by numerous pegmatite and aplite dikes.

The diabases are the youngest intrusives in the area. One mile east of North Troy the diabase cuts the serpentinous and steatitic masses, giving a clear zone of contact metamorphism on the western side of the exposure and brought up also an inclusion of steatite on the eastern side. It therefore cuts the oldest ultrabasic intrusive. As dikes of considerable proportion it appears cutting both upon the east and the west the broad belt of gneiss and gneissoid granite in both Newport and Coventry. It is therefore younger than the oldest acid intrusive. Still further to the east it is found cutting the Devonian granites. It is therefore younger than the most acid intrusive.

Many of the diabases that cut the Cambrian are sheared and closely resemble altered sedimentaries. The joint planes vary from a small fraction of an inch to only a few inches apart. The fracture on the freshly broken surface is dull, and the kaolinization of the plagioclse feldspars has been carried to a considerable depth. In Canada in certain areas the ferro-magnesian minerals have been metamorphosed into serpentine. These diabases certainly appear to be older than the dikes that cut the Devonian granites. Some of them may have been introduced as early as the close of the Cambrian.

The diabases that cut the Ordovician terranes and some that traverse the Cambrian schists show a perfectly fresh fracture and only a thin weathered surface. These are extremely tough and without definite rift or grain. These diabases have been regarded as introduced either at the time of the great crustal movement at the close of the Carboniferous or in Triassic time. Some of the smaller dikes at least appear to be as young as the Triassic.

ECONOMICS.

The economic products of the area involved may here receive a brief summary although their presence has been intimated from time to time in the general discussion.

The granite on the E. A. Dutton farm is well suited for monumental work. In the further development of the quarry now in operation it may be used for structural work. In fact out of the boulders of granite scattered over the township and in Greensboro to the east several houses have already been built. The granite quarry that has been opened on the farm of Robert Harper has already I understand been used for structural purposes to a limited extent but it can be largely used as underpinning and bridges. The orbicular granite at Craftsbury village on account of the many nodules it carries can best be used for underpinnings and bridge construction.

The basic intrusive diabase is best suited for the construction of permanent roads and there seems to be no reason why the town should not thus utilize this product.

The limestones have been burned locally for lime but on account of the high percentage of silica and the iron pyrite in the stone, the project was abandoned several years ago. The output has been used to some extent as a fertilizer and could be used to advantage in the western part of the township where the lime content of the soil is small or entirely wanting. The calcareous quartzite in Whetstone Brook gorge has been utilized for whetstones to some extent. As good a scythestone can be secured here as many of the stones in the marts of trade today. The stone with perfect rift and grain would be easy to manufacture.

About one mile south of the village of West Albany and in Craftsbury there has been some little talk of opening a marble quarry on property controlled by Peter Wells. Blocks of the stone with perfect rift can be secured of any length desired The stone is well suited for flagging purposes. It presents a smooth surface parallel with its bedding planes which does not gum when used as an abrasive. The author desires to do some laboratory work upon this material before his definition is permanently given to the rock. The value of all these possible products to the town is hampered by the distance from the railroad.

Traces of gold occur in many of the quartz veins traversing the area but none of them seem rich enough or extensive enough to forecast the development of gold mining industry in Craftsbury

PALEONTOLOGY.

True paleontological evidences of the age of the sedimentaries in Craftsbury the author admits is meagre. Yet certain facts have been brought to light from time to time bearing upon the problem that may be recapitulated here.

In October, 1897, the author made quite an extensive collection of the graptolites at Willard's Mills, Castle Brook, Magog, Quebec. This material has been donated in part to the museum at Dartmouth College and in part to the Richardson collection in the Museum at Syracuse University. Out of this material the author identified some fifteen species and named them in his report on the Terranes of Orange County, Vermont, 1902, in the annual report of the State Geologist. These slates are lithologically homogeneous with the various phases of the Memphremagog slates as they appear in Vermont. A little later graptolites were found by the author in the black slates on the east side of Lake Memphremagog in Canada. These slates pass under the lake and appear in Vermont as the Memphremagog slates.

Diligent search for fossils in the Memphremagog slates and shales south of the International boundary has not been rewarded with the first evidence of the discovery of organic matter suggestive of a graptolite. In the Canadian territory the planes of cleavage and of bedding largely coincide with each other while in Vermont the planes of bedding have been recorded at a low angle to the west while the planes of fissility are either at a high angle to the west or to the east. Under this condition the graptolites would not be so readily preserved.

In June, 1907, in the township of Coventry near the hill road leading from Newport to Barton Landing I made my discovery of crushed graptolites in the Waits River limestone. Many samples were collected showing these evidences of crushed graptolites lying parallel with the planes of cleavage and bedding of the limestone.

In June 1908, the second discovery of crushed graptolites in the Waits River limestone was made in Brownington some five miles further to the east than the locality of the first discovery. Their facial aspect is exactly identical with those in Coventry. Samples from these two localities were submitted to Prof. J. A. Dresser of the Canadian Geological Survey who wrote " Your graptolites will no doubt prove genuine." Several samples were also submitted to Mr. Perkins, a geologist and civil engineer of Canadian training who immediately recognized the crushed graptolites as an important and true diagnostic feature of the age.

For further confirmation in the summer of 1911 samples from both localities were submitted to Dr. Rudolph Ruedemann, State Paleontologist, Albany, N. Y., who wrote under date of September 20, 1911 as follows. "After carefully going over the material I agree with you that the carbonaceous films are quite probably crushed graptolites. I found this summer in my work about Schuylerville, exactly like blotches in the Snake Hill (Trenton) rocks. Your specimens appear to be a crushed Diplograptus or Climatograptus, and if this identification is right, the rocks are of Ordovician age."

It would seem therefore as tho the age of the Memphremagog slates and the upper members of the Waits River limestone could be stated with definiteness as Ordovician and specifically as Lower Trenton. With a depth of several thousand feet of the limestones and schists the lower members were laid down partly as calcareous sediments and partly free from lime much earlier in the Ordovician series than Lower Trenton.

The quest has been diligent for other forms that might tell the story of age. Hitchcock in his Geology of Vermont, 1861, cites many crinoidal stems in the Waits River limestone in Derby, Vt. In December, 1897, I found a well preserved crinoidal stem in the Waits River limestone in the marble quarries at Waits River. The stem was about one half inch in diameter and the block exhumed from ten feet below the surface.

Some suggestive material from Irasburg and Albany was sent to Dr. Ruedemann together with the graptolites and of these he writes: "The supposed Orthoceras lacks the septa, and the corals the septa and tabulae, and it would therefore be too hazardous to refer them to those classes. The supposed Orthoceras may be straight pieces of large worm borings or so-called fucoidal markings. Another specimen while suggesting a Colunnaria lacks the finer structure and may be of inorganic origin. From the appearance of the rocks it seems to me that better material may still be found."

Another day was spent this summer in quest of fossils in the same field but no better material was secured. It would only be by removing a considerable amount of the decomposed rock

and by the use of explosives that better specimens would be secured. In it all no fossil has been found to indicate that the limestones of the Black River Valley are other than Ordovician.

The evidences of Cambrian age of the metamorphic schists flanking the Ordovician terranes in two fold. The erosional unconformity between them and the lowest member of the Ordovician series with its boulders of pre-Ordovician intrusives and sedimentaries would establish the proof that these terranes were pre-Ordovician. The lithological similarity and continuity of these terranes into Canadian territory where Upper Cambrian fossils are found would establish the quartzites and sericites schists upon whose beds the Irasburg conglomerate was laid down as a true basal conglomerate, as Upper Cambrian.

THE TERRANES OF ALBANY, VERMONT.

C. H. Richardson and M. C. Collister, Syracuse University.

INTRODUCTION.

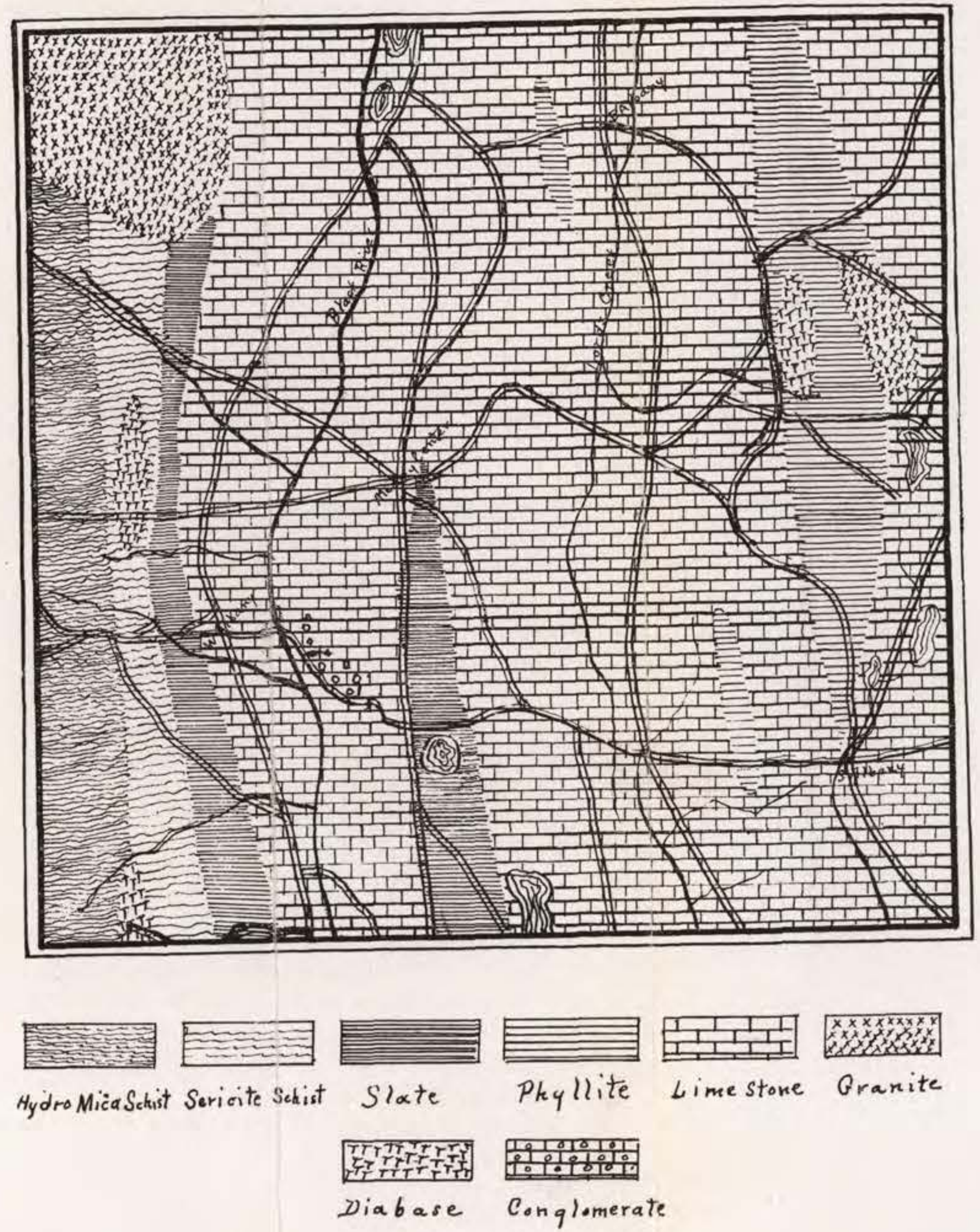
A detailed study of the structural and geological relations of both the sedimentary and igneous rocks in Albany was taken up by the above named authors conjointly during the summer of 1911. The primary reason for invading this field was that it lay about twenty miles south of the International Boundary, directly in the line of the erosional unconformity between the upper Cambrian and the Ordovician. Futhermore there existed hope that definite paleontological evidence of the age of these terranes could be found in the suggestive region at West Albany previously visited and studied by the first named author.

Several photographs were taken and some of the plates made from them are used to illustrate this article. Seventy-five rock samples were collected and carefully trimmed three by four inches for laboratory study and exhibition in the State Museum at Montpelier. Two maps will be found accompanying this report. One represents the stratigraphical relation of the terranes in the township involved and is drawn from east to west near the center of the town. The other is an areal map showing the distribution of the different terranes in the area covered as traced out in the field work in the limited time at our disposal.

TOPOGRAPHY.

The territory discussed in this article lies between parallels 70° 16′ and 70° 26′ west longitude and 44° 39′ and 44° 48′ north latitude. The township is a rectangle of a little more than six miles square and thus has an area of approximately forty square miles. The east and west boundaries lie at an angle of north 42° east of the magnetic meridian which is nearly parallel with the strike of the terranes.

The accompanying structural map shows, Plate LXIII, three lines of high altitude passing thru the township parallel with the strike of the rocks. Along the eastern side of these hills and often on the western there are many outcrops of slate and phyllite to whose superior hardness and resistance to erosion and solution the ridges owe their existence. The broad U-shaped



Geological Map of Albany.

valleys between these ridges are essentially in limestone, which by its greater ease of solution and abrasion, has been more rapidly removed from the area.

Plate LXIV represents a pot-hole several feet in diametre in the bed of the stream in the western belt of limestone. The broad U-shaped valleys of the area have an altitude of about 950 feet above the sea level while the slate and phyllite highlands sometimes reach an altitude of 2,000 feet.

GLACIATION.

The most of the territory covered by this paper lies under a great mantle of glacial drift. It was all ice covered and in a few sections but little morainal material remains. The eastern part of the town is especially rich in morainal debris. All the more resistant rocks show a line of striae in a southerly direction showing that one movement of the ice was nearly south. In some instances the direction of the ice movement was south 20° west, showing more than one advance of the great ice mantle. Many large boulders are scattered over the area that are foreign to the bed rock upon which they rest. Especially the eastern part of the township is literally covered with boulders of granite and diabase resting upon beds of Ordovician limestone. The angularity of their mass shows that they have not been transported for any considerable distance. In the following line of the ice movement it is easy to find their original habitat in the intrusive masses in Irasburg. Some of these boulders weigh hundreds of tons and consist of a good granite for structural purposes, in fact often used for underpinnings and bridges. Some boulders contain enough granite to construct an entire house.

A common report in the western part of the township was the existence in the forested area of asbestos bearing rocks. Upon examination these in all cases proved to be serpentine boulders from the peridotite lying to the northwest in Eden and Lowell. Nowhere in this town could an outcrop of peridotite be found. The presence of these boulders proves a southeasterly trend of the ice. This great ice mantle was responsible in part at least for the broad valleys between the high ridges and for the ponds existing in the southern and southeastern part of Albany.

DRAINAGE.

Albany lies near the height of land that traverses the State in this section in an east and west direction. The general flow of the water is north by northeast. The streams are all a part of the great St. Lawrence system and so empty into the northern Atlantic. The drainage southeast of this water shed is by means of the Connecticut River with its tributaries.

The main streams to be considered are the Black River, Lords Creek and a small tributary of the Barton River. These all flow into Lake Memphremagog. In the extreme eastern part of the township there is a pond covering several acres. The bed of this pond is in limestone. The present depression may have been caused in part by erosive action of the great ice sheet but in the main it was formed by a deposition of morainal material across the outlet of a pre-glacial valley. This pond which is fed largely by springs has its outlet to northeast in a small stream that empties into Barton River.

Lords Creek rises in the southern part of Albany. Its head waters are just south of the road between Albany Center and South Albany. It flows to the north cutting its way thru the limestone, enters Irasburg to the north and empties into Black River at Irasburg village. There are only a few tributaries to this stream hence the area drained by it is small.

Black River has its head waters in Eligo Pond in Craftsbury several miles south of the Albany line. This stream flows in a northerly direction thru Albany in the western limestone valley. A large portion of the township is drained by this river. On the east the Black River has a very interesting tributary which instead of flowing in a westerly direction or even in a northerly direction until it empties into the Black River flows in a southerly direction around the central belt of slate in Craftsbury and then changes its course to the northward. It furnishes an excellent illustration of how the resistance of a terrane to solution and corrasion determines the course of a stream.

In the eastern part of the township there are several small ponds all of which save the one previously mentioned have their outlets to the south. These tributaries finally empty into Black River. The streams are mostly sluggish and therefore worthless for water power. They are however used for the transportation of logs in the spring when the waters are high.

PLATE LXIV.

Pot Hole, Albany.

GEOLOGY.

The clastic terranes in Albany consist of two groups, the Cambrian and the Ordovician. The boundary line between the the two is about one mile east of the Lowell line. The intrusives in somewhat isolated areas are both acid and basic.

CAMBRIAN.

This series of schistose rocks are the oldest terranes in the township. They comprise a series of hydromica schists and sericite schists. The hydromica schist is the western most member in the township. It is dark in color, greasy to feel and studded with pyrite. The crystals however in Albany are neither as large nor as abundant as they are in the northern extension of this formation thru Irasburg and Troy.

The sericite schist is found in a belt scarcely one-half mile in width lying directly to the east of the hydromica schist. It extends the entire length of the township except the extreme northwestern corner where it is cut off by a large mass of granite in Albany and Irasburg.

On the last road leading to the west from the Black River valley in the northern part of the town, there is an interesting anticlinal valley cut in the Ordovician slate in the lower portion of the valley and in the sericite schist in its upper portion. Just west of the contact between the slate and the sericite schist the schist stand in the ravine with perpendicular walls rising about twenty-five feet in height. The high angle of dip, the perfect fissility of the schist and its sericitic nature can be seen to no better advantage anywhere in the township.

The fineness of the grains of silica however is not quite equal to those in the same formation near the village of North Troy where the rift and grain of the sericite suggest a slate.

ORDOVICIAN.

The Ordovician terranes comprise a group of rocks extending eastward across the township and consist of slates and limestones more or less interstratified with each other. Some of the beds are only a few inches in thickness while others are hundreds of feet across them. Some of these beds are now fissile enough for slate while others suffering more metamorphism are phyllite schists with scales or crystals of ottrellite set transverse to the planes of foliation. Where the limestones predominate over the phyllite the region is cataloged as limestone.

IRASBURG CONGLOMERATE.

The Irasburg conglomerate which lies at the base of the Ordovician is represented in Albany. Its best outcrop is found on the east side of Black River near the village of West Albany. Pebbles of quartzite and porphyrite ranging from a small fraction of an inch to nearly a foot in diameter are very abundant. Some of these are quite angular but the most of them are well rounded by the action of water. In fact the longer diameter is often many times the shorter as if they had been rolled back and forth on the shore of an ancient sea by wave action. Plate LXV shows some of these pebbles as they appear in the conglomerate. The pebbles are all pre-Ordovician while the matrix is limestone. Some pebbles were sericite schist. No pebbles of the slate that flanks the sericite on the east could be found. The conglomerate is badly crumpled and its strike varies widely. It has been traced a considerable distance to the northward towards Irasburg in the direction of the strike and then it disappears under the great mantle of glacial debris. It has been traced also to the southward where it disappears again for the same reason. That it represents the southern extension of the Irasburg conglomerate is proven by the fact that the pebbles are all pre-Ordovician and the matrix Ordovician. It differs from the outcrop at Irasburg in that it contains no boulders of granite or diabase in Albany. These intrusives in the Cambrian rocks may have been too far away from the shore line at this point to yield their fragments as material for the conglomerate.

This conglomerate bears many cavities, together with many fragments of crushed calcite, that are strikingly suggestive of fossils but nothing has yet been discovered sufficiently well preserved for positive identification.

WAITS RIVER LIMESTONE.

The larger part of the area discussed in this article is covered with limestone. The Waits River phase is best represented in

A. Irasburg Conglomerate, Albany.
White spot near center is a pebble of Cambrian quartzite.

B. Quartz Boulder in Conglomerate, Albany.

the northeastern corner of the township. Here is found a belt of light colored limestone which is uniform in texture and especially free from pyrite. In some instances the light and dark bands appear in the stone but the rock is not so distinctly banded as in Waits River, the locality from which it received its name. The strike of this terrane is nearly normal, north 20° east, but in the eastern part of the township near the central line the strike changes to north 50° east and so passes out of the township in question. The dip of the limestone is fairly uniform at an angle of 50° west.

The Washington phase of the Waits River limestone to the west of this belt just described but separated from it by a band of phyllite. The limestone is uniformly dark colored and compact. A considerable amount of silica enters into its composition. This does not prevent its cutting to a keen edge, but the presence of minute crystals of pyrite precludes its large economic application for structural work.

The strike varies from north 30° east to north 40° east and the dip from 60° west to 65° west.

The Coventry phase of the Waits River limestone lies to the west of the Washington phase and between the two western belts of slate. This terrane is marked by its abundance of cubes of pyrite. Several kilns have been constructed for the purpose of manufacturing white lime but the product was of inferior quality and gray in color and the project was quickly abandoned. The lime however, has been used to some extent as a fertilizer. It is of some value for the soil in the western part of the township that bears little or no lime content.

The strike varies from north 35° east to north 50° east and the dip from 55° to 80° west.

SLATE AND PHYLLITE.

The slates of this region are known as the Memphremagog slates, this name having been given to them by C. H. Richardson in his report on Newport, Troy and Coventry, published by the State Geologist 1907-1908.

There are three distinct belts of slate and phyllite traversing the township in a northeasterly direction. They represent the southern extension of the belts of slate so well defined in Newport and Coventry. Altho not widely separated from each other they differ widely in texture and degree of metamorphism.

The eastern belt traverses the eastern part of the township as indicated by the high altitude on the cross section at this point. It dies out near South Albany where the land becomes gently undulating and an excellent farming section. Here the soil is mostly limestone and very fertile.

The southern extension of this line of high altitudes passes out of Albany into Glover where it is cut by the acid intrusive, granite. This belt is more highly metamorphosed than the western members to which it is closely related. It is often crumpled and plumbagenous. Thin beds of limestone are interstratified with it. It does not weather uniformly and this differential weathering is illustrated by Plate LXVI.

Large veins of milky quartz are common in this terrane. The largest vein is located on a hill in the eastern part of the township where it serves as a capping for the hill and to which the hill in part owes its altitude. The smaller veins of quartz often extend into the limestones that flank the phyllite both upon the east and the west. In this same belt of phyllite in the eastern part of the township there appears to be an interesting thrust fault. The greatest amount of throw is near the main east and west road and is about twenty feet. It seems to die out gradually both to the north and to the south.

The strike of this belt of phyllite varies from north 20° east to north 40° east and the dip from 60° west to 70° west.

The middle belt of slate is separated from the eastern by the Washington phase of the Waits River limestone. The terrane does not appear in the extreme northern part of the township but it extends in a southerly direction into Craftsbury. On Chamberlain hill several patches of this slate appears metamorphosed into phyllite. In its southern extension it becomes more slaty in texture, often with the rift and grain of good roofing slate. This condition can be seen near the crest of the hill east of West Albany.

In Albany this belt contains small crystals of pyrite which would mar its market value provided its rift and grain were perfect. The strike of this belt varies from north 35° east to north 40° east and the dip from 65° west to 70° west.

The western belt of slate is separatedfrom the middle belt by the Coventry phase of the Waits River limestone. It flanks the sericite schist on the east and appears to be the youngest of the three belts of slate or phyllite. It is worthless in Albany so far

PLATE LXVI.

Differential Weathering of Phyllite Schist, Albany.

as the commercial side of the problem is concerned because of the many crystals of pyrite which it contains. It is not uncommon to find cubes one-half inch in diameter. These leave hexagonal holes in the slate upon oxidation. It splits into very thin slabs not more than three-sixteenths of an inch in thickness. Its surface is often reddish in color due to the oxidation of the iron content.

Its dip is uniformly 75° west save where it is associated with instrusives. The strike varies from north 45° east to north 60° east. In the northwestern part of the township this slate is traversed by a small V-shaped anticlinal valley. This valley is illustrated by Plate LXVII. The dip of the slate on the east side is 65° east and on the west side it is 80° west.

INTRUSIVES.

The intrusives in Albany are both acid and basic. They do not comprise as extensive areas as the similar intrusives in the northern townships yet they are worthy of mention in this article.

ACID INTRUSIVES.

The acid intrusives consist of granites and pegmatites. The best representative of the granite areas is found in the northwestern part of the township. It is a part of the same large area that extends into Irasburg on the north and Lowell on the west. It cuts the western belt of slate, the sericite schist and apparently the hydromica schist. It is a light colored granite with the prevailing feldspar orthoclase and biotite far in excess of the muscovite. Yet the biotite is not present in sufficient quantity to give the stone the hue of the dark Barre or Hardwick granite. It is apparently free from iron and but little sap appears in the lower part of the granite. The stone will split into slabs of any desired length and thickness. It would make a valuable monumental and structural stone were it not for its distance from the railroad.

Another granite intrusive appears in the eastern part of the township in close proximity to the Glover line. It is flanked on the one side by limestone and on the other by phyllite. The granite taken from the eastern side of this outcrop has been used to some extent for underpinning. The grout from these blocks of underpinning seems to discolor quite rapidly upon exposure to the atmosphere. The western side of this granite is valueless for it weathers to a considerable depth. About one mile east of the village of East Albany there appears a pegmatite dike about two feet in width and of unknown length.

BASIC INTRUSIVES.

The basic intrusives in the area involved consist of microcrystalline diabases. In some instances however phenocrysts of hornblende or augite may appear. A diabase area of considerable extent is found in the sericite schist directly west of Albany Center. This rock is green in color, extremely tough, and without rift or grain whereby it might be quarried easily. It could be used to good advantage in the manufacture of permanent roads.

In this same belt of sericite near the town line of Craftsbury there appears another outcrop of diabase, the area of which is not so large as the one mentioned above. Several other outcrops no doubt could be found in the wooded portion of this western belt of metamorphics.

Only one small outcrop of diabase was found associated with the limestones and phyllites. This is found in the eastern part of the township on the west side of the eastern belt of phyllite.

PALEONTOLOGY.

The paleontological evidence in this territory up to the present time is very meagre. B. K. Emerson of Amherst College says that many cavities in this region are suggestive of fossils, but up to the present time nothing has been found that has been preserved sufficiently to warrant its classification. A diligent search for fossils was made by the authors of this article in the area that appears to be the most promising in the cut near the saw mill at West Albany. A considerable amount of material was collected for laboratory examination but nothing could be identified with absolute certainty. The evidences are suggestive of an orthoceras, corals and crinoidal stems. It is hoped as more of this limestone is removed for road material or other purposes less decomposed areas will be made available for examination and that here type fossils will be discovered.

The crushed graptolites discovered by the first named author of this article, and later recognized by J. A. Dresser of the Canadian

PLATE LXVII.

Anticlinal Valley, Albany.

Geological Survey and still later by Dr. Rudolph Ruedemann, State Paleontologist of New York, proves substantially that the limestones are Lower Trenton in their upper beds. The southern extension of the graptolitic slates of Canada into Albany places the Memphremagog slates with definiteness as Lower Trenton.

The western terranes while devoid of fossil content have been traced continuously into Canada where they are recognized as Upper Cambrian.

The granites were introduced with the Devonian Revolution for they cut Devonian terranes in Canada. Some of the diabases at least belong to a later period for they cut the granites in certain localities and may have been as late as the Triassic.

ECONOMICS.

The economic possibilities of the terranes in Albany are limited on account of distance from the Boston and Maine railroad. Should a branch road ever connect Newport on the north with Hardwick on the south it would enhance the value of several possible products.

The granite in the northwestern part of the town is a part of the same outcrop that appears so extensively in Irasburg and on the eastern side of Lowell mountain. This light gray granite, with perfect rift and grain, with freedom from iron, and therefore weathering well, should ultimately become a source of income to the town. The granite in the eastern part of the town used locally for underpinning has not so promising a future on account of the rapidity of discoloration on exposure to the atmosphere and the depth to which the sap seems to extend in the stone.

The trap rocks of the western belt of metamorphics would make most valuable material for permanent roads on account of its resistance to abrasion and its cementing qualities. The difficulty with which the stone would be quarried would render it undesirable for structural work.

The limestones find their field as underpinning for houses and barns. They are not sufficiently pure or free from iron for the ordinary uses of limestones. They have however to some extent, in a project abandoned, been burned for their lime content but this product will remain unsatisfactory unless it be for lime for the soil in the noncalcareous areas.

The slates are not sufficiently fissile and free from cubes of pyrite for roofing slate save here and there in isolated patches. A small area of this higher quality exists in the western belt of slate and another in the central belt east of West Albany.

Gold has been sought for in the white and pyritiferous quartz veins traversing the limestones and the slates but never found in commercial quantity.

PARTIAL ANALYSES.

There has been some doubt as to the history of the three belts of limestone extending thru the township of Albany. Their position makes it a little uncertain whether these terranes represent different phases of the Waits River limestone or whether they were laid down as three distinct belts in different periods in the Ordovician sea.

The authors have attempted to throw some light upon the problem thru a knowledge of the magnesium content. No complete analyses were made but the calcium carbonate and the magnesium carbonate were determined that the dolomitic character might be ascertained. The methods utilized in the analyses were those suggested by Dr. W. F. Hillebrand, Chemist of the U. S. Geological Survey, in his work on Rock Analyses. This is only a beginning of the analytical work and the data from six analyses is too meager to draw a conclusion.

The following data shows the result of the investigation. Each set represents the average of two analyses made from carefully selected samples.

Waits River Phase.

Calcium carbonate,	48.93%
Magnesium carbonate,	3.68%
Total carbonates,	52.61%

Washington Phase.

Calcium carbonate,	39.20%
Magnesium carbonate,	23.52%
Total carbonates,	62.72%

Coventry Phase.

Calcium carbonate,	29.98%
Magnesium carbonate,	5.40%
Total carbonates,	35.38%

In these results any iron that might appear as a carbonate is not considered. The limestones differ widely in magnesium content.

SUMMARY.

The authors of this article made a detailed study of the terranes of Albany in the summer of 1911; (1) mapped more accurately than has been done heretofore the underlying strata; (2) shown the stratigraphic relation of the terranes to each other; (3) proved that the three belts of Memphremagog slate appearing in Newport are not continuous thru Albany; (4) proved the Irasburg conglomerate at the base of the Ordovician to outcrop as a conglomerate for a considerable distance near the village of West Albany: (5) given the paleontological evidence of these terranes so far as it is known; (6) proved an erosional unconformity between the latest Cambrian and the earliest Ordovician; (7) shown the economic possibilities of the mineral products.

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HIGH TENSION TESTING OF VERMONT SLATE AND MARBLE.*

Introduction.

WYMAN A. BRISTOL.

The object of this thesis is to investigate as carefully as is practicable the value of Vermont State Marble and Slate for Switch Board purposes. It has been found very difficult to obtain great accuracy because of the variability of the materials, the difficulty in controlling the conditions of tests, and the natural unreliability of measuring instruments on high tension circuits.

Although different investigators obtain widely varying results, it has been my aim so far as possible to get data that will show the relative properties of all pieces tested, and to obtain all data under such conditions as to be of real value in the design and construction of marble or slate switchboards.

The following statements herein represent the actual experience of the writer and have been obtained on slabs of sufficient size to warrant their reliability in application to commercial practice.

Also it may be well to state that in this investigation no attempt has been made to cover the varying affects of different conditions of test, such as forms of electrodes, mediums surrounding test pieces, etc.; but to make tests under normal working conditions.

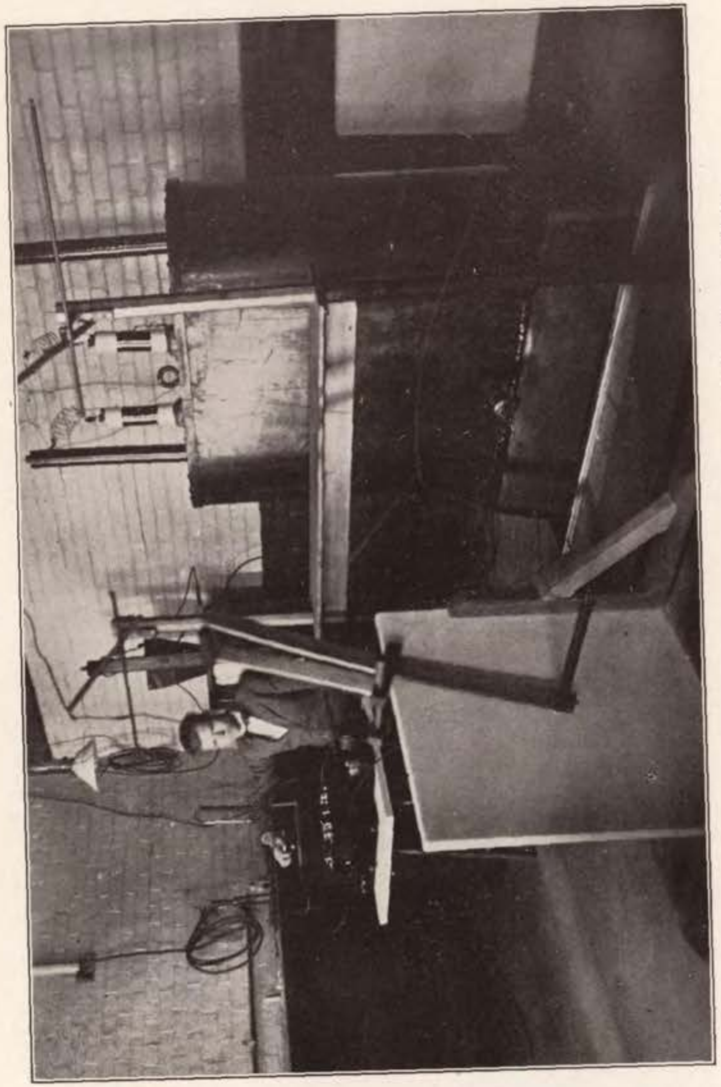
Tests.

The tests under consideration are those for the determination of

1. Ultimate dielective strength.
2. Arcing voltage.
3. Dielective hysteresis.

*Thesis submitted for the degree of Bachelor ot Science in Electrical Engineering. University of Vermont, June, 1912.

PLATE LXVIII.



Apparatus Used in Making High Tension Tests of Marble and Slate.

TESTING APPARATUS.

The principle elements to consider under this head are
1. Source of Power.
2. High Tension Transformer.
3. Controlling Apparatus.
4. Measuring Apparatus.

Source of Power. Since it is essential to use a normal sine wave of constant form and frequency, the writer found it advisable to use the power directly from the main power station which furnishes the laboratory in which the tests were carried on. This was found to be entirely satisfactory, since the wave shape was of the proper sinusoidal form, and the frequency was maintained constant at 60 cycles.

The Transformer. The transformer used was one of 10 K. W. capacity 220—100,000 volts. This transformer was designed and constructed by Walter Belding, Geo. Landry and Geo. A. Meigs for Thesis in the spring of 1911. For description and data of same, see above named Thesis in Elec. Eng. library University of Vermont.

In order to relieve the extreme stress and static induction, the middle point of the high tension side of the transformer was carefully grounded.

Controlling Apparatus. For protecting all measuring instruments against excessive current due to any sudden short circuit or dynamic arc, a grid resistance of about 12 ohms was placed in series with the primary coil. This was found sufficient to lower the puncture voltage to a value such that the current remained under a safe working value.

Also in series with the primary was place a variable resistance which gave splendid control over the initial voltage, for all values above 50 volts. For voltages below 50 volts a coil was short circuited across the line, and the primary voltage tapped off by means of a slider, giving any desired voltage from 1-110, while working with 110 as a maximum.

During the large part of the tests on marble, this latter coil was disconnected by throwing switch D (see diag. of connections) over to the left and entire control of voltage was obtained with a large rheostat E in series with the primary coil. The varying rheostat steps were sufficient to give any desired voltage from 110-270.

The main switch block H contained a fuse to further safeguard all apparatus against an excessive current. The switch was normally held open by a stiff spring to guard against any accidental closing, when unexpected.

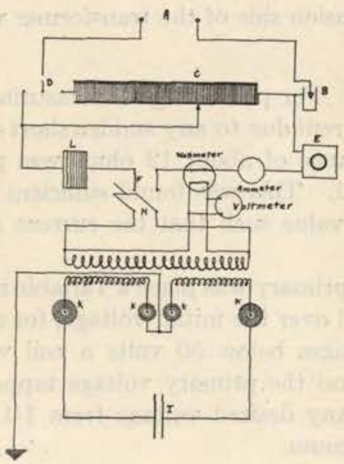
Measuring Apparatus.

Obviously the most important measurement during test, was that of voltage; consequently, great care and study was given to the obtaining of means such that the secondary voltage could be very accurately known. The transformer, Plate LXVIII in use had a test coil which was designed for indicating in constant ratio, the potential at any instant across the terminals of the secondary.

Diagram.

Fig. 2.

Showing arrangement of apparatus used in high tension tests.



A Source of Power 110, 220 or 500 volts as desired.
B Water Tank Rheostat.
C Voltage Regulator, Drop method.
D Double Throw Switch.
E Regulating Rheostat.
F Fuse on Switch Block.
H Main Switch.
I Test Piece.
K Trans. Secondary Terminals.
L Grid Resistances.

First, the ratio between the primary coil and the exploring coil was carefully determined by plotting the simultaneous values indicated by one against those of the other. This gave a straight

Plate LXIX.

Apparatus Arranged for High Tension Tests of Marble and Slate.

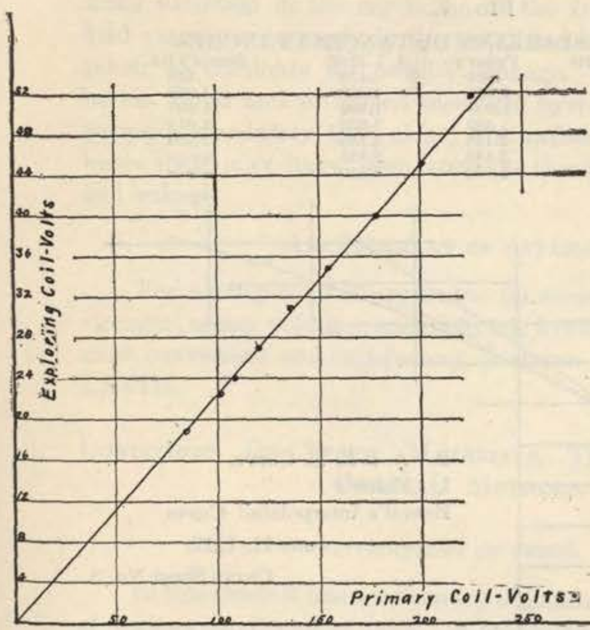
line curve the equation of which is y — 4.47x; y being the voltage across the primary. See Curve Sheet No. 1. Figure 3.

Then the matter of obtaining the ratio between the primary and secondary voltages was undertaken in the following manner.

Reference was made here to the A. I. E. E. standard spark gap voltages and also to the results of Fisher's investigations as found in references mentioned under head of Bibliography.

Since Mr. Fisher's curve of voltage versus spark gap distances in air, cross the A. I. E. E. curve at the point corresponding to a spark gap distance of 1.3 inches; he recommends that, for relative comparison and the rating of any high tension transformer, the exploring coil voltage be carefully found, which corresponds to the voltage across the secondary terminals necessary to cause a spark between the points of sharp needles No. 12, when placed 1.3 inches apart.

This was done many times under various conditions of atmosphere, using new needles for each test. The primary voltage was measured in place of the exploring coil, since they have a straight line ratio; and on account of obtaining greater accuracy due to the larger readings.



CURVE OF PRIMARY VOLTAGE
versus
EXPLORING COIL VOLTAGE
June 8, 1912.

TABLE No. 1.

Exp. Coil.	Prim. C.
19.0	85
22.5	101.5
24.0	109.0
27.0	120.5
31.0	136.5
34.8	154.0
40.0	178.0
43.6	194.0
45.0	200.0
51.8	225.0

Curve Sheet No. 1

Voltages were also measured corresponding to spark gap distances of one inch and two inches. The following table shows the average results of the readings taken.

TABLE No. 2a.

Average Volts across Primary	Sparking Distances in Inches R. J. Robert's Needles No. 12 Sharps
50.0	1.00
63.5	1.30
90.0	2.00

According to the advice of Fisher, the secondary voltage required to cause a spark of 1.3 inches was assumed to be 25,000 volts.

The ratio between primary and secondary is therefore

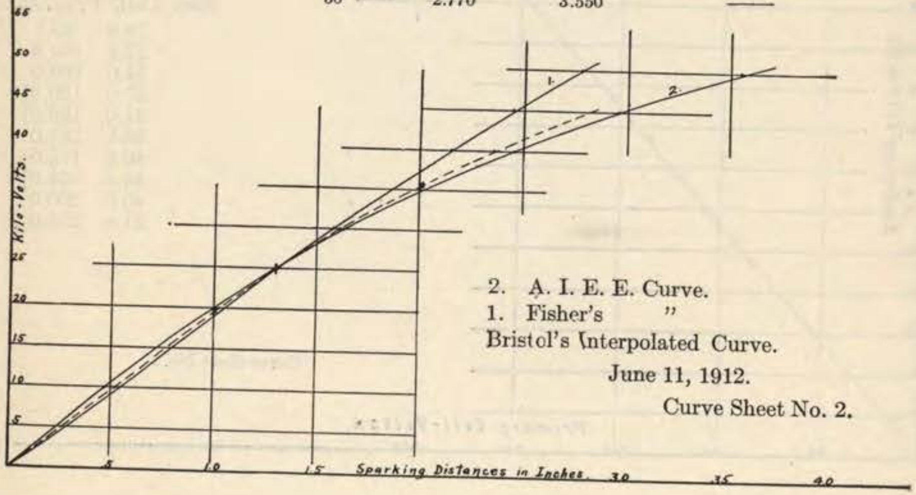
$$25{,}000 \div 63.5 = 394.$$

This ratio was then multiplied by the primary voltages 50, and 90, corresponding to spark gap distances of 1.00 and 2.00 inches respectively, and these values plotted along with the curves of Fisher and the A. I. E. E., for the purpose of comparison. The curve drawn through these points, gives Bristol's Interpolated Curve as labelled on Curve Sheet No. 2. Figure 4.

FIG. 4.

TABLE No. 2b. SPARKING DISTANCES IN INCHES.

Kilo-Volts	Fisher's	A. I. E. E.	Bristol's Int.
10	.540	.470	.525
20	1.040	1.000	1.025
25	1.300	1.300	1.300
30	1.580	1.625	1.612
40	2.140	2.450	2.350
45	2,440	2.950	——
50	2.770	3.550	——



INSTRUMENTS USED.

Ammeters—

Scale 1 Ammeter.	Weston	No. 5508
Scale 5 Ammeter.	Weston	No. 4465
Scale 15 Ammeter.	Weston	No. 4798

Voltmeters—

Scale 65	Thompson	No. 5508
Scale 150	Weston	No. 5316
Scale 300	Thompson	No. 132089

Wattmeter—

Scale 500	Weston	No. 229021

For voltages above 150 Multiplier No. 11625 was used. Ratio 3.8.

MEASUREMENT OF DIELECTRIC HYSTERESIS OR ENERGY LOSS.

To get the energy loss of any given reading, the watt loss at open circuit for the corresponding voltage was subtracted from the watt loss in the reading under consideration.

The justification for this was on account of the extremely small variation in the regulation of the transformer under such load variations as apply in the tests; and because great care was taken to eliminate all possible leakage. The value, however, herein found and so named dielectric hysteresis, is not intended to mean absolutely that alone, but rather includes what other losses there may have been, such as those due static discharges and leakage.

ARRANGEMENT OF APPARATUS.

The arrangement of apparatus for measurements of dielectric strength, arcing voltages, and dielectric hysteresis which was found most convenient and satisfactory, is shown in Figure 2 and Plate LXVIII.

CONDITIONS OF TESTS, MATERIALS, TESTING DEVICES AND GENERAL METHODS.

CONDITIONS OF TESTS.

In this thesis it has not been my object to investigate the effect of various conditions of tests; as mentioned in the introduction.

Therefore all tests have been made in the most normal of working conditions under which finished switch boards are used. The slabs previous to tests were allowed to stand in the testing room after having been warmed and dried beside a large furnace for a number of weeks. Just before tests they were carefully ducted and inspected for varitions in color, for defects such as evidences of mineral matter, and checks.

MATERIALS.

The marble shipment contained 14 slabs 2 ft. x 2 ft. x 1 in. Seven were white and seven were blue. One white and one blue had one side and the edges polished.

The unpolished white marble slabs were numbered W-1, W-2, etc., and the unpolished blue slabs were numbered B-1, B-2, etc.

For history of test pieces see statement at back of this thesis.

TESTING DEVICES.

As to the testing devices, the writer wishes to call attention to the form of electrodes and method of holding them in position. Plate LXIX. The electrodes were turned out of brass to a diameter of 0.785 inches so as to give an area approximately at least, of one square inch. The edges were slightly rounded, and the whole polished with emery cloth and finally with plain cloth and chalk.

The device for holding the electrodes was about two feet in length, so as to make it possible to easily place them at any desired position, on the slab under test. By means of a vise, the electrodes were held against the test piece with such force as to hold them firmly in place. The flexibility of the arms holding the electrodes with respect to the frame, allowed the electrodes to lie flat against the surface of the test piece.

Since the conditions of the tests were so nearly absolutely the same throughout all the tests, the results are relative to one another and do therefore show comparison between the several samples under consideration.

GENERAL METHODS.

Test for Dielectric Strength.

In running tests for dielectric strength, three methods were used.

1. Instantaneous Tests. Voltage was applied at about one-half the puncture voltage and slowly and steadily raised until puncture occured. Only a few of these tests were taken as will be seen by referring to the data of observations, and are not especially significant. There was difficulty in almost every case attempted, in getting a test of this kind, since the voltage necessary to cause immediate puncture, generally caused arcing over, even with electrodes at the center of the slab.

2. One Minute Tests. In these tests, the voltage was brought quickly up to about 75 per cent of the puncture voltage and held constant for one minute; then increased slowly by a small percentage, again held constant for one minute, and so on till puncture occured. The aim was to regulate the rise in voltage so as to continue the test about five minutes.

3. Time Tests. Beginning with the puncture voltage for the instantaneous test, successive tests were made at decreasing voltages, each being maintained constant until puncture occurred.

These were continued on each slab as far as was found desirable, and it is from these that we get the best and most substantial data with regard to the marble. It was during these tests that the heating effect was so conspicuous, as is further mentioned in explanations of the tables taken during tests on white marble.

TEST FOR ARCING VOLTAGE.

In these tests the same electrodes were placed at various distances from the edge, and the voltage gradually and continuously raised until arcing over occurred.

TEST FOR DIELECTRIC HYSTERESIS OR ENERGY LOSS.

This was obtained by reading the watt meter in conjunction with the other tests, particularly time tests. During time tests all instruments were read every minute and during the shorter tests every half minute and some even as often as every 20 seconds.

The behavior of dielectric hysteresis is discussed later with respect to both white and blue marble and also slate.

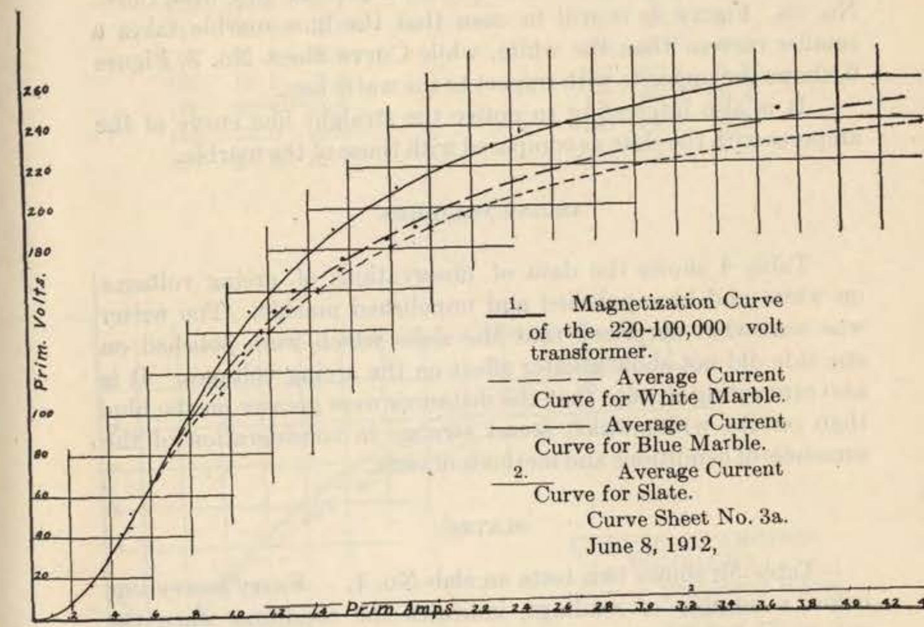
RESULTS OF TESTS AND EXPLANATION OF TABLES AND CURVES.

Table 3 gives the data for the magnetization curve and the Watts loss on open circuit with secondary wires disconnected from the electrodes. It gives the same readings with respect to the one inch slabs of white and blue marble, and also the amperes versus volts on the inch slate. All readings pertain to the primary circuit and the values of current and watts for marble and slate, are the averages of a large number of readings. The marble values are the averages of all available readings taken. The curves numbered 4 and 5 on Curve Sheet No 3b, Figure 6 shows the energy loss; the data of which was found by the method stated on page 7.

TABLE NO. 3.

OPEN CIRCUIT			WHITE MARBLE			BLUE MARBLE			SLATE	
Volts	Amps.	Watts.	Volts	Amps.	Watts.	Volts	Amps.	Watts.	Volts	Amps.
2.4	0.1	......	......	....	....	....	....	....	1.6	0.4
7.1	0.2	......	......	....	....	....	....	....	3.2	0.7
16.3	0.3	......	......	....	....	....	....	....	5.1	1.4
32.9	0.4	......	......	....	....	....	....	....	6.1	2.0
51.9	0.5	......	......	....	....	....	....	....	7.5	2.7
67.5	0.6	......	......	....	....	....	....	....	9.3	4.1
83.0	0.7	......	......	....	....	....	....	....	10.5	4..
98.0	0.08	......	130.	1.07	1.48	....	....	....	....	..7
128.0	0.95	......	140.	1.16	1.56	....	1.20	1.76	....	...
150.0	1.10	152.	150.	1.29	1.89	....	1.22	1.94	....	...
170.0	1.29	200.	160.	1.44	2.18	....	1.42	2.32	....	...
180.0	1.38	220.	170.	1.55	2.44	....	1.55	2.58	....	...
190.0	1.52	239.	175.	....	....	....	1.56	2.68	....	...
200.0	1.69	262.	180.	1.80	2.96	....	....	....	....	...
210.0	1.83	289.	185.	....	....	....	1.78	3.12	....	...
220.0	2.03	315.	190.	2.00	3.38	....	1.92	3.38	....	...
230.0	2.30	342.	200.	2.55	....	....	....	....	....	...
240.0	2.68	376.	238.	4.40	....	....	....	....	....	...
250.0	2.93	......	246.	....	....	....	3. 7	7.22	....	...
254.0	3.30	......	......	....	....	....	....	....	....	...

FIG. 5



1. Magnetization Curve of the 220-100,000 volt transformer.

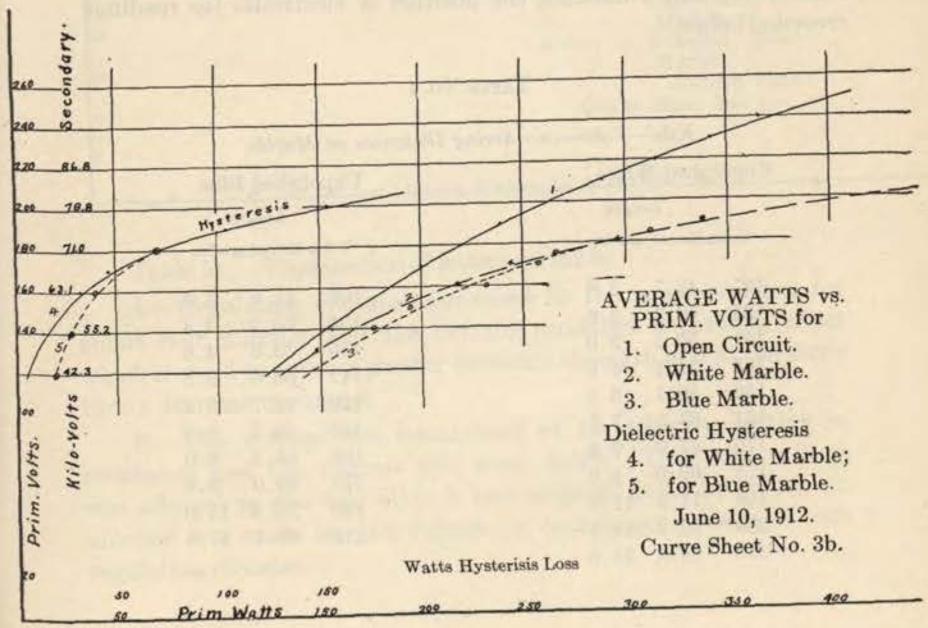
— — Average Current Curve for White Marble.

—— Average Current Curve for Blue Marble.

2. Average Current Curve for Slate.

Curve Sheet No. 3a.
June 8, 1912,

FIG. 6.



AVERAGE WATTS vs. PRIM. VOLTS for

1. Open Circuit.
2. White Marble.
3. Blue Marble.

Dielectric Hysteresis

4. for White Marble;
5. for Blue Marble.

June 10, 1912.
Curve Sheet No. 3b.

It is significant to notice that the power factor is quite different on blue and white marble. By reference to Curve Sheet No. 3a, Figure 5, it will be seen that the blue marble takes a smaller current than the white, while Curve Sheet No. 3, Figure 6, shows the opposite with respect to the watts loss.

It is also interesting to notice the straight line curve of the amperes with the slate as compared with those of the marble.

ARCING VOLTAGES.

Table 4 shows the data of observations of arcing voltages on white and blue polished and unpolished marble. The writer was somewhat surprised that the slabs which were polished on one side did not show greater effect on the arcing voltages. It is also interesting to note that the distances were greater on the blue than on the white which seems strange in consideration of the sameness of conditions and methods of tests.

SLATES.

Table 5b shows two tests on slab No. 1. Every heavy line below a number of readings, indicates the condition when the voltage suddenly dropped and the current suddenly went up. Numbers 1 and 2 indicate the position of electrodes for readings recorded below.

TABLE NO. 4.

Kilo—Volts—vs—Arcing Distances on Marble.

Unpolished White			Unpolished Blue		
		Length			Length
Volts	Kv.	of arc-In.	Volts	Kv.	of arc-In.
107	42.7	2.8	106	41.8	3.0
125	49.3	3.6	135	53.2	4.4
141	55.5	5.0	136	53.6	4.6
145	57.1	5.9	142	56.0	5.5
150	59.1	6.5	149	58.7	5.4
161	63.5	7.7	163	64.3	8.3
170	67.0	9.4	166	65.4	8.0
175	69.0	9.9	175	69.0	9.8
196	77.2	11.1	190	74.9	11.6
234	92.2	18.2	216	85.1	17.3
250	98.5	25.0	....	....	....

Polished White			Polished Blue		
118	46.5	3.1	110	43.4	3.3
144	51.8	4.6	126	49.7	4.2
155	61.1	6.0	149	58.7	6.3
168	66.2	7.4	157	61.9	8.8
181	70.4	9.3	177	69.8	10.3
198	78.0	12.0	190	74.9	12.6
206	81.2	15.0	....	....	....

FIG. 7.

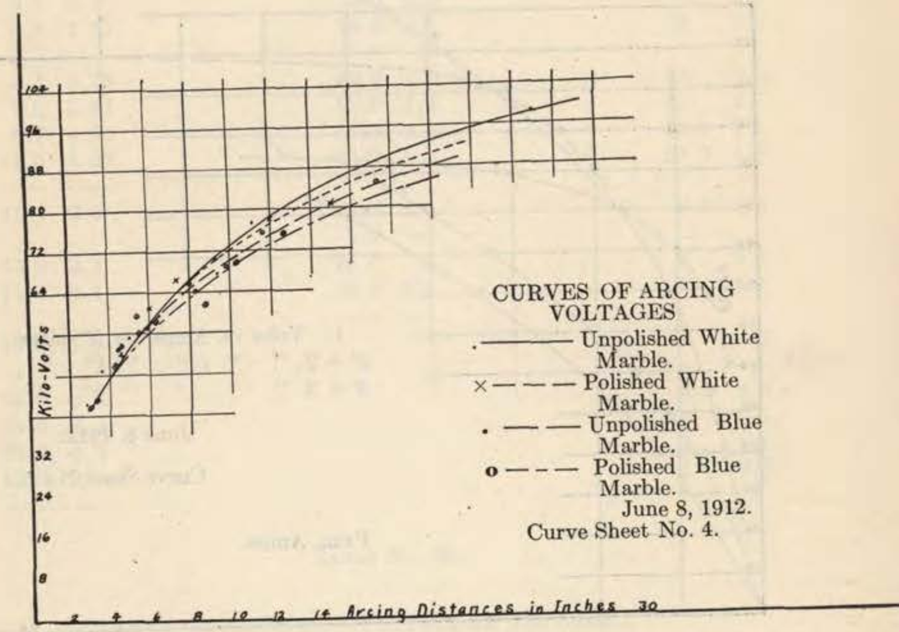


Table 5b. Explanation of letters on table.

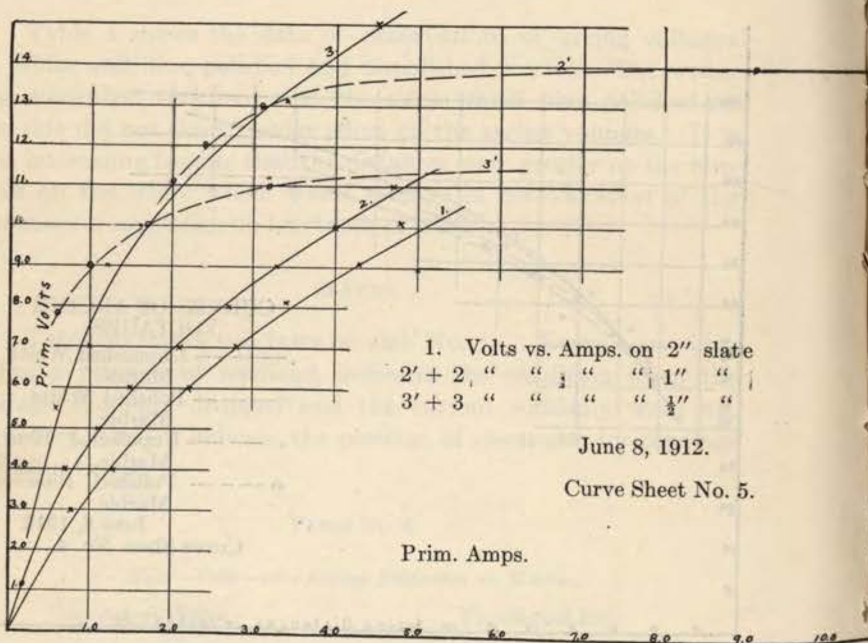
A—Regulating rheostat remained in the same position for about four minutes and the current produced a cooking effect which seemed to cause a greater dielectric strength and at the same time a decrease in current.

B—The voltage was maintained at 15 volts by cutting in resistance and the current still went down. Then the voltage was allowed to rise and after it had stopped going up at 20, an attempt was made to raise voltage by cutting out resistance with regulating rheostat.

All that needs explanation on Curve Sheet No. 5, Figure 8, is that the curves 2′ and 3′ represent the behavior of tests on second runs, with electrodes in the same position; taken immediately after a sudden drop in voltage.

It is interesting to notice the increase in dielectric strength, and the increased acceleration of current on breaking down, during the second tests, as compared with the first.

FIG. 8.



WHITE MARBLE.

Table 6 contains the data taken on the three slabs of white marble; which were tested namely W-1, W-2, and W-4.

A—refers to a test which was run over a place unusually free from any discoloration and therefore exceptionally white.

B—had the appearance of being still whiter than that of A, and also was exceedingly white over a large area surrounding the electrodes on either side.

The letter P indicates puncture.

TABLE No. 5A.

Observations on Slate Slab No. 1. Thickness—1.03 inches.

No. 1. Prim. Volts.	Amps.	No. 1. Prim. Volts.	Amps.	No. 2. Prims Volts	Amp.
1.6	0.4	22.5	1.0	4	0.7
2.5	0.7	23.0	1.6	5	1.1
3.4	1.0	23.5	2.0	6	1.5
4.2	1.3	19.5	0.2	7	2.1
5.3	2.0	25.0	3.0	8	2.7
6.4	2.65	28.0	4.4	9	3.3
7.1	2.73	30.5	1.0	10	4.0
7.8	3.65	32.0	1.5	11	4.7
8.7	4.30	33.0	4.5	10.5	5.1
11.0	4.60	30.0	1.0	10.0	4.8
11.1	2.0	34.5	Up	9.1	4.3
13.0	3.1	26.0	.5	8	3.7
14.0	9.1	34.0	Up	7	3.1
15.0	15.0			6	2.5
21.0	< 1			5	2.0
24.0	< 1			4	1.5
26.0	< 1			3	1.1
15.0	10			2	0.7

TABLE No. 5B.

Observations on Slate Slab, No. 2, Thickness 0.54 inches.

No. 1. Prim. Volts.	Amps.	No. 2. Prim Volts.	Amps.	Also on Slate Slab No.3 Thickness 2″. Prim. Volts.	Amps.
7.8	0.6	5.5	0.6	3	.8
9.0	1.0	7.0	1.0	4	1.3
10.0	1.7	9.0	1.2	5	1.7
11.0	3.2	10.0	1.6	6	2.2
12.0	up	11.0	1.9	7	2.8
13.0	0.6	12.0	2.4	8.1	3.4
14.0	0.6	13.1	3.4	9.0	4.1

15.0	0.7	14.0	4.0	A10.1	4.8
13.0	0.5	15	4.5	10.0	4.4
14.0	1.0			12.0	4.3
15.0	1.2			13.0	425
16.0	1.3			B15.0	4.22
17.0	1.7			15	2.6
27.0	up			15	1.5
10.0	6.9			18	2.2
17.0	3.0			20	3.0
22.0	1.7			20	2.0
34.0	1.4			C 20	1.0
33.5	1.0			20	1.6
27.5	0.5			20	2.2
34.0	2.0			10	5.0
10.0	6.9				

C—indicates a position where the electrodes were over a streak in the marble which contained dark colored foreign matter.

COOKING EFFECT ON WHITE MARBLE.

D—During test labelled D, there was a remarkable heating effect. A mottled glow area formed around the electrode about two inches in diameter and the corona was much less in evidence. This cooking effect, which is thought to be due to moisture, caused a greater dielectric strength, as was the case with the slate. The effect was, however, much less pronounced. During the process of the test, the glow area at first grew until it had a diameter of about three inches. Then the area grew less and the current increased for a short time previous to puncture. This was an exceptional case, and showed to a marked degree the cooking effect on white marble; which was much in evidence during all white marble tests. Even the instantaneous tests, showed the glow area and mottling effect for a few seconds previous to puncture.

W-1 was a remarkably strong piece with reference to its dielectric qualities. This is seen from the fact that it stood up under the highest of all tests, namely, 104 K. V. for thirty seconds. This showed the strength of the piece, while the next test shows quite as remarkably, its wonderful toughness. It was noticed that before puncture occurred, there seemed to be a general breaking down all over the whole area of the slab. This showed itself in the growing brilliancy, of a very large number of fine points to which the ends of the brush discharge directed themselves. The truth of the general breaking down over the whole slab was perfectly shown by the tests which followed. Even as low as 60 K. V. would cause an almost instant puncture and every test following the second, showed distinctly the fine points where the dielectric strength had been broken down.

TABLE No. 6.

Observations on White Marble.

No. W-4 Thickness—0".96. Prim. Volts	Secondary kilo-volts	Time Puncture in Min.	No. W-3 Thickness—1."00. Prim. Volts	Secondary kilo-volts	Time Puncture in Min.	No. W-1 Thickness-0".95. Secondary kilo-volts	Time Puncture in. Min.
238	93.8	1.5	258	101.7	0.2	104.0	0.5
194	76.5	2.5	190	74.9	2.5	78.8	9.0
180	71.0	3.8	170	67.0	3.3	A67.0	2.0
170	67.0	4.4	160	63.1	3.5	65.1	0.3
165	65.1	5.3	150	59.1	4.9	63.1	0.4
160	63.1	7.5	150	59.1	3.0C		
160	63.1	5.7	140	55.2	8.3		
156	61.5	4.0	135	53.2	9.0D		
155	61.1	10.0A	130	51.3	10.0		
154	60.7	15.7B					
150	59.1	6.0					

Minute Tests Secondary kilo-volts	Time in Sec.	Prim. Amps.	Minute Tests Secondary kilo-volts	Time in Sec.	Prim. Amps.	Minute Tests Secondary kilo-volts	Time in Sec.	Prim. Amps.
71.0	0	....	70.1	0	1.75	59.1	0	1.35
74.9	60	2.12	74.9	60	2.05	63.1	60	1.60
78.9	120	2.85	78.8	120	2.55	67.0	120	1.92
78.9	145	Puncture	78.8	140	Puncture	67.0	166	2.50
67.0	0	1.56						
70.2	60	1.72						

			Dielectric Hysteresis vs. Time on W-1 at 67.0 kv. (a) Prim. Amps	Prim. Watts	Hys. Watts	Time
73.4	120	1.98				
76.5	180	....				
76.5	205	Puncture	1.7	24.5	43	0
59.1	0	1.21	1.72	24.9	47	20″
62.3	60	1.31	1.73	29.3	91	40″
65.5	120	1.44	1.78	29.7	95	60″
68.6	180	....	1.85	30.8	106	80″
72.5	240	1.80	1.87	32.7	125	100″
75.7	300	2.05	2.15	41.7	215	120″
75.7	350	Puncture				

POLISHED MARBLE.

It is plainly evident from the results of the tests on polished marble, that the blue is far better for insulation purposes, than the white. Notice the increased starting amperes on the white as well as the greater dielectric strength of the blue.

TABLE No. 7A.

Observations on Blue Marble.

No.B-6 Thickness-1″06 — Dielectric Hysteresis vs. Time on B-6 at 6.90 ku.

Prim. Volts	Secondary Puncture kilo-volts	Time in Min.	Prim. Amps.	Prim. Watts	Hys. Watts	Time in Min.
246	92.0	0.5	1.56	266	55	0
210	82.8	1.0	1.55	262	51	.5
190	74.9	3.2	1.55	266	55	1.0
175	69.0	6.0	1.55	266	55	1.5
170	67.0	4.5	1.57	266	59	2.0
160	63.1	4.5	1.57	270	59	2.5
150	59.1	9.2	1.60	270	62	3.0
			1.61	273	62	3.5
			1.62	276	65	4.5
			1.65	281	70	5.0
			1.73	303	92	5.5
			2.00	...	...	6.0
			Also at 59·1 Kv.			
			1.14	186	18	0
			1.14	182	14	1
			1.13	168	18	2
			1.18	186	18	3
			1.13	186	18	4
			1.17	186	18	5

1.22	190	22	6
1.22	190	22	7
1.25	194	26	8
1.50	224	56	9
1.70	....	....	9.2

TABLE No. 7B

Observations on Blue Marble.

No. B-5 Thickness-1″.02 — Dielecric Hystesis vs. Time on B-5 at 67.0 kv. Time

Prim. Volts	Secondary Puncture kilo-volts	Time in Min.	Prim. Amps.	Prim. Watts	Hys. Watts	Time in Min.
210	82.7	1.0A	1.60	266	64	0.
185	73.0	3.5	1.61	270	68	1.
170	67.0	3.9	1.64	281	79	2.
168	66.2	4.0	1.66	285	83	3.
170	67.0	5.1	1.69	287	85	4.
165	65.1	6.0	1.76	319	117	5.
160	63.1	6.1	....	....	...	....
150	59.1	9.3	2.06	346	144	5.1P

Minute Tests.

Secondary kilo-volts	Time in Sec.	Prim. Amps	Prim. Watts.	also at 63.1 kv.			
55.2	0	1.20		1.45	239	55	0
57.2	60	1.26	190	1.45	236	52	1.
59.1	120	1.36	209	1.47	236	52	2.
61.1	180	1.47	228	1.50	239	55	3.
63.1	240	1.58	247	1.51	243	59	4.
63.1	276	2.10	285P	1.55	251	67	5.
55.2	10	1.20	182	1.67	277	93	6.
57.2	60	1.30	194	1.92	...	...	6.1P
59.1	120	1.38	209				
61.1	180	1.49	228				
63.1	240	1.57	247				
63.1	242	1.82	Puncture				

TABLE No. 8.

Observations on Polished Marble.

Blue Thickness-1".01

Prim. Volts	Secondary Puncture kilo-volts	Time in Min.	Prim. Starting Amps.	Prim. Starting Watts.
205	80.8	2.2	2.3	570
200	78.8	2.5	2.0	...
180	71.0	8.2	1.65	387
180	71.0	6.5	1.70	389
174	68.5	8.0	1.55	262
170	67.0	11.3	1.55	241
White Thickness-0".92				
180	71.0	0.5	....	...
170	67.0	0.8	2.00	342
170	67.0	0.3	1.80	296
160	63.1	0.8	1.70	266
155	61.1	1.5	1.55	247
150	59.1	2.5	1.30	201
145	57.1	2.75	1.30	201
140	55.1	4.00	1.20	177

The table also shows the variations in Watts on the two different colored slabs and when it is remembered that for any given voltage, the open circuit Watts to be subtracted in order to give the energy loss, are the same in both cases; it can be easily seen what a large increase in energy loss there is with the white, over that of the blue.

THE ELECTROSTATIC FIELD.

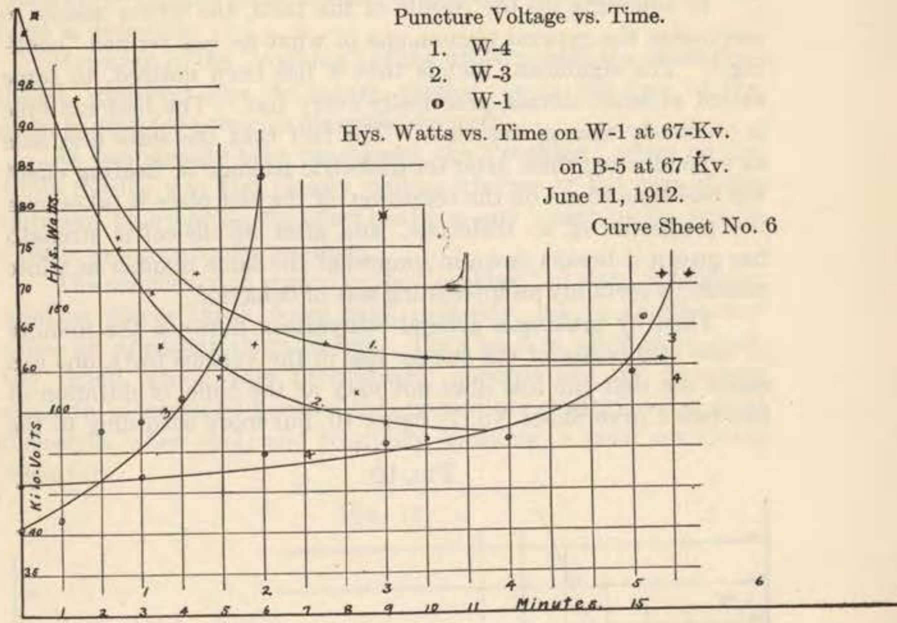
This topic can hardly be classed as the results of tests but for want of a better place, is put in here at the end of this chapter.

This phenomenon was exceedingly interesting and decidedly spectacular at times. The coronas or brush discharges were truly beautiful under the higher voltage tests, and they covered in general an area proportional to the stress applied. Under a stress of 100 K. V. the field covered practically the entire slab.

During most of the tests there was a very brilliant corona which remained very nearly fixed, taking a form which apparently was an indication of the natural characteristics of the portion of the slab under stress. These relatively fixed lines were accompanied by the ordinary flashing and changing brush-like corona.

Because of the low maximum stress applied to the slate very little corona was noticed.

FIG. 9.



BLUE MARBLE.

7-a—The table needs no explanation other than to call attention to the fact that all readings recorded therein were taken on slab B-6.

7-b—The A indicates an instantaneous test which took approximately one minute to puncture, but since the initial voltage was so high, it was placed along with the puncture voltage versus time readings.

The manner in which the two one minute tests check one another, is worthy of notice. As to the curves on Curve Sheet No. 7, figure 10, the small variation between the two puncture voltage curves, is noticeable

The (a) before the 67 K. V. reading, simply shows the test during which the readings for the table at the bottom of the page, Dielectric Hysteresis versus Time, were taken.

The curves on Curve Sheet No. 6, figure 9 are self explanatory.

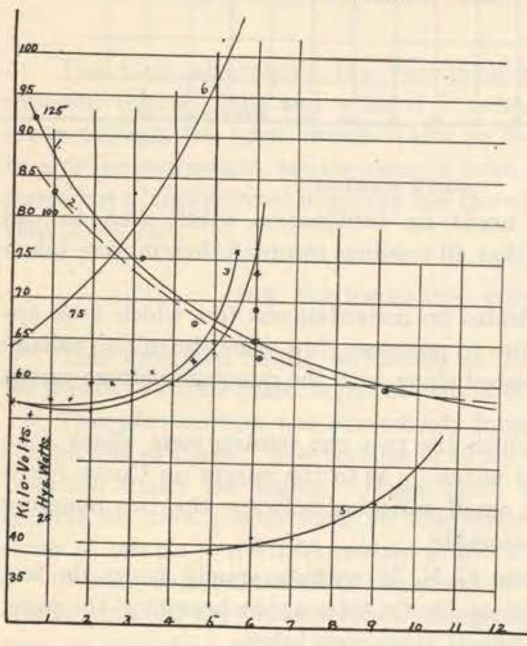
Conclusions.

DIELECTRIC HYSTERESIS LOSS.

In summing up the results of the tests, the writer wishes to emphasize the general phenomena of what he has termed "cooking." The significant fact is that it has been noticed, to some extent at least, during practically every test. The best example is obviously that of the slate. The fact that the slate first acts as a conductor, then after the dielectric leakage or heating effect has had time to act on the condition of the test piece it takes over the properties of a dielectric, and after its dielectric strength has grown it breaks down in somewhat the same manner as white marble; is certainly an interesting sort of behavior.

Then by making a general comparison between the manner or rate of increase of the energy loss in the various tests, one can easily see that the loss does not vary as the time of duration of test (see Curve Sheet No. 7) figure 10, but more according to the

Fig. 10.



Puncture Voltage vs. Time
1. B-6
2. B-5

Hys. Watts vs. Time
3 on B-6 at 69.0 Kv.
5 " " " 59.1 Kv.
6 on B-5 at 67.0 Kv.
4 " " " 63.1 Kv.

June 11, 1912.

Curve Sheet No. 7.

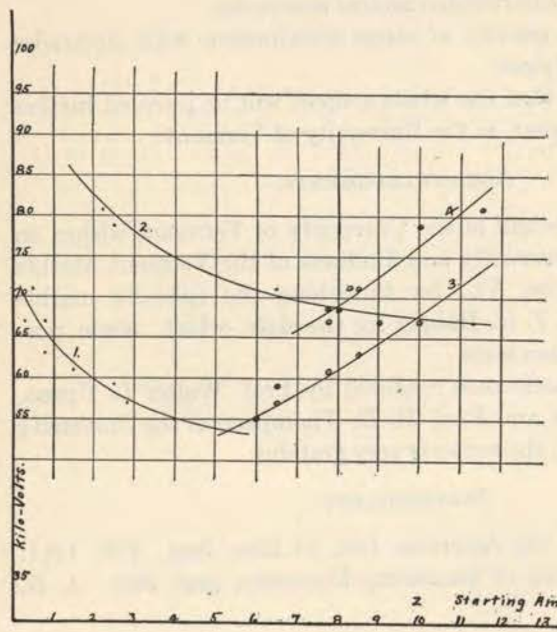
strength of the electrostatic field. This fact makes it evident that it is not the heating that has caused the ultimate rapid acceleration of current before puncture, but rather a real breaking down of the natural molecular forces which go to make up what we term a dielectric.

However, in the "cooking" of the white marble the effect produced, whatever was its nature, tended, as in the case of the slate, to raise for a time its dielectric strength.

As has already been mentioned, the "cooking" effect on the white marble was also plainly visible, whereas in the case of the slate and blue marble, the effect has been only known by the results of tests as shown by the readings.

The conclusion in regard to the "cooking" of slate, is that the weakest places break down first, probably due to heating and cause an apparent short circuit. Then as it is allowed to cool, the liquid which was precipitated, hardens and the dielectric strength is increased because this precipitate evidently is a good dielectric, when cool; and relatively speaking, a good conductor when hot.

Fig. 11.



POLISHED MARBLE

Punct. Voltage vs. Time
1. On White
2. " Blue

Starting Amps. vs. Kilo-Volts.
3. On White
4. " Blue

June 11, 1912.

Curve Sheet No. 8

The only evidence of the effect on the blue marble, was the slight decrease in current and watts, during the first minute's application of the stress. This decease was also accompanied by a corresponding tendency toward a higher voltage, which of course was maintained constant by means of a regulating rheostat. The effect was so very small, that at first, it was thought to be due to a fluctuation in the line voltage; but on careful investigation it was found to be in evidence, in practically all the blue marble tests.

The only conclusion which can rightfully be drawn in regard to the slate as a dielectric is, that it falls far below marble. Since only one variety was tested no comparison can be made except as regards thickness; and in this manner one is surprised to note that dielectric hysteresis watt loss increased with the thickness.

The work of this thesis naturally suggests new fields, and fields here but slightly touched upon, namely:

1. Power factor on various kinds of slate and marble.
2. Puncture voltage versus thickness on marble.
3. Further study of dielectric hysteresis and the "cooking" of slate.
4. The stress distribution around electrodes.
5. Center of gravity of stress distribution with electrodes on same side of test piece.

It is expected that the whole subject will be pursued further during the coming year, at the University of Vermont.

ACKNOWLEDGMENTS.

The writer in behalf of the University of Vermont, wishes to acknowledge the generosity and kindness of the Vermont Marble Company of Proctor, Vt., for furnishing the splendid marble slabs, and also Mr. F. C. Hooper for the slate, which made possible these high tension tests.

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THE STRENGTH AND WEATHERING QUALITIES OF VERMONT ROOFING SLATES.*

E. R. BAKER AND A. R. DAVIDSON

INDEX.

INTRODUCTION.

The slate belt of eastern New York and western Vermont lies between the Taconic range on the east and Lake Champlain and the Hudson on the west, and chiefly between the Hoosic River one of the eastern tributaries of the Hudson, on the south, and the towns of Benson and Hubbardton in Vermont, on the north, a stretch of about 55 miles; but slate is said to continue as far north as Cornwall, making an extreme length of 68 miles. As, however, good slate is hardly obtainable south of Shushon and Greenwich, in Washington County, the actual length of the slate belt is about 45 miles.

The slates are green of various shades, purple, variegated, (that is, mixed green and purple), red and also black. They are used for roofing and other purposes. The value produced in Vermont amounts to about one-quarter of the entire slate produce of the United States.

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While the slates of Vermont and those of New York are quarried in the same vicinity and are difficult to separate, this thesis deals primarily with only the Vermont slate. We have received a few specimens of the New York red slate, however, and these we tested along with the others for comparison.

The best-known and largest slate region in Vermont is that in Rutland County west and a little south of the marble area. It is not more than half as long and twice as wide as the latter. It extends from West Castleton through the towns of Fair Haven, Poultney, Pawlet, and ends in Rupert. There are about fifty companies now operating and not far from a hundred quarries in this region.

The other slate belt is mostly in Washington County, though it runs south into Orange County for a short distance. Its chief center is at Northfield where the black slate exists, but not any of the quarries in this region are being worked at the present time.

During the past two years the slate industry has been somewhat irregular. Although on the whole the sales of slate of all kinds have been larger than at any previous time, this is not wholly due to increased quantity of slate sold, but in part to higher prices received. The total sales in Vermont now amount to nearly $2,000,000 annually. While the sales of Pennsylvania are more than twice as great, no other state at all equals our own in this respect; Maine, which is next only producing one-eighth as much. About eighty-five percent of the total producion of the state is in the form of roofing slate, this being by far the more important part of the industry.

A greater part of the slate quarried in the United States is for roofing purposes and is put on the market and sold by "squares," a square meaning a sufficient number of pieces of slate of any size to cover 100 square feet of roof allowing a three-inch lap. The sizes of slate in a square vary from 24x16 inches to 9x7 inches, and the number of pieces necessary for a square varies from 85 to 686, according to the size of the pieces.

The ordinary price varies from $3.50 to $10.00 per square f. o. b. at the quarries and depends on the quality, color, size thickness, smoothness, straightness and uniformity of the pieces.

Some of the inferior slate, which is mottled or ribboned, sells as low as $2.50 a square, but specially prepared slate, with pieces carefully selected with regard to color, extra thickness and size and extra cutting, sells as high as $30.00 per square.

In this thesis we shall deal only with the roofing slate and will follow the procedure of Mansfield Merriman in his tests on Pennsylvania roofing slate for convenience of comparison in strength and weathering qualities. As far as we have been able to discover in our research work no other standard tests on roofing slate have been made. Our object then is to obtain an average value for the different tests, to compare the values and interpret the results, noting any peculiarity in the behavior of the specimens while being tested.

TABLE I.

Mark on Spec.	Dist. between supports, inches, l	Width of slate, inches, b	Thickness of slate, inches, d	Breaking load, pounds, W	Modulus of rupture, S	Deflection reading at beginning, inches
A1	12	8	0.25	145	5220	1.25
A2	12	8	0.22	79	3670	1.22
A3	12	8	0.22	129	5995	1.22
A4	12	8	0.22	....	....	1.22
A5	12	8	0.22	109	5070	1.22
A6	12	8	0.19	107	6670	1.19
					5325	
Means—						
B1	22	12	0.16	71	8135	1.15
B2	22	12	0.25	114	5016	1.25
B3	22	12	0.19	70	5445	1.19
B4	22	12	0.22	118	6705	1.22
B5	22	12	0.22	82	4660	1.22
B6	22	12	0.19	102	7775	1.19
					6290	
Means—						
C1	22	12	0.16	65	6980	1.16
D1	22	12	0.19	79	6020	1.19
E1	18	10	0.22	129	7200	1.18
E2	18	10	0.25	70	3027	1.22
					5115	

Means—						
F1	18	10	0.22	118	6580	1.19
G1	18	10	0.25	110	4755	1.22
H1	18	10	0.25	124	5361	1.22
I1	18	10	0.19	114	8525	1.16
J1	18	10	0.19	105	7860	1.16
J2	18	10	0.19	118	8825	1.27
J3	18	10	0.22	162	9035	1.22
J4	18	10	0.22	85	4735	1.22
J5	18	10	0.22	84	4685	1.22
J6	18	10	0.19	85	6360	1.19
					6915	
Means—						
K1	18	10	0.25	212	9160	1.25
K2	16	10	0.22	90	4465	1.21
K3	16	10	0.25	191	7335	1.24
K4	16	10	0.25	221	8480	1.24
K5	16	10	0.28	185	5665	1.27
K6	16	10	0.28	187	5725	1.27
					6805	
Means—						
L1	16	12	0.28	302	7705	1.25
L2	16	12	0.25	180	5760	1.25
L3	16	12	0.22	118	4875	1.22
L4	16	12	0.22	167	6900	1.22
L5	16	12	0.22	155	6405	1.22
L6	16	12	0.22	163	6740	1.22
					6400	
Mark on Spec.	Dist. between supports, inches, l	Width of slate, inches, b	Thickness of slate, inches, d	Breaking load, pounds, W	Modulus of rupture, S	Deflection reading at beginning inches
Means—						

	Deflection reading at rupture, inches	Ultimate deflection in inches	Modulus of elasticity, E	Weight in air, grams	Weight in water, grams	Spec. gravity	Weight after drying 24 hrs. at 135 degrees F.
A1	1.10	0.15	3,340,000	42.49	26.97	2.74	37.58
A2	1.15	0.07	5,730,000	52.07	33.28	2.77	67.09
A3	1.07	0.15	4,360.000,	33.56	21.43	2.76	50.40
A4	....	....	....	34.84	22.27	2.78	69.21
A5	1.12	0.10	5,525,000	54.21	34.65	2.77	84.86
A6	1.10	0.09	9,375,000	46.32	29.63	2.77	74.21
			5,666,000			2.77	

Means—

B1	0.80	0.35	10,980,000	57.42	36.85	2.79	51.09
B2	1.10	0.15	10,800,000	46.57	29.85	2.79	95.68
B3	0.75	0.44	5,150,000	39.24	25.20	2.81	50.24
B4	0.98	0.24	10,240,000	34.68	22.23	2.79	67.42
B5	0.95	0.27	6,325,000	40.60	26.06	2.79	36.30
B6	0.86	0.33	10,000,000	56.19	35.95	2.79	67.41
			8,916,000			2.79	

Means—

C1	0.80	0.36	9,790,000	39.06	25.20	2.82	51.20
D1	0.93	0.26	9,840,000	37.54	24.25	2.82	44.18
E1	1.02	0.16	11,020,000	43.22	27.80	2.80	65.82
E2	1.10	0.12	5,440,000	38.67	24.83	2.79	48.52
			8,230,000			2.80	

Means—

F1	0.90	0.29	5,560,000	46.69	30.00	2.80	48.25
G1	0.99	0.23	4,460,000	49.20	31.78	2.82	48.39

	Deflection reading at rupture, inches	Ultimate deflection in inches	Modulus of elasticity, E	Weight in air, grams	Weight in water, grams	Spec. gravity	Weight after drying 24 hrs. at 135 degrees F.
H1	1.06	0.16	7,225,000	67.45	43.38	2.80	92.40
I1	1.00	0.16	15,100,000	45.13	28.91	2.80	66.93
J1	0.96	0.20	11,120,000	25.50	16.50	2.83	62.59
J2	1.14	0.13	19,250,000	47.65	30.45	2.83	54.33
J3	0.99	0.23	9,630,000	29.96	19.30	2.81	86.33
J4	1.05	0.17	6,830,000	41.03	26.38	2.81	61.37
J5	1.15	0.07	16,400,000	42.20	27.45	2.83	80.16
J6	1.01	0.18	10,020,000	90.75	58.30	2.79	80.90
......	....	....	12,208,000	....	......	2.82	.....

Means—

K1	1.06	0.19	10,400,000	65.92	42.50	2.81	97.41
K2	1.01	0.20	4,325,000	56.57	36.36	2.80	86.31
K3	1.07	0.17	7,360,000	54.72	35.22	2.81	106.35
K4	1.09	0.15	9,650,000	41.81	26.86	2.80	60.79
K5	1.14	0.13	6,640,000	48.08	30.90	2.80	70.94
K6	1.03	0.24	3,660,000	35.73	22.98	2.80	61.75
...	....	....	7,006,000	.....	.....	2.80	.....

Means—

L1	1.11	0.14	8,390,000	54.29	34.50	2.74	109.79
L2	1.05	0.20	4,910,000	46.99	30.23	2.80	80.69
L3	1.00	0.22	4,300,000	55.85	35.91	2.80	55.99
L4	1.03	0.19	7,050,000	27.07	17.48	2.82	85.06
L5	1.04	0.18	6,910,000	27.56	17.73	2.80	78.19
L6	0.98	0.24	5,440,000	31.46	20.35	2.83	50.12
...	....	....	6,167,000	....	....	2.80	....

Means—

	Weight after being immersed 24 hrs. in water grams	Per cent. water absorbed in 24 hrs.	Weight before immersion in acid, grams	Weight after 63 hrs. in acid and dried for 2 hrs. in laboratory, grams	Per cent. weight lost in 63 hrs. in acid
A1	37.90	0.85	42.49	42.07	0.99
A2	67.57	0.72	52.07	51.91	0.30
A3	50.82	0.83	33.56	33.43	0.38
A4	69.80	0.85	34.84	34.70	0.40
A5	85.26	0.48	54.21	54.02	0.35
A6	74.85	0.86	46.32	46.20	0.26
...	.....	0.76	.....	.....	0.45

Means—

B1	51.75	1.29	57.42	57.01	0.71
B2	96.27	0.62	46.57	46.39	0.39
B3	50.70	0.81	39.24	38.93	0.79
B4	68.12	1.04	34.68	34.50	0.53
B5	36.82	1.43	40.60	40.39	0.52
B6	68.12	1.05	56.19	56.03	0.29
...	.	1.04	......	.....	0.54

Means—

C1	51.81	1.19	39.06	38.93	0.33

	Weight after being rmmersed 24 hrs. in water, grams	Per cent. water absorbed in 24 hrs. grams	Weight before immersion in acid,	Weight after 63 hrs. in acid and dried for 2 hrs. in laboratory, grams	Per cent. weight lost in 63 hrs. in acid
D1	44.63	1.02	37.54	37.50	0.11
E1	66.45	0.96	43.22	43.17	0.12
E2	48.94	0.87	38.67	38.64	0.08
.	.....	0.91	.....	.....	0.10

Means—

F1	48.63	0.79	46.69	46.64	0.11
G1	48.65	0.54	49.20	49.16	0.08
H1	92.80	0.43	67.45	67.14	0.46
I1	67.55	0.92	45.13	45.01	0.26
J1	63.00	0.65	25.50	25.44	0.24
J2	54.66	0.61	47.65	47.24	0.86
J3	86.69	0.42	29.96	29.90	0.20
J4	61.66	0.47	41.03	40.90	0.32
J5	80.74	0.72	42.20	.....	....
J6	81.66	0.94	90.75	90.63	0.13
...	.....	0.63	.....	.....	0.35

Means—

K1	98.10	0.71	65.92	65.88	0.06
K2	87.03	0.83	56.57	56.54	0.05
K3	107.69	1.26	54.72	54.58	0.26
K4	61.33	0.89	41.81	41.77	0.09
K5	71.40	0.65	48.08	48.04	0.08
K6	62.25	0.81	35.73	35.61	0.34
...	.....	0.86	.....	.....	0.14

Means—

	Weight after being immersed 24 hrs. in water, grams	Per cent. water absorbed in 24 hrs.	Weight before immersion in acid, grams	Weight after 63 hrs. in acid and dried for 2 hrs. in laboratory, grams	Per cent. weight lost in 63 hrs. in acid
L1	110.27	0.44	54.14	53.68	0.85
L2	81.11	0.52	46.99	46.92	0.15
L3	56.35	0.64	55.85	55.84	0.02
L4	85.67	0.72	27.07	27.05	0.07
L5	78.87	0.87	27.56	27.54	0.07
L6	50.53	0.82	31.46	31.42	0.13
...	.....	0.66	.....	.....	0.21

Means—

The A slates were obtained from Norton Bros., Granville, New York; they were described as sea-green slates. The B slates were No. 1 sea-green slate, from the Rising & Nelson Slate Co., West Pawlet, Vt. The C slate was No. 1 sea-green, Griffith & Nathaniel, Poultney, Vt. The D slate was No. 1 purple vein, Griffith & Nathaniel, Poultney, Vt. The E slates were genuine north vein, unfading green, No. 1 grade, New England quarry, Matthews Slate Co., Poultney, Vt. The F slate was hard vein clear purple, No. 1 grade, Empire quarry, Matthews Slate Co., Poultney, Vt. The G slate came from the same company and was eagle vein, unfading red, No. 1 grade Quarry Eagle. The H and I slates were also from the same company; the H was national vein unfading red, No. 1 grade, National quarry; the I was hard vein, variegated green, No. 1 grade, Empire quarry. The J slates were from the Rising & Nelson Slate Co., West Pawlet, Vt., No. 1 unfading green. The K slates were No. 1 unfading mottled green and purple, from the same company; the L slates were No. 1 red also from the same company. Hearty acknowledgements are due to the companies named for supplying the samples of slate used.

The G, H, and L slates were New York slates, which we tested with the Vermont slates for purposes of comparison.

PLATE LXX.

Apparatus for Testing Strength of Marble and Slate.

METHOD OF INVESTIGATION.

It was purposed in investigating these roofing slates, to experiment as closely as possible upon those properties which are called into service in resisting the stresses to which they are subject, and upon those qualities which either assist or resist the disintegrating action of the atmosphere and weather. The strength and toughness of slate are important elements in preventing breakage in transportation and handling, as well as in resisting the effect of hail, or of stones maliciously thrown upon the roof. They are also brought effectively into play by the powerful stresses produced by the freezing of water around and under the edges. Porosity, on the other hand, is not a desirable property, for the more water the slate absorbs, the greater the disintegrating action when it freezes and thaws. Density is a quality of value, for in accordance with a fundamental principle of the science of the resistance of materials, the greater the specific gravity of one of several similar substances, the greater is its strength. Hardness may or may not be a desirable quality according as it is related to density or to brittleness. Lastly, corrodibility, or the capacity of being disintegrated by the chemical action of smoke and of fumes from manufactories, is certainly not desired in roofing slates.

The investigation was undertaken primarily to discover the qualities of Vermont roofing slates in a scientific manner. Some samples of the red slates of New York State were also investigated as noted elsewhere. In order to carry out such an investigation, such tests were selected as seemed likely to be both precise and simple, and of such a character that quantitive results concerning each of the properties investigated could be determined. These results are given in Table I for a number of specimens, and they will be discussed and compared with the view of ascertaining the relation between the different properties. Plates LXX and LXXI show the principal apparatus used.

The pieces tested varied in size. (See Table 1 for details of length, breadth, thickness, etc.; the length in each case was two inches greater than the distance between supports.) All specimens of the same kind of slate from the same quarry were marked with the same initial letter, followed by the number of the specimen. These letters and numbers were kept upon the specimens and their fragments throughout the different tests, thus enabling the different properties to be compared for each individual specimen.

Strength. The transverse or flexual strength of the slates was selected for experiment because of the ease and accuracy with which the tests can be made, and also because such stresses are brought upon it in actual use rather than those of pure tension or compression. The pieces were supported in a horizontal position upon wooden knife-edges such a distance apart as the length of the slates permitted, and then loads were placed upon another knife edge half way between the supports. This load was applied by means of sand running out of an orifice in a box, at the uniform rate of 70 pounds per minute, and by the help of a mechanical attachment the flow of sand was stopped at the instant of rupture. The slates were always placed upon the supports, so that the beveled edges were on the lower side. As the load was increased, the deflection of the slate could be observed upon a scale and the ultimate deflection recorded.

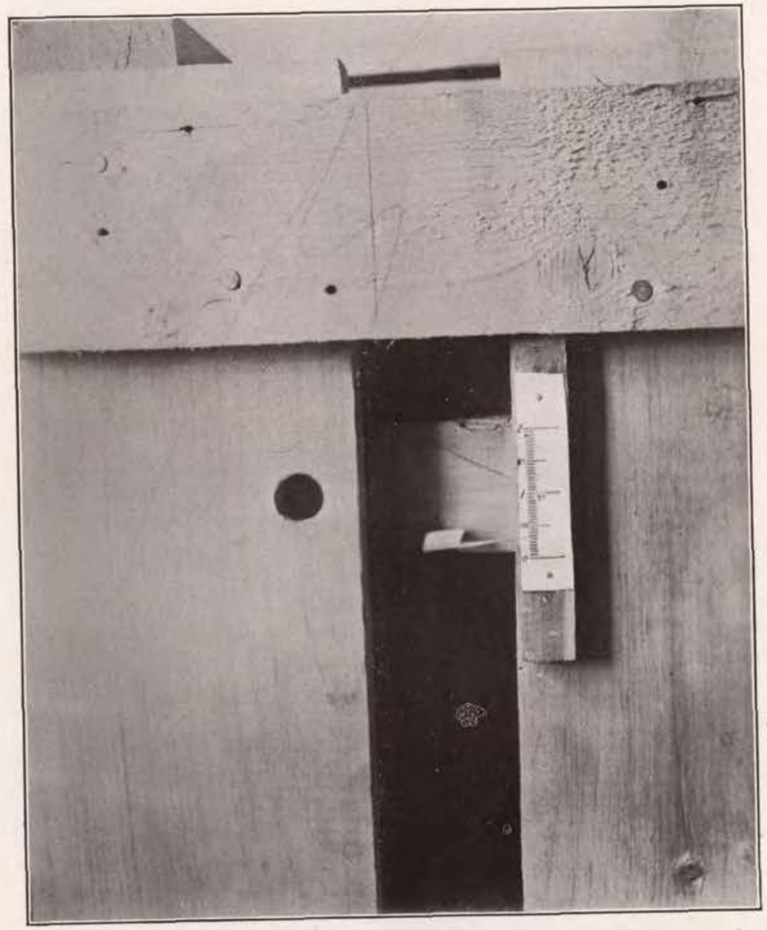
The strength of a beam or plate broken in this manner is indicated by the modulus of rupture which is the computed horizontal rupturing stress on the upper and lower fibres, and is intermediate in value between the ultimate tensile and compressive strength. Let W be the load in pounds which causes rupture when applied at the middle, let 1 be the distance between the supports in inches, b the breadth and d the thickness of the plate in inches. These being carefully found by observation, the formula

$$S = \frac{3W1}{2bd^{2}}$$

furnishes the means of computing the modules of rupture S, whose value is then in pounds per square inch. In Table 1 are given the values of the modulus of rupture for each of the specimens.

Toughness. The ultimate deflections of the pieces broken under transverse stress furnish an indication of their toughness, provided the pieces were all of the same size, in the same manner that the ultimate elongation of a metallic specimen under tensile strain is an index of toughness and extensibility. The greater the ultimate deflection of a bar, the less is its brittleness, and the greater its toughness, other things being equal. All the specimens of slate were so elastic that the deflection of the middle part, where the load was applied, could easily be noted on a scale by

PLATE LXXI.



Apparatus for Measuring Deflection of Stone under Pressure.

the eye. The scale was graduated to $\frac{1}{20}$ of an inch, or 0.05", and fractions of a division were estimated and interpolated. The deflections for the different specimens are given in Table 1. Since the pieces were not of the same size, the modulus of elasticity computed from the data furnishes an index of the toughness of the slates. The formula used for computing the modulus of elasticity is the deflection formula for simple beams; the slate acts as a simple beam with the load applied at the middle. Let W be the load in pounds which causes rupture when applied at the middle, let 1 be the distance between supports in inches, 1 the moment of inertia, which for a rectangular section is $\frac{1}{12}bd^3$, where b is the breadth and d the thickness of the slate in inches, and E the modulus of elasticity. Then the formula

$$f = \frac{1}{48} WI^3/EI$$

furnishes the means of computing the modulus of elasticity E, whose value was then in pounds per square inch, f being the ultimate deflection in inches. In Table 1 are given the values of the modulus of elasticity for each of the specimens tested.

Almost all the specimens ruptured in different planes on the upper and lower surfaces; so that, in fact, they sometimes split or sheared into two thinner pieces.

Specific Gravity. The density was next determined for each specimen by weighing it in air, and then in water, from which data the specific gravity was computed.

Porosity. The well-known test for porosity is to determine the percentage of water absorbed by the specimens under similar conditions. The following procedure was carried out: A piece of slate of a size about 3x3 to 3x4 inches was taken from each specimen, the edges being left rough and irregular. These were dried for 24 hours in an oven at a temperature of 135 degrees F. After cooling to the normal temperature of the room, they were weighed on delicate scales, and then immersed in water for 24 hours, when they were taken out and weighed again. The difference of these weights, divided by the first weight, gives the percentage of water absorbed by a specimen. The results thus obtained are given in Table 1.

Corrosion by Acids. In order to imitate the action of smoke and of sulphurous fumes of manufactories, the following test was used: A solution of hydrochloric and sulphuric acid was prepared, consisting by weight of 98 parts of water, 1 part of hydrochloric and 1 part of sulphuric acid. In this, pieces of slate about 3x3 inches in size were immersed for 63 hours, having first been carefully weighed. After being taken out of the solution they were dried for two hours in the normal air of the laboratory, and were again weighed. Thus the loss of weight due to the corrosive action of the acids was ascertained. The results were then transformed into percentages of the original weight, which gave an absolute measure of the corrosion. The results of this test are given in Table 1. After the tests, the surfaces of the pieces showed but slight traces of acid action, notwithstanding the loss of weight.

Discussion of the Tests. A recapitulation of the mean results of these tests is given in Table II below.

TABLE II.

MEAN RESULTS OF PHYSICAL TESTS.

Property	Measured by,—	A	B	J	K	L
Strength	Modulus of rupture, in pounds per square inch.	5325	6290	6915	6805	6400
Density	Specific gravity.	2.77	2.79	2.82	2.80	2.80
Toughness	Modulus of elasticity, in pounds per square inch, thousands.	5666	8916	12208	7006	6167
Porosity	Per cent of water absorbed in 24 hours, when thoroughly dried.	0.76	1.04	0.63	0.86	0.66
Corrodibility	Per cent of weight lost in acid solution in 63 hours	0.45	0.54	0.35	0.14	0.21

The mean values given in Table II may be expected to furnish a tolerably reliable indication concerning the properties under investigation. A study of the table will at once lead to the conclusion that the different qualities are connected by definite relations, the strongest slate being highest in density and toughness. The porosity and corrodibility do not seem to bear such a direct relation to the other properties under investigation of the specimens tested except in a very general way. The extent of

the tests, however, does not warrant drawing a general conclusion as to the relations existing between the relative strength and corrodibility or porosity of the slate specimens. The conclusion is very apparent, however, that the strongest slate is also the toughest, as well as the highest in density.

CONCLUSIONS.

1. Vermont roofing slates weigh about 175 pounds per cubic foot, and the best qualities have a modulus of rupture of from 6,000 to 9,000 pounds per square inch.

2. The stronger the slate, the greater is its toughness and density.

3. The modulus of elasticity of the best qualities of Vermont slate is from 6,000,000 to 12,000,000 pounds per square inch.

4. The weathering qualities, as determined from the tests of porosity and corrodibility, appear not to be uniform and to vary with more or less well-defined limits.

5. In general, the flexural test furnishes a good index of all the properties of the slate, the strongest slate being the one most suitable for the ordinary building purposes.

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RILL-CHANNELS AND THEIR CAUSE.

A rock-surface Character of Glacial Origin.

GEORGE H. HUDSON.

On many of the elevated and more exposed portions of Valcour Island and adjacent territory on the mainland one meets with bared knolls or bosses (roches moutonnees) of middle Chazy limestone which appear to have been curiously cut by the action of small, short and confluent streams of running water. These rill-channels, as I have called them,* are here illustrated by plates LXXII—LXXXI inclusive. While the studies leading to the discussion here presented were made on Valcour Island, the illustrations are from photographs of a cliff surface some 200 meters north of the north end of Beekman Street, Plattsburgh, N.Y. The elevation here is about 80 feet above the present surface of Lake Champlain or some 180 feet above sea level. References will be made to this region unless Valcour Island is specified. At first sight it looks as if we had before us the effects of post glacial precipitation on exposed glaciated surfaces, but a careful study of the matter leads us to the conclusion that these rill-channels were cut by sub-glacial waters loaded with sediment and at times moving under extra pressure. The evidence for this conclusion is here presented under sub-headings which follow.

SURFACE FEATURES NOT SUCH AS SOLUTION WOULD HAVE PRODUCED.

There must be a very fundamental difference between the features produced by solution on limestones and those produced by corrasion. Solution must bring into relief the variations in substance possessing varying degrees of resistance to the solvent. Corrasion on the other hand will apparently ignore minor and closely placed chemical and physical differences and work as if they did not exist. Solution must leave the thin sheets in the bedding that contained a greater abundance of silicious sediments as sharply raised sub-parallel ridges. Corrasion would cut down

*N. Y. State Museum Bulletin 140, etc.

PLATE LXXII.

Glaciated Rock Boss with Rill Channels.

such thin sheets and leave them almost flush with the softer material lying between. Solution possesses no planing action, in corrasion such action is very apparent.

If we assume that the rill-channels are the result of post-Hochelagan solution by rainfall we should be able to show how this agent could produce the peculiar features of arrangement, form, surface, and rapid deepening which these channels present. With this purpose in view, let us imagine the conditions for solution on a day when the period of rainfall was 80 minutes long and the relative humidity, wind and temperature such that the first dry areas would begin to appear 10 minutes after the cessation of the shower. Imagine also this rainfall to occur early in the history of the development of these features or soon after the exposure of the glaciated bosses.

Within a few seconds from the time when the first scattered drops reach the rock, the areas in question become completely covered with a thin film of water and solution begins by acting uniformly over the entire exposed surface. The impact of new and swiftly falling or wind driven drops constantly enables them to penetrate and dislodge portions of the film in molecular contact with the rock and gravity quickly removes the partially charged water from these very limited areas. At the end of 80 minutes the rain ceases, but for nearly 10 minutes more solution will continue on the top of the bosses or until saturation is reached and dry areas are about to appear. At the end of an addional 10 minutes, the dry areas should have extended their borders for say a meter and a half in every direction. In the case here stated solution has been active for nearly 90 minutes on the tops of the bosses and nearly 100 minutes on those portions of the natural flow-ways situated one and a half meters from these summits. The portions longest under the influence of solution should be cut the deeper.

If now we examine a typical boss we shall find that at the distance of one and one half meters from the summit these rill-channels have attained a depth of from five to ten centimeters below the general surface or outlines of the knoll. If this work is due purely to solution, then extra depth of, say 7 centimeters, may be attributed to the extra time in which solution was allowed to act. If during this extra one-tenth of the whole time, the water could remove rock to the depth of 7 centimeters, then during the other nine-tenths it should have been able to dissolve nine times as much and thus remove 63 centimeters from the top of the same knoll.

As published meteorological data give neither the average length of periods of rainfall for this region nor the average rate of evaporation during the hour following the cessation of rainfall, we can claim no more for the above ratio of 9:10 than that it is a very rough approximate to average conditions. In summer we have many light showers in which the tops might be wet for about 20 minutes and the drainage channels for 30. Using this ratio we should have 14 centimeters of top removed for the extra 7 centimeters of the channels. As however a trace of rainfall might keep the top simply wet for 20 minutes and on drying redeposit all the calcium carbonate taken into solution, the use of such a ratio would be manifestly unfair. The longer rains, to which we must look for results, usually last for hours and sometimes for from one to two days. In these larger storms the rate of evaporation would be slower on account of the lower temperature of the season when they occur and the higher relative humidity reached by the lower layers of the atmosphere. The period between the cessation of rainfall and the first appearance of the dry patches would thus be much lengthened, but so soon as such dry spots began to appear their extension would be fairly rapid and this because of the longer time allowed for the complete draining of the surface involved. Under such conditions we should find many ratios nearer 24:25 and these would mean the loss of 168 centimeters from the tops, while the channels were being deepened their extra 7 centimeters.

The ratio really should be calculated by using the average time from the beginning of rainfall to the attainment of saturation on the tops, for the first term, and adding to this the extra time required to reach saturation at the one and a half meters distance down the channels, for the second term. As saturated waters would soon be drawn into these channels after cessation of rainfall I believe that the extra time so found would be nearer one-twentieth of the whole than it is to one-tenth and this would mean a loss of 133 centimeters from the tops.

In this argument we have attributed the extra depth which these channels attain, in running such short distances, to differential solution where the only factor considered was difference in the time allowed for action of solvent. Along with this factor there was always present the factor of difference in rate of solu-

Plate LXXIII.

Rill Channels on Glaciated ledge, showing loss in depth as the lower basin-like surface is reached.

tion due to variations in rock character. The kind of surface this factor leaves, on small separate rock fragments, was illustrated on Plate XX of the Director's report (N. Y. State Director of Science) for 1909. Now the rill channels are cut across the bed edges almost regardless of this second factor yet under the conditions as stated this factor should have had by far the most effective influence of the two. With so great a loss from these surfaces as our arguments would show, the varied relief due to this second factor should be much more marked than the relief of the channels themselves. A glance at our plates however, will show an apparent absence of the work of this factor. The actual difference in relief so caused amounts to but a few millimeters. It has not been sufficient to mask the glacial contours of the areas in question. We are therefore compelled to conclude that neither difference in time allowed for solution to act nor difference in rate of solution due to variation in rock character have produced the features here witnessed.

It was an argument of this character that caused the writer in the Director's report for 1909 (page 168) to introduce a third factor, that of "difference in rate of movement of the solvent" to account in part for the rapid deepening of the channels, though at that time he was compelled to acknowledge that these rill-channels were "not wholly due to rainfall but were in some measure due to melting glacial ice." If a portion of the deepening of the channels is due to extra speed of flow, the use of this factor would reduce our approximate estimates of the amount of rock removed from the tops of the bosses. We should note however that the water acting on the tops of the bosses during precipitation is never quiet. The distributing force which the velocity of a rain drop communicates to the molecular layers next the rock surface might be as competent to replace portions of this film with fresh water as would be the frictional force of the movement down the channels. And again, while the raindrop brings fresh water to the tops, the channel current is already partially charged and has therefore lost solvent power. After making all proper allowances for this third factor we shall still find that if we attribute the cutting of the rill-channels to solution by rainfall it will involve a loss over the whole surface so manifestly in excess of fact that we shall have to abandon it as an hypothesis. These surfaces were unmistakably planed not only over the tops but in the beds of the channels. The principal agent in their

That there has been but little loss of surface since glacial time may be readily seen. Plate LXXII also shows a deep basin on the summit of a well arched boss and this also contained water when the negative was secured. We have already noted similar basins in the channels themselves—like lakes in an Alpine stream. These basins are not solution features, but they are just such features as would be produced by small and loaded rills descending on these surfaces through a melting ice sheet above. Their outlets were cut when they were made. Both the basins and their overflow channels are very evidently glacial phenomena not yet effaced by either solution or weathering. The part played by post-Hochelagan solution is again seen to be of very minor importance.

(f) Rills draining contiguous areas and running over similar slopes do not have depths in proportion to the areas drained. The sudden deepening at (*a*) and (*b*) shown in Plate LXXVII are cases in point.

(g) The drainage does not seem to have been determined wholly by the contour of the original surface. In many places channels seem to cross each other as at (*a*) in Plate LXXV. The short but deep channel at (*b*) on the same plate seems to have no reason for its existence. The channels often divide in the direction of their flow. Some channels part at a wide angle and almost immediately swing back and empty into each other as at (*a*) in Plate LXXVI. One boss in this region has a small summit depression so well drained by three divergent channels that a half cup of water sufficed to send streams down its north, south, and east faces. These and other features indicate different points of supply at different times and consequent changes in direction of flow. Certain channels may also have been temporarily blocked.

For an agent competent to produce exactly such conditions and features as we have noted we must look to a melting glacial ice sheet. The cliff edge in this locality is about 40 feet above the plain to the east. Here is where crevasses would form, admit surface water to the cliff top and sweep it free of moraine material. The supply of water would vary in volume and in places of application. Small caverns etched from the under surface of the ice at times of greater flow could not maintain their existence. Fracture and moulding would insure their destruction and block rill-channels already cut. Glacial waters would also be rich in rock debris and so furnish efficient material for producing the corrasive features noted.

(h) All elevated ridges or mounds lying between the rill-channels have remarkably rounded or convex surfaces. In most of the plates accompanying this paper this feature is very pronounced. These minature valleys differ remarkably from land valleys in that their higher portions are convex instead of concave. If while being cut by sub-glacial streams such action was frequently interrupted by some glacial movement, we should have precisely the rounded outlines here witnessed and the larger valleys would become U-shaped as well.

Post-Hochelagan Solution not Competent to Remove the Loss Noted.

The rivers of the world annually carry to the sea nearly 5,000,000,000 tons of mineral matter in solution and by this process alone lower land areas an average of something like one foot in 13,000 years.* If solution could carry away the surfaces of our exposed bosses at an equal rate it might be able to account for the loss of material which is here manifest though it would not account for the peculiarities of the features left.

By far the greater part of the work of solution is accomplished by ground water where humous acids, comminution of material, pressure, and other conditions enormously increase the solvent power. Water falling on our bosses is so quickly withdrawn that it has not even the factor of time in its favor. The Thames, after receiving loaded waters that for years have been working their way through the fracture zone, comes to possess 294 milligrams of calcium carbonate per liter. The Woodhead water supplied to Manchester, although it has in large part become ground water yet contains but 25 milligrams per liter or little more than one-twelfth of the amount.† This would indicate but the removal of an inch in 13,000 years. Take next for analysis the water that has had but momentary contact with a hard, polished limestone boss and we shall find another marked drop in the amount of matter dissolved. Going from the rivers' accumulation up to the bare areas just receiving rainfall is, figuratively speaking, like passing down the diagonal of a parallelogram from a vertical distance above the base represented by

* Geology. Chamberlain and Salisbury. Vol. 1, etc.
† Wanklin, etc.

Plate LXXV.

Glaciated Rock Surface showing irregular Character of Rill Channels.

294 milligrams to the 0 point on the base itself. Erosion and solution differ markedly in respect to the conditions under which each does its best work. Erosion accomplishes most on the exposed masses of our highlands; solution finds its power best developed deep in fissures, in talcs, and in the more comminuted material which streams have left in our valleys. Looking at the matter from the standpoint here presented we should be led to expect a loss from our bosses of only a small fraction of an inch. So small an amount is wholly inadequate to account for the material lost in the cutting of the rill-channels.

We may approach this quantitative aspect of our question from a still different standpoint. The present annual precipitation at Plattsburgh Barracks as determined for a period of 58 years is 29.95 inches. The precipitation was probably heavier when the reterating ice front was near this region but we can find no reason for believing it to have been much heavier at the time of the withdrawal of the Hochelagan sea. If we use this average, covering nearly six-tenths of a century, as we find it and consider the withdrawal of the sea to have taken place about 10,000 years ago (which is likely to be an overestimate) the total precipitation of the period would have been equal to a water depth of 299,500 inches or 760,732 centimeters over this area. The volume of water precipitated on each square centimeter of surface would then be nearly 761 liters. Pure water cold or boiling will dissolve carbonate of lime only to the extent of 18 milligrams to the liter.* As rainwater is almost free from carbon dioxide† we may consider its action on the limestone to be closely like that of pure water. Could each liter of this rainfall have remained in contact with the rock long enough to become saturated the total weight dissolved from each square centimeter of surface would have been but 13.69 grammes. Dividing this by a specific gravity of 2.7 we find that the loss in depth could not have been much over 5 centimeters.

Small as this figure is when compared with our rough estimates of a required 35 or more centimeters, we must point out that it cannot be increased. The new argument as presented is open to serious criticism. Let us note some of the more important errors.

1. The factor introducing the greatest possible error in our tentative conclusion (that the loss by solution cannot exceed

*Roscoe and Schorlemen, etc.

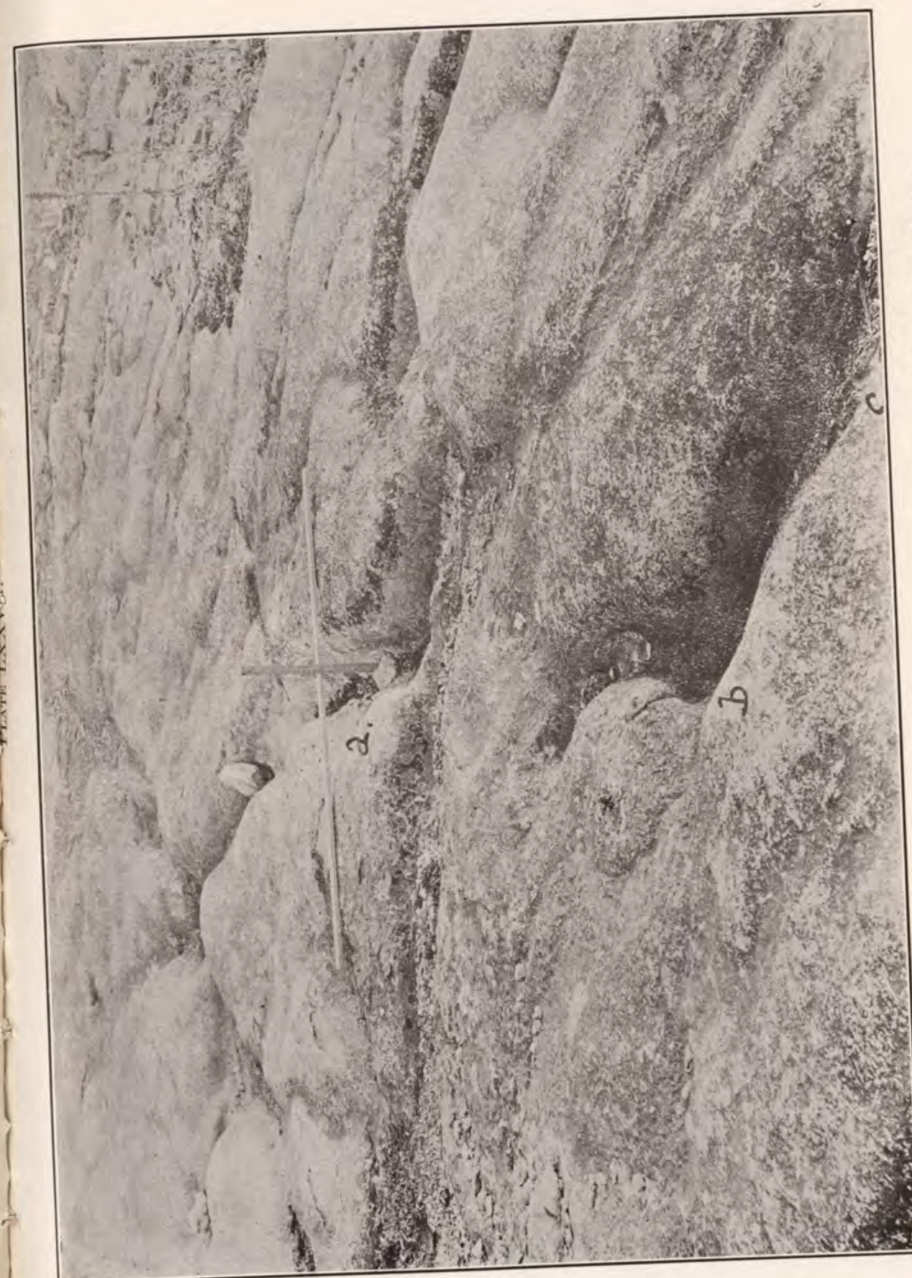
†Wanklin, etc.

5 centimeters) is the unwarranted assumption that rainwater falling on a clean and polished rock boss and running over its steeply sloping surface but one and a half meters could possibly become saturated in the exceedingly limited time allowed for contact with such a small area. Much of the water of the rebounding raindrops would simply flow over the contact film because of its adhesion and viscosity and would leave the boss practically unchanged. It is doubtful if the water as a whole could take up material in solution to even one-tenth of its capacity. Making this allowance the total amount removed would be less than 5 millimeters.

2. We would make a very important correction in the use of the figure 29.95 inches as representing the annual rainfall. About one-fourth of the annual precipitation is snow-fall and winds sweep most of this off from the rock knolls in question leaving them bare for the greater part of the winter. This large proportion of the annual precipitation accomplishes but little work on these bosses.

3. Of not so great importance, but still worth noting, is the fact that the annual evaporation taking place on these areas must be deducted from the annual rainfall. The drying film must reach saturation and redeposit the calcium carbonat taken into solution. Such deposit too, would be heavier in the channels and tend to build them up. The under surfaces of large loose blocks on Valcour Island have been thus whitened as if by whitewash. These two corrections together should reduce the figure 29.95 by at least one-fifth and that will bring the calculated amount of removal down to not over four millimeters.

4. Should we seek to increase this amount by allowing for a greater rainfall than that received at present we must note that the really important factor is the length of time per year during which gravity is removing water from the surface and not the amount of the rainfall. In our imagined shower we allowed an additional 10 to 20 minutes to cover the period of continued flow and consequent removal of calcium carbonate. If now we imagine two showers of equal length, the precipitation in one being one centimeter and in the other just double that amount we can find no reason for assuming that the amounts taken into solution would differ markedly. The heavier the rainfall the less the dissolved material in each cubic centimeter of the run off. To increase the annual hours of precipitation in this region we



Glaciated Surface showing rapidly increasing depth of certain channels and the crossing of others.

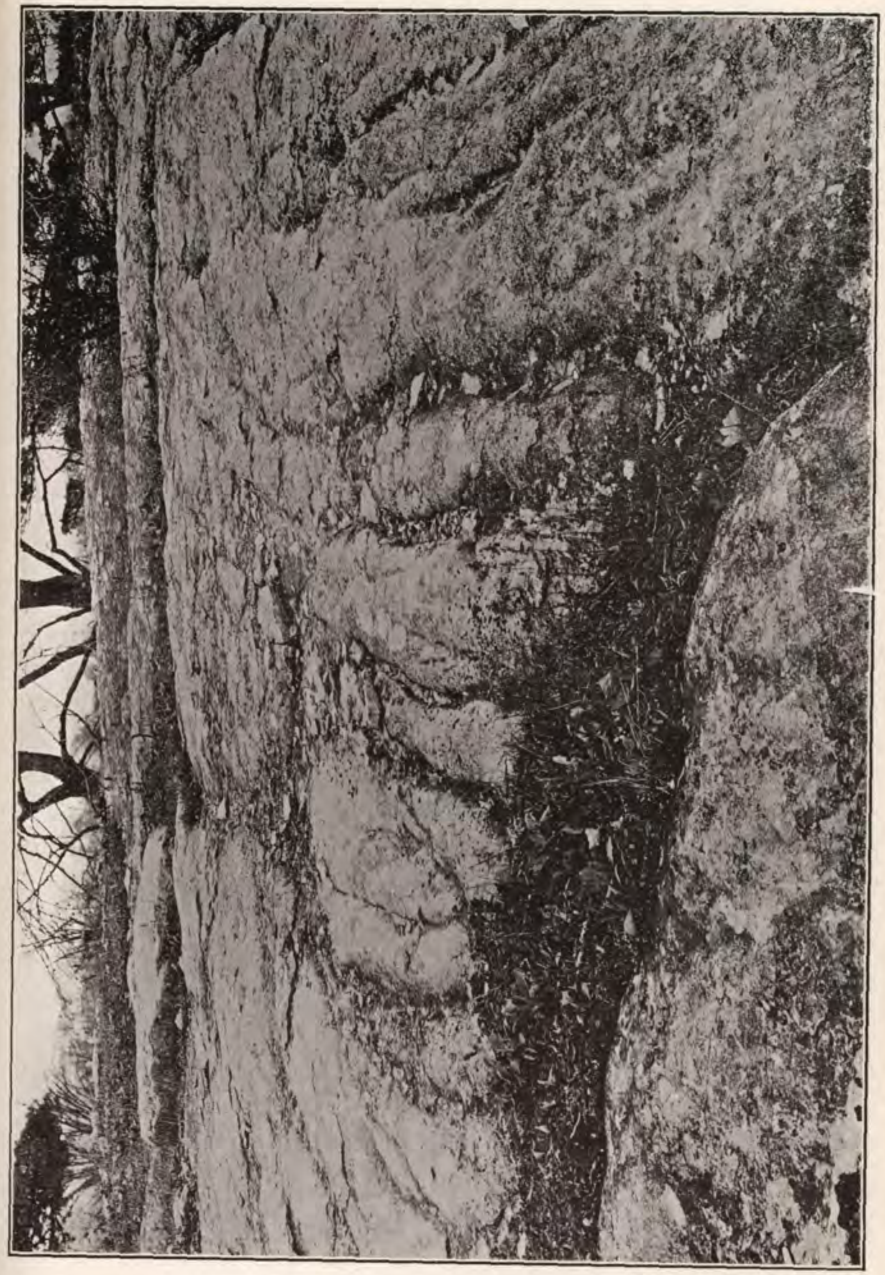
A peculiar feature presented by Plate LXXIII will afford us evidence of a different type. The rill-channels here run down the boss only to fade away before the base of the slope is reached. In the immediate foreground there is a large rock basin still capable of holding considerable water but not enough to have the water surface cover the mouths of the channels. This basin seems to have been breached near the end of the glacial melting or by wave and expansion of freezing water when the sea was working at this level. Rainfall has for some centuries been free to cut the lower portion of this surface but it has failed to do so.

A similar and very conclusive bit of evidence may be derived from a study of the glaciated boss found in the bay back of the lighthouse on Valcour Island. This boss is illustrated in the report of the Director of Science (N. Y. State) for 1909, Plate III. It has been uncovered for at least two centuries and exposed to those summer and fall rains which yield more than half of our annual rainfall. At high water the naked boss is covered by the solvent waters of Lake Champlain. It shows no trace whatever of rill-channels. Areas left covered by till were rarely subjected to sub-glacial wash. Many such areas were uncovered by wave action during the recession of the Hochelagan sea. Rainfall has acted on their surfaces for a time fully as long as in other regions where the rill-channels are present. Need we demand evidence of a more conclusive character.

RILL-CHANNELS ARE TODAY BEING DESTROYED NOT MADE.

There is a marked difference in the state of preservation of these channels. If the bosses are situated nearer the level of the mantle rock or shielded in part by higher bosses toward the south, their faces show but little of the effects of weathering. They appear almost as if they had been recently uncovered. In such situations the rock surface is more likely to be covered by snow during portions of the winter. On the other hand the higher and more exposed bosses, particularly on their southern exposures, have had their surfaces almost entirely removed by the wedge-work of freezing water and by exfoliation induced by marked and rapid changes in temperature. A study of the surface shown in Plate LXXVIII reveals this feature only too clearly. That the channels were once there is however plainly to be seen. The same characteristics may also be noted in Plate LXXVI. In this view we are looking southeasterly. The northern end of the highest boss (the

PLATE LXXVIII.



Exposed Rock Boss showing that exfoliation is now removing the Rill Channels cut on the surface at an earlier period

PLATE LXXIX

Glaciated Surface showing an area in which drainage was at first over a transverse joint which was later opened to receive subglacial drainage.

left end) still shows rill-channels in a fair state of preservation. The more southern end of the boss has lost all trace of them.

These Rill-Channels Were Already Cut on These Surfaces When They Were First Uncovered by the Hoghelagan Sea.

The separate items of evidence will here be lettered.

(a) These bosses in their outlines and smooth ground surfaces are very evidently the product of glacial action. When the effects of freezing water and insolation began to work on them it was a glaciated surface they began to remove. These agents did not wait for 10,000 years of rain and solution to first do its work. The glaciated surfaces and the rill-channels have evidently been acted upon for equal periods by these destructive agents and both are disappearing together.

(b) The loosened surface blocks already mentioned as lying just north of Spoon Bay, Valcour Island, were evidently separated and shifted by wave action when the receeding waters reached their level. The channels were cut before the movement took place. A comparison of the separated edges shows that the channels at first crossed from one block to another as if the joints did not exist.

(c) In Plate LXXIX the rill-channels may be seen to pass under the sod. The writer recently uncovered some of this buried portion to a distance of from one to two meters from the irregular line of contact. The depth of this distance was 30 centimeters and was steadily increasing. The soil section showed first 8 to 9 centimeters of very fine loam blackened with humus. Just under this was a very irregular layer, varying from a few millimeters to two or more centimeters, in which most of the sand grains had been whitened through loss of iron oxids. Under this was 20 centimeters of a yellowish brown sandy loam. The strip uncovered was about 30 centimeters wide.

From this covering material and at depths between 8 and 30 centimeters there were secured nine rock fragments weighing between 2 and 60 grams each. Seven of these were angular; (three of limestone and four of sandstone). Two were well rounded; (one of granite and one of sandstone). The rill-channels were still present and in strong relief on this uncovered area. It will be readily seen that this is not a residual soil. Neither is it the result of wind blown dust; nor the work of earthworms. The scattered and varied rock fragments point clearly to wave work on glacial material. The evidence is conclusive that the rill-channels here lie beneath deposits of Hochelagan age.

The Surface Features in Question Were Produced by Subglacial Drainage During the Period of Recession of the Wisconsin Ice-Sheet.

That we may realize the capacity for work of this agent let us first form an approximate estimate of the solvent powers of melting glacial ice and compare them with those of rainwater.

A continental ice-sheet has five sources from which it can obtain carbon dioxide.

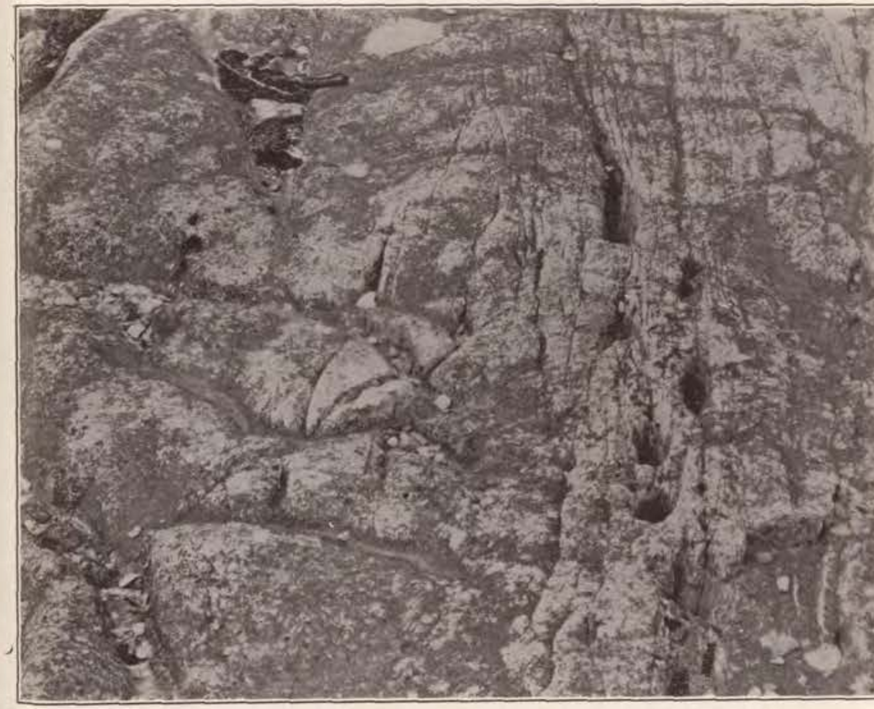
1. The atmosphere, through precipitation and centuries of contact.
2. Organic matter in the mantle rock which it covered in its advance.
3. Chemical decarbonization.
4. Carbon dioxide rising from the fracture zone.
5. Carbon dioxide occluded in igneous and metamorphic rocks and liberated through comminution of these rocks.

The last two items in certain localities would suffice at times to saturate the deeper waters. Water at the freezing point and saturated with CO_2. will dissolve 700 parts per million of calcium carbonate. An amount practically forty times as great as that of rainwater. Were these underwaters saturated they would remove as much in 250 years as rainwater in 10,000 years. Make whatever corrections may be necessary here but do not omit the fact that the time per year that the subglacial waters are active is at the very least more than five times as long as that of intermittent rainfall. If we are looking for solvent effects, let us look for those of the glacial period.

What we want to find is a corrasive agent so powerful that it will completely mask the effects of solution and we need look no farther for it than the heavily loaded waters of a melting ice sheet. Let us now see how this agent worked on the areas in question.

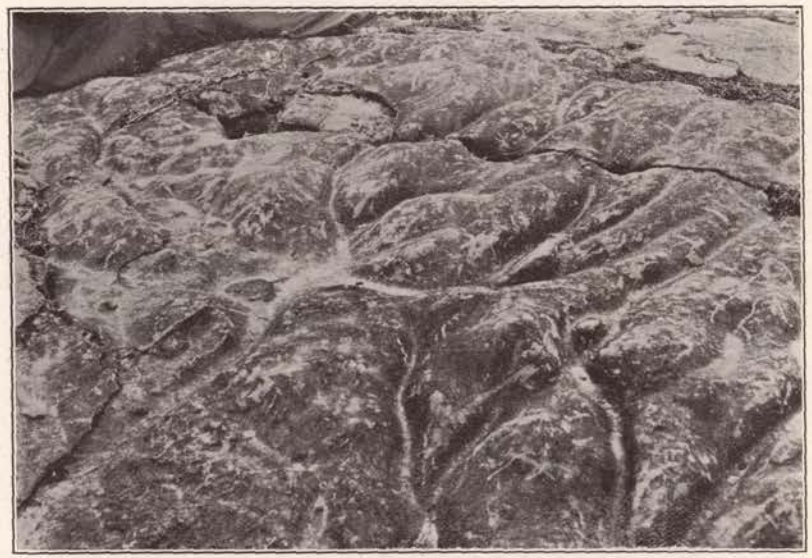
Rill-channels, as Plates LXXVI and LXXVIII clearly show, occur on high outcrops of rock which are here usually due to the pres-

Plate LXXX.



Joint Wells in Limestone Ledge.

Plate LXXXI



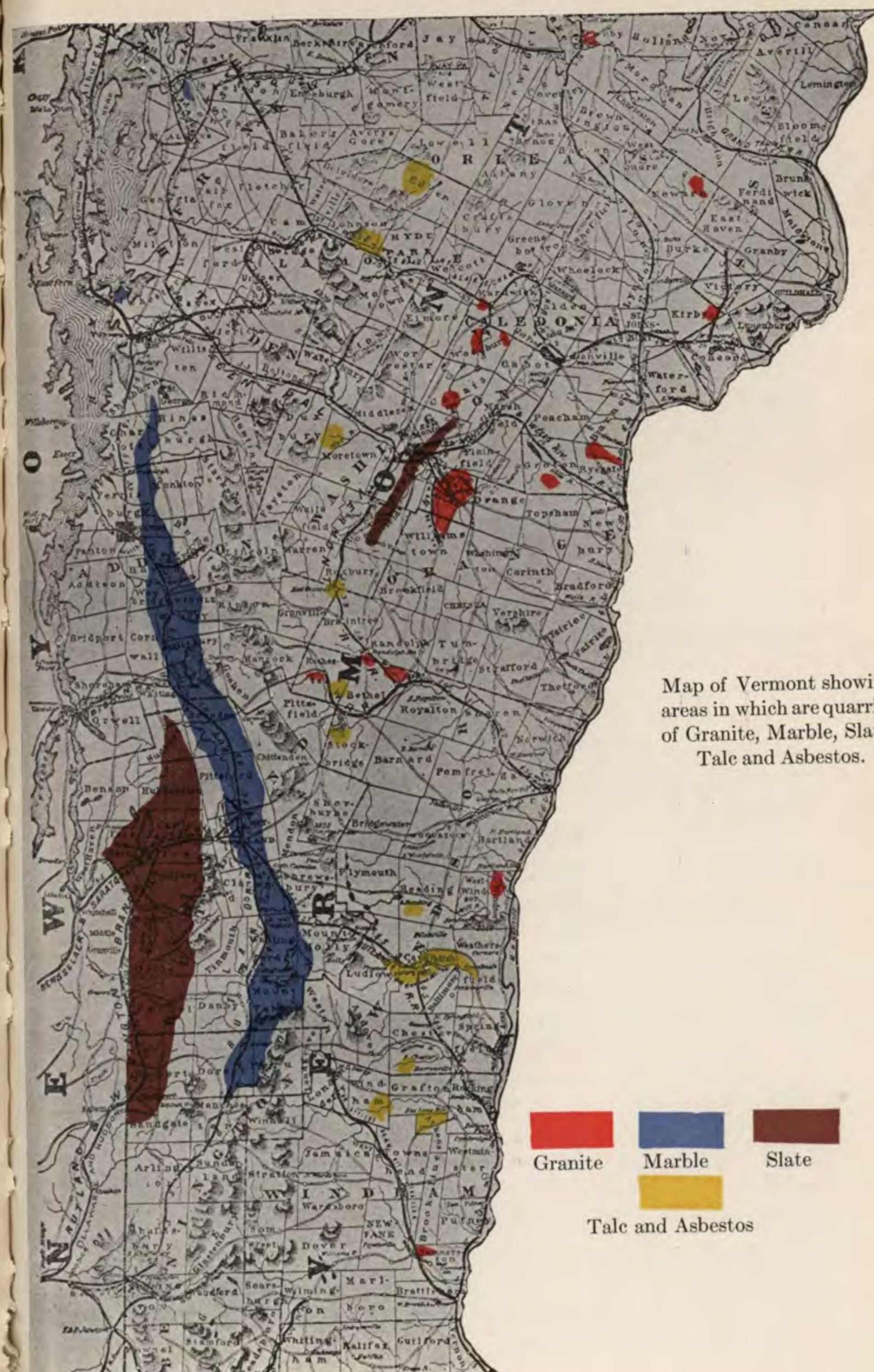
Surface of Ledge Showing Rill Channels cut at first across a joint, but later draining into it.

them. Where waters entered most freely a rotary motion would rapidly give circular outlines to horizontal sections. Where solution was still an important factor owing to slight corrasive work the outlines of cross sections would be elliptical with the joint line in the direction of the major axis. In many instances these joint wells were started so near each other as to make them soon confluent. Now there are places where rill-channels cut across joints that were not sufficiently open to carry all the waters below. At a later period they did take the flow and beheaded the rill-channels. This feature is clearly seen in Plate LXXXI. Plate LXXIX shows the condition of things in a more advanced stage. Here continued work above the joint opening has so modified the surface and the joint is now so wide that channels cannot be traced across with certainty. The beheaded character of the channels starting from the lower joint edge is very evident.

If now the joint-wells, enlarged joint-channels, and moulins have been cut by the action of sub-glacial waters should we not expect to find associated with them an arrangement of rock cut surface channels like those we have been considering? To claim the action of glacial waters for the larger features of corrasion on these evidently glaciated surfaces and deny such action in the formation of well marked minor features would be absurd, and particularly so when precisely similar features are today found on the borders of existing glaciers where direct rainfall can have had nothing to do with their formation.

As the result of these studies we must conclude that these rill-channels were formed late in the history of the Wisconsin ice-sheet and that their subsequent modification by rainfall is confined to the loss of a few millimeters differentially removed from their surfaces.

PLATE LXXIII.



Map of Vermont showing areas in which are quarries of Granite, Marble, Slate, Talc and Asbestos.

Granite Marble Slate

Talc and Asbestos

MINERAL RESOURCES

During the two years since the publication of the Seventh Report no very important changes have occurred in the building and monumental industries of the state nor in less extensive stone or mineral production. There has been however, gratifying progress in the production of most of those materials which are usually included under the above head. Most of the Companies engaged in supplying the demand for stone of one sort or another report satisfactory conditions and prosperous business. Many have increased their ability to furnish required stone by opening new quarries, erecting new buildings and adding new machinery. As a comparison of the lists of companies now active in the business with those of former reports will show, there have been many changes in the personnel of the firms engaged in stone quarrying and cutting a few of them important, but taken as a whole, it may be said that the stone industry in Vermont has never been as strong nor as extensive as at present.

The question is sometimes asked, possibly with a degree of anxiety, whether there is danger that the various sorts of stone sold in the State may be soon exhausted and thus this great source of revenue be lost. Certainly it would be a very great calamity to Vermont if the supply of marble, granite or slate should fail and when one considers the magnitude of our present production, it is not to be wondered at that the question should arise. Anyone who is sufficiently interested in the subject to take time and trouble enough to make even a rather superficial investigation of the various deposits in different parts of the state will soon be convinced that they are great beyond calculation. It is indeed true that large drafts upon the supply are continually made, but as these drafts necessarily develop the deposits and reveal their character and extent, their magnitude becomes more evident. Few realize how little is taken from a great deposit, a mountain of granite for example, during a years quarrying. There are said to be not far from seven hundred marble quarries in the Carrara district in the Apuan Alps. Some of these have been worked for many centuries and the annual production is large, yet there is no thought, apparently, of exhaustion.

The Geologist has been examining the Vermont quarries for more than twenty years and the supply of stone, at least of marble and granite, appears more vast this year than ever. Of course this is because very much covering and waste material has been necessarily removed in operating the quarries so that what stone there is can be more fully seen. It must always be true in almost any marble quarry and to a less degree in those of granite and slate, that varieties are met as quarrying proceeds of which there is only a limited amount and it is sooner or later taken out, but this does not affect the great mass of what may be called standard stone. This varies in different quarries, but in any given quarry is usually the main mass of rock present. Then too this or that quarry may cease to afford material which can be profitably taken out, or there may no longer be salable stone. All this does not affect the general supply. There are great masses of marble and granite in the state as yet scarcely touched or not at all and the supply may be considered inexhaustable. I speak here more particularly of marble and granite because I have this season gone over the beds of these rocks much more fully than those of slate. While we have a large amount of excellent slate and the supply is very far from failing, it probably is not as enormous as that of the other building stones named. As has been stated in former Reports, Vermont produces more marble and granite than any other state and is second only to Pennsylvania in the production of slate. In our sales of sandstone and limestone, we are far behind some other states and always must be for there are no extensive beds of these stones in Vermont. As will be seen, sandstone, limestone, talc, asbestos, soapstone, and clay are porduced in the state, but not in very large amounts.

The map, Plate LXXXII, shows the location of quarries of granite, marble, slate, talc, and asbestos. The map does not show all the areas in which these materials are found, but only those in which they are taken out at present. Attention has elsewhere been called to the relatively limited areas in which the quarries are located as compared with the entire State. The following statistics are not complete and a full report of the stone production for Vermont would, I am sure, be considerably larger than that given, but the figures are the most complete that can be obtained. They are taken from the latest volume of Mineral Resources of the United States and are for 1910, I can furnish none later. According to the above authority Vermont sold in

1910 stone as follows:

Marble	$3,562,850.
Granite	2,694,474.
Slate	1,894,657.
Lime	202,686.
Limestone	25,250.
Clays	89,253.
Sand	19,000.
Total	$ 8,489,170.

Marble.

In previous reports especially the sixth, descriptions of the principal kinds of marble quarried in this State have been given as well as of the methods of quarrying and finishing and anyone interested in these matters is referred to them. All of the marble of Rutland County and also of the few adjoining quarries is metamorphic limestone, probably mostly of the Chazy period. It is usually compact, fine grained, and light colored. In much the main color is white and this is more or less thickly veined or clouded, or both, with black, blue brown, yellow or red. As the account referred to in the Sixth Report shows, there are numerous varieties, due not only to the color, but also to the relative abundance of the veins. In some varieties the white ground is only sparsely intersected by colored veins etc. while from this condition there are all grades to those in which the color covers the whole stone. Blue varieties are also common in which there is no white, the whole surface showing now a light and again a very dark blue and between these are all gradations. The red and white mottled marbles of Swanton and the green and white verde antique of Roxbury are perhaps the most elegant as they are much the hardest of the marbles sold. These latter are not limestone, the red marble being a calcareous phase of the Lower Cambrian Sandrock and the Roxbury a serpentine.

From time to time this office has received inquiries as to the electrical qualities of our slate and marble and also of the physical character of these stones. Tests of these have been made during the past season in the Engineering laboratories of the University of Vermont and the results of these tests so far as they have been completed are given in the papers by Messrs. Bristol, Barker and Davidson which are published in this volume. It is hoped that these tests will be supplemented by further investigations. Unlike granite and slate, marble is quarried and manufactured mostly by a few large companies. This has always been the case, but during the past few years several of the old companies have been bought by the Vermont Marble Company which is much the largest concern of its kind in this or any country. At present the following are the marble companies doing business in Vermont:

Barney Marble Company, Swanton.
Brandon Marble Company, Brandon.
Clarendon Marble Company, Clarendon Springs.
Eastman Marble Company, West Rutland.
Green Mountain Marble Company, Rutland.
Manchester Marble Company, East Dorset.
Norcross-West Marble Company, Dorset.
Vermont Marble Company, Proctor.
Vermont Italian Marble Company, Brandon. The locality given is that of the main office, not necessarily of the quarries.

The very great increase in the use of marble as building material for both outside and interior work and the consequent increase in demand has greatly changed the character of the marble business. And the change has been advantageous since much marble is excellent for outside walls or even for interior finish which would not be considered suitable for monuments. Hence a great deal of stone; sometimes the entire product of a quarry, can be utilized now while a few years ago it would be only waste. The above named quarries supply 41% of all the building marble used in this country. But the long continued preeminence which Vermont has held in this business has been more largely based upon its finer grades such as were suitable for monuments and statuary. Formerly no less than 87% of all such stone sold in the country came from Vermont quarries. While with the discovery of good marble in other states, so that now twenty six states furnish marble, this great preeminence no longer exists, yet even now this state supplies nearly 70% of the more choice kinds of marble sold. With increasing prosperity, or even without it, the fashion once set by the finer buildings erected, the demand for this stone in construction is sure to increase. No other material can offer so great variety in color, none can be

PLATE LXXXIII.

Holland Blue Quarry of the
Green Mountain Marble Co., Pittsford.

so readily carved elaborately, none is so well adapted for interior finish. A few notes concerning the companies named in the list may not be without interest.

THE BARNEY MARBLE COMPANY.—This is practically a part of the Vermont Marble Company, but it does business under the old name. The quarries and mills are at Swanton where the water power of the Missisquoi River is used. Only the highly colored Champlain Marbles and the green Verde Antique are worked. As these are much harder than most marbles they are more expensive, but also more durable and receive a finer polish. They are for some kinds of interior finish unsurpassed in elegance and durability.

THE BRANDON MARBLE COMPANY.—This is a new company which operates a quarry southwest of Brandon Village and is building a mill near the old Corona property. The marble is a pure white statuary.

THE CLARENDON MARBLE COMPANY.—A large quarry in Clarendon Springs is operated by this company and there is a small mill near at hand. The marble is light with dark veins and there is also dark stone in the quarry. A spur from the Delaware and Hudson R. R. connects the property with the main line of this road. Hitherto the marble has been mainly used for building, especially in the new Educational building at Albany, N. Y.

THE EASTMAN MARBLE COMPANY.—This firm quarry a very handsome marble at West Rutland a little south of the village. The stone is fine in grain and veined, often most attractively, with green or greenish lines, bands or colors. The veining is very distinct and the appearance of many blocks is exceedingly attractive. There is no mill, all the stone being sold in blocks.

THE GREEN MOUNTAIN MARBLE COMPANY.—The property of the corporation known for years as the The Columbian has been purchased by this new company and is operated by it together with additional quarries. The new company was organized two years ago and is now in full activity. One of the quarries is the large opening known as the Columbian south of Proctor Village. This quarry has been worked for more than sixty years, but there remains a very great mass of first class marble. The quarry is fully equipped with all needed machinery of modern type and there is ample hoisting machinery. There are here 150 acres of marble land. The stone in the Columbian quarry is light for the most part the ground being usually white or nearly so with veins varying in color in different layers and some dark beds add to the variety. The marble is handsome and sound. In West Rutland the company has a quarry, also long worked, from which a stone much like that of the Eastman quarry, which is only a short distance away, is obtained. The marble is white, light green veined and clouded or in some portions, quite dark. As in the Eastman quarry, several distinct varieties can be obtained in this quarry which has been named "The Baronial." North of these properties at Pittsford there is a fine large quarry, The Holland Blue of which the company has furnished the illustration in Plate LXXXIII. This quarry is located on an immense mass of blue marble, an inexhaustable supply. Like all the so-called "Blue" marble of Vermont, the color is a soft light blue, or in some blocks it is rather a bluish gray. The company own here twenty two acres of marble land. This marble is a very compact finely crystalized stone and takes a beautiful polish. The quarry is fully supplied with necessary machinery and is in active operation. Still farther north in Florence the company has another quarry and about 12 acres of land of similar marble which has not yet been developed but it promises well. This is The Sterling Blue quarry. Beyond Florence in the west part of Brandon there is a large and as yet undeveloped property of 200 acres which has been opened sufficiently to show large possibilities. There is here considerable dark and blue stone, but there is also what appears to be a great mass of the purest white. So far as can be seen at present, this white statuary marble is of the best quality, sound and in large quantity. There is in addition to the property named other marble land, 67 acres in North Middlebury and New Haven. The marble is all white or light. Three quarries have been opened on this property, but no very extensive development accomplished. What is called the Manning and Woodward Blue Marble property consists of about 80 acres adjoining the Holland Blue land in Pittsford. There is one quarry on this property which has been worked for some time. As stated, the mills, etc. are located in Rutland. Here are 11 acres on the Rutland and Delaware and Hudson Railroads and there are two sidings for the use of the company.

THE MANCHESTER MARBLE COMPANY.—The property formerly known as The Freedley quarries and mill in East Dorset are now owned and operated by the Manchester Marble Company. The quarries are well up on Dorset Mountain and have been worked for many years. The mill is at East Dorset. The marbles are all light and have been well known for a long time.

THE NORCROSS-WEST MARBLE COMPANY.—This company have quarries at Dorset and Danby and also mills, but the main mill is near the Railroad Station at Manchester. This one of the most completely equipped establishments of the kind to be found anywhere. A railroad six miles long connects the Manchester mill with the Dorset quarries. The marble is harder than most of that in Rutland County and more brilliantly crystalline. It is a most excellent building stone and has been mainly used, as such, but some very handsome interior work has been furnished by this firm. A number of the finest public and office buildings in the country are wholly built of marble from these quarries.

THE VERMONT MARBLE COMPANY.—This is the largest marble company in existence and one which has a most honorable record of fair dealing with both customers and employes. During the past few years this corporation has added to its already very extensive plant the entire property of the Brandon-Italian Company and more recently, that of the Rutland-Florence Company. Each of these was a large concern, especially the latter. It is probable that no better mill in structure or equipment was ever built than that of the Rutland-Florence at Florence or, as it was for a time called, Fowler, the name having been changed to that formerly given the place since the present owners took possession. The Vermont Marble Company carries on quarries at West Rutland, Proctor, Pittsford, Florence, Danby, Brandon, Monkton, Swanton, and Marble Island Alaska. In some of these places there are a number of quarries. Between a million and a half and two millions of cubic feet of Marble are obtained annually. Besides the enormous plant at Proctor there are six large mills at West Rutland, three at Center Rutland, one in Florence, one in Middlebury, one in Swanton besides small mills in San Francisco, Tacoma, St. Louis, Cleveland, Chicago, Philadelphia, and New York. Thirty five hundred men are employed in these different works. A visit to the main works at Proctor, where in one or another of the many buildings may be seen all the various processes necessary in manufacturing marble from the rough block to the delicately carved ornament or statue, is full of interest. In order to supply the demands of the Pacific Coast without transcontinental transportation this company a few years ago sought and found marble in Alaska. They own marble rights on a small island, twenty-six miles west of Prince of Wales Island. On this Marble Island fifty men are employed in quarrying and during the past year somewhere about ten thousand tons were taken out. When quarried, the stone is taken to San Francisco or Tacoma where as above mentioned, there are mills in which the marble is cut as may be desired. Large slabs of this Alaskan marble which I have seen are superb in quality and appearance. The stone is capable of a brilliant polish, and is of the lighter varieties as compared with Vermont marble, tho there are beds of a very handsome green charmingly shaded.

THE VERMONT ITALIAN MARBLE COMPANY.—This is one of the most recently formed Companies and has not yet reached the point of putting stone on the market. The company are developing a quarry near Brandon from which white marble is expected.

GRANITE.

After an almost phenominal growth for more than ten years until it exceeded that of any other state, the granite industry in Vermont has remained of late about the same from year to year.

As in every business, there are greater or less fluctuations in the demand for granite so that the sales are a little greater during some years than others, but the variation in the amount of sales is not great. It will not be considered boastful, I am sure, if we say that for all purposes the granite of Vermont is unsurpassed and for many unequalled. Moreover, if one may judge from the best information to be had, this is recognized over the country with increasing emphasis. While there is no red granite quarried in this state, there are so many varieties of gray and such fine deposits of white that almost every requirement of builders may be met. The proof of this is seen in the numerous splendid buildings and stately monuments that have been erected during the past few years the material of which is granite from one or another of our quarries. Nearly forty of the states produce granite in greater or less quantities and some of these in very large quantities so that it is not possible that Vermont can reach such preeminence as a producer of granite among other states as she has in producing marble. Still, Vermont leads all the

rest and it appears certain that this superiority being gained will be maintained.

The use of Vermont granite in building is large, but at present our granite is especially noted for its excellence as a monumental stone. Vermont supplies either the material or the finished work for more than twice as many mausoleums and monuments as does any other state, at least so far as the money value indicates this. The sale of granite for road making has never been great in this state, but it is expected that the demand will increase as well as that for paving blocks and that in this way much granite that now goes to waste may be utilized. Granite quarries that are located near large cities have an advantage in this respect the demand for paving stone, crushed stone and the like being so much greater than it can be in a rural state.

As shown in the table on a previous page, Vermont according to the reports of the U. S. Geological Survey produced in 1910 granite to the value of $2,694,474. A recent statement of the Barre Board of Trade declares that "Barre pays her workmen about $4,000,000 each year." Now there must be some mistake in one of these statements, for it is inconceivable that the granite companies are paying out over $1,000,000 annually more than all the stone that is taken out amounts to and still report business as very satisfactory.

There are, aside from the many companies of less magnitude, several very large concerns in Barre, Montpelier and Northfield, but I have not the reports of these companies at hand. In Hardwick also, there are some good sized companies and one, the Woodbury Granite Company, has probably the largest and most completely equipped plant to be found anywhere. Though this company from some of its quarries produces fine monumental granite from which masoleums, shafts, etc., are cut, their great work has been in building. Within about fifteen years a business amounting annually to $1,500,000 has been built up and they report that there are contracts now on hand which amount to $3,000,000. During the last two years this firm have supplied the stone for fifty U. S. Post Offices, some of them large, and within five years over twenty large and costly buildings including five state capitals have been furnished from the quarries of this company. They not only quarry, cut and carve the stone, but when desired put it in place in the building. A late addition to the equipment is a lathe on which it is possible to turn a column thirty-six feet long and eight and a half feet in diameter. In one of the quarries was a sheet of stone flawless throughout, which was 500 feet long, 20–50 wide and 20–30 feet thick.

There are, moreover, smaller, but not to be neglected pay rolls at Bethel, Groton and Ryegate, which are not included in the Barre statement, but are included in that of the Survey.

It seems impossible to avoid the belief that the Government figures are quite incomplete and therefore erroneous and that the output and consequent sales of granite have been very much greater than the survey figures indicate. It should be said in this connection that accurate estimates of the output of any region are often very difficult to obtain. It is a great task, though a pleasant one, to visit each quarry or plant and collect materials for a statement of the work of each and letters of inquiry do not always receive much attention. There are some companies, usually those most prosperous which reply satisfactorily to all proper enquiries, but there are more which do not reply at all.

More changes have occurred among the granite companies than in any other industry. This is partly because the number of firms is greater, partly because companies are often formed and start in business without sufficient capital to enable them to time over any financial difficulty that may arise with the result that the business is either sold or goes to pieces.

At present, there are as nearly as I can ascertain, one hundred and forty companies quarrying or manufacturing granite on a considerable scale in Vermont. Besides these there are many small concerns cutting a few monuments each year. Of the number over thirty carry on one or more quarries. Some of these as the list shows, do only quarrying a few not only quarry but also have cutting plants, but most of those whose names appear on the list do only cutting, buying the rough stock from the quarries. While some of the granite firms have ceased to do business, many have enlarged their facilities and are therefore able to supply larger demands which they are doing as already has been remarked with regard to the other branches of the stone trade. As of the marble so of the granite there are now more varieties offered and larger and better means of preparing them and supplying the market than ever before.

The following list has been carefully revised from that published in the last Report. In its preparation the writer has

been greatly assisted by Mr. Charles Wishart, Secretary of the Barre Granite Manufacturers Association, Mr. George James of the Woodbury Granite Company, Mr. C. E. Eliason, South Ryegate. Corrections or additions to the list will be welcomed. Q. C. respectively indicate Quarry or Cutting Plant. The total number of quarries worked is much greater than appears in the list since many quarrying companies carry on several quarries.

LIST OF GRANITE COMPANIES IN VERMONT.

BARRE AND VICINITY.

Adie & Milne, Barre, C.
Art Granite Co., Barre, C.
Barclay Brothers, Barre, Q. C.
Barclay, Andrew & Co., Barre, C.
Barre Granite Co., Barre, Q. C.
Barre Granite Turning Works, Barre.
Barre Medium Granite Co., C.
Barre Monumental Yard, Barre, C.
Barre White Granite Co., Barre, Q.
Barre Granite Quarry Co., Barre, Q.
Beck & Beck, Barre, C.
Bianchi, Charles & Son, Barre, C.
Bond, Geo. E. & Co., Barre, Q. C.
Boutwell-Milne-Varnum Co.,
Barre, Q. C.
Brown, Carroll & Co., Barre.
Brown, John & Co., Barre, C.
Brusa Brothers, Barre, C.
Bugbee, E. A. & Co., Barre, C.
Burke Brothers, Barre, C.
Canton Brothers, Barre, Q. C.
Carroll & McNulty, Barre, C.
Carswell-Wetmore Co., Barre.
Carusi, E. A., Barre, C.
Central Granite Co., Barre, C.
Chiold Brothers, Barre, C.
Cole, W. & Sons, Barre, C.
Comolli & Co., Barre, C.
Consolidated Quarry Co., Barre, Q. C.
Corskie, J. P. & Son, Barre, C.
Cutler, Storer & Fay, Barre, C.
Davis Brothers, West Berlin, C.
Dessureau & Co., East Barre, C.
Dewey, Col. Cutting Works, Barre, C.
Dineen & Co., Barre, C.
Freeman & Wasgatt, Barre, C.
Gasparello Brothers, Barre, C.
Gallagher, L. B., Barre, C.
Goodwin & Milne, Barre, C.
Glysson, E., Barre, C.
Grearson & Lane, Barre, C.
Grearson-Beckett Co.,
Williamstown, Q.
Guidici Brothers & Co., Barre, C.
Hall & Nicholson, Barre, C.
Harrison Granite Co., Barre, C.
Hays, J. T., Barre, C.
Herbert & Ladrie, Barre, C.
Hoyt & Lebourveau, Barre, C.
Johnson & Peterson, Barre, C.
Johnson & Gustafson, Barre, C.
Jones Brothers' Co., Barre, Q. C,
Jones, A. S., Barre, C.
LaClair & McNulty, Barre, C.
Libersont, George, Websterville, C.
Littlejohn, Odgers & Milne, Barre, C.
Lucia Granite Co., East Barre, C.
McCall, John, Barre, C.
McDonell & Sons, Barre, C.
McMillan, C. & Son, Barre, C.
McMinn, J. & Sons, Barre, C.
Macchi, Z., Barre, C
Malnati Brothers, Barre, C.
Manufacturers' Quarrying Co.,
Barre, Q.
Marr & Gordon, Barre, C.
Marrion & O'Leary, Barre, C.
Martinson Estate Co., Barre, C.
Melcher & Hadley, Barre, C.
Milne, Alex, Barre, C.
Milne, Geo. P., Barre, C.
Newcombe, T. J., Barre, C.

North Barre Granite Co., Barre, C.
Novelli & Calcagni, Barre, C.
Oliver & Co., Barre, C.
O'Herrin, Robert & Co., Websterville, C.
Palaora Brothers, Barre.
Parry & Jones, Barre, C.
Parnigoni Bros., Barre, C.
Passera Bros., Williamstown.
Peerless Granite Co., Barre, C.
Pirie, J. K., Graniteville, Q.
Presbrey-Coykendall Co., Barre, C.
Provost, S. & Son., West Berlin, C.
Pruneau, John, Websterville, Q.
Rostelli & Cruickshank, Barre, C.
Rizzi Brothers, Barre, C.
Rizzi, L. G., Barre, C.
Robertson, J. C., Barre, C.
Robins Brothers, Barre, C.
Ross & Ralph, Barre, C.
Ross & Cassellini, Barre, C.
Roux Granite Co., Barre, C.
Rust & Brew, Barre, C.
Saporiti, J. P., Barre, C.
Sassi & Co., Barre.
Scandia Granite Co., Barre, C.
Scott Brothers, Barre, C.
Sector, James & Co., Barre, C.
Sibson Quarry Co., Barre, Q.
Smith, E. L. & Co., Barre, Q. C.
Smith Brothers Granite Co., Barre, C.
Standard Granite Co., Barre, Q.
Star Granite Co., Barre, C.
Samuel Gerrard, Barre, Q.
Stevens, H. D., Barre, C.
Straiton, George, Barre, C.
Sunnyside Granite Co., Barre, Q.
Sullivan Eugene, Barre, C.
Tosi, Sanguinetti & Co., Barre, C.
Valz Granite Co., Barre, C.
Walker, Geo. & Sons, Barre, Q. C.
Wells-Lamson Quarry Co., Barre, Q.
Wells & Barney, Websterville, C.
Woodcock Bros., Barre, C.
World Granite Co., East Barre, C.
Young Brothers, Barre, C.

MONTPELIER.

Airoli, G. & Co., Montpelier, C.
Aja Granite Co., Montpelier, C.
American Granite Co., Montpelier, C.
Bianchi Granite Co., Montpelier, C.
Bonazzi, Bonazzi & Co., Montpelier, C.
Bowers, R. C. Granite Co., Montpelier.
Columbian Granite Co., Montpelier, C.
DeCalaines, R. J. Granite Co., Inc. Montpelier, C.
Dillon & Haley, Montpelier, C.
Doucette Brothers, Montpelier, C.
Excelsior Granite Co., Montpelier, C.
Fernandez, P., Montpelier, C.
Fraser, R. M., Montpelier, C.
Gill, C. P. & Co., Montpelier, C.
Globe Granite Co., Montpelier, C.
Jellyman & Jones, Montpelier, C.
Jurras, J. & Co., Montpelier, C.
Lillie, D. K., Montpelier, C.
Lowe-Mercer Co., Montpelier, C.
McGovern Granite Co., Montpelier, C.
Maloney, M. G., Montpelier, C.
Mills & Co., Montpelier, C.
National Granite Co., Montpelier, C.
Patch & Co., Montpelier, Quarry at Adamant.
Pecu Brothers, Montpelier, C.
Pioneer Granite Co., Montpelier, C.
Poulin, J. Granite Co., Montpelier, C.
Sheridan & Poole, Montpelier, C.
Sibley, Clark E. Montpelier, Q.
Wetmore & Morse Granite Co., Montpelier, Q.

NORTHFIELD AND BETHEL.

Brusa Granite Co., Northfield.
Burns, J. L., Northfield, C.
Cross Brothers Co., Northfield, C.
Ellis, E. B. Granite Co., Quarry. Bethel, Cutting works at Northfield, Q. C.
Empire Granite & Quarry Co., Northfield, C.
Osgood Granite Co., Northfield.
Pelaggi, N. & C., Northfield, C.
Phillips & Slack, Northfield, C.
Woodbury Granite Co., Bethel, Q. C.

WATERBURY.

Carr, W. L. & Co., C.
Drew, Daniels Granite Co., Q. C. Quarry at Adamant.
Oclair & Anair, Waterbury, C.
Perry Granite Co., Waterybury.
Union Granite Co., Waterbury, C.

HARDWICK AND WOODBURY.

Alberitini & Co., Hardwick, C.
American Granite Co., Hardwick, C.
Bardelli, G. & Co., Hardwick, C.
Bailey Bros., Woodbury, Q.
Calderwood & Merriam, Hardwick, C.
Crystal Brook Granite Co., Hardwick

Donald, Wm. B., Hardwick, C.
Emerson & Bond, Hardwick, C.
Eureka Granite Co., Hardwick, C.
Fletcher, E. R., Woodbury, Q. Hardwick, C.
Hannigan, John, Woodbury, Q.
Hardwick Polishing Co., Hardwick.
Hay, John., Hardwick, C.
Howard & Martin, Hardwick, C.
Jackson, Howard B., Hardwick, C.
James Granite Co., Hardwick, C.
Murch, E. R., Hardwick, C.
Pinera, Ramon, Hardwick, C.
Purdy, F. A., Hardwick, C.
Robie, L. S., Woodbury, Q.
Smith, Ashley, Hardwick, C.
Stewart Granite Works, Hardwick, C.
Stewart & Douglas, Hardwick, C.
Vermont Quarries Co., Hardwick.
Woodbury Granite Co., Hardwick. Quarries at Woodbury, Buck Lake and Bethel. Works at Hardwick and Bethel.

GROTON AND RYEGATE.

Augustini, Ryegate.
Anderson, Axel, South Ryegate, C.
Beaton, James, Ryegate, C.
Beaton, A. T., Ryegate, C.
Benzie & Company, Groton, C.
Blue Mountain Granite Works, Ryegate, C.
Brock, S. E., Ryegate, C.
Cerutti, C. F., S. Ryegate.
Checchi, A., Groton, C.
Craigie, James, Ryegate, C.
Eliason, C. E., S. Ryegate, C.
Hartz, L., S. Ryegate, C.
Hendry, C. H., Groton, C.
Hosmer Brothers, Groton, C.
Nicolo, T., Ryegate.
Leonard, G., S. Ryegate, C.
McDonald, M. F. Ryegate, C.
Rosa Brothers, Ryegate, Q. C.
Ryegate Granite Works, Ryegate, Q. C.
Samuelson, H., S. Ryegate, C.
Zambelli, S Ryegate, C.
Zambion, Peter., S. Ryegate, C.

OTHER PARTS OF THE STATE.

Ayer, E. S., West Danville, C.
Calais Granite Co., Calais, Q.
Chapman, W. J., West Concord, C.
Clark, James, West Dummerston.
Daniels, J. C., West Concord, C.
Goss, A. J., West Danvile, C.
Grant, C. H., Granite Co., Dummerston, Q. C.
Grout Granite Quarry, West Concord Q.
Haselton, Charles, Beebe Plain, Q.
Kearney Hill Granite Co., West Concord, Q.
Lake Shore Granite Quarry, Adamant Q.
Newport Granite Co., Albany, N. Y. Quarry at Derby.
Norton, S. B., Beebe Plain, Q.
Stanstead Granite Quarries Co., Beebe Plain, Q.
Tillcrop Granite Co., West Concord, C.
Union Granite Co., Calais, Q.
Union Granite Co., Morrisville, C.
Welch, Joseph, West Concord, C.
Williamson, Harry W., Concord, C.

Slate.

Tho far behind Pennsylvania in the amount and value of the slate produced, Vermont is far in advance of any other State. Only five or six States produce any considerable amount of good slate, tho there are several others which supply each a small amount. The States which produce the largest quantity are as follows: named in order of production: Pennsylvania, Vermont, Maine, Virginia, New York, Maryland.

Pennsylvania supplies a little more than half of the whole quantity sold in this country; Vermont about half as much as Pennsylvania; Maine about one seventh as much as Vermont; Virginia rather more than half as much as Maine and Maryland somewhat less. All the other States produce only about half as much as New York. Not very rapidly the value of the slate sold from this State is increasing, but this is mainly because the price has increased rather than the quantity. The business, especially that concerned with roofing slate, has on the whole been satisfactory so far as I have reports. By far the larger part of the slate sold in this State is in the form of roofing material. The Northfield area is at present not worked at any point. Nearly all the Vermont quarries are, like that shown in Plate XXXV, deep pits. Sometimes the excavation is two or even three hundred feet deep.

In previous Reports the methods employed in preparing slate for market have been described and in Bulletin 275, U. S. Geological Survey, Dr. T. N. Dale has published a very useful account of the slate industry of the United States. The Vermont slate belt, especially that portion of it which is worked is of small area. Hence, as the quarries are numerous, it necessarily follows that many of the quarries are contiguous or at least very near each other. In some places, such as the "Switchback" the derricks look like a forest of leafless trees. A common beginning for a slate quarry is a strip of land twenty rods wide and of variable length determined by the character of the mass of slate. Pits may be so near that in time the removal of the stone takes away the division between them and thus in time one large quarry may be formed from several smaller ones. A few quarries are more or less horizontal cuts worked into a side hill, but most go down nearly directly or at any rate at a high angle.

There are now about forty companies carrying on the slate business by far the greater number producing roofing slate, a few get both roofing slate and mill stock from the same quarry.

LIST OF VERMONT SLATE COMPANIES.

CASTLETON.

Criterion Slate Company, Hydeville.
Hayes Slate Company, Hydeville.
Hinchey Brothers, Hydeville.
Hinchey, O. & Company, Castleton.
John J. Jones Slate Company, Castleton.
MinogueBrothers & Quinn, Hydeville.
Metalo Slate Company, Hydeville.
Penryn Slate Company, Hydeville.

FAIRHAVEN.

Bedford & Ryan SlateCo., Fair Haven.
Durick & Flannagan, Fair Haven.
Durick & Keenan, Fair Haven.
Durick, Keenan & Flannagan, Fair Haven.
Fair Haven Marbleized Slate Company, Fair Haven.
Jones & Francis, Fair Haven.
McNamara, Brothers, Fair Haven.
Mahar Brothers, Fair Haven.
Vermont Unfading Green Slate Company, Fair Haven.
Victor Slate Company, Fair Haven.
Young, A. B., Fair Haven.

POULTNEY.

Auld & Conger, Poultney.
Eastern Slate Company, Poultney.
Eureka Slate Co., North Poultney.
Frasier Slate Company, Poultney.
Green Mountain Slate Co., Poultney.
Griffith & Nathanael, Poultney.
Hughes-Snyder Slate Co., Poultney.
Johnson, E. J. Slate Co., Poultney.
Roberts & Rowland, Poultney.
Matthews Slate Company, Poultney.
Parry, Jones & Owens, Poultney.
Poultney Consolidated Slate Company, Poultney.
Rice Brothers, South Poultney.

PAWLET AND WELLS.

Layden & Burdick, West Pawlet.
Hughes, W. H. Slate Company, West Pawlet.
Nelson Bros. & Morow, West Pawlet.
O'Brien Brothers, Wells.
Rising & Nelson, West Pawlet.
Roberts, G. T., West Pawlet.

GRANVILLE, NEW YORK, QUARRIES IN VERMONT.

Norton Brothers, Granville, N. Y.
Owens, O. W. Sons, Granville, N. Y.
Sheldon, F. C., Granville, N. Y.
Vermont Slate Co., Granville, N. Y.

Soapstone and Talc.

Early in the present year Professor E. C. Jacobs of the University joined the Survey and undertook to make a thorough study of the Soapstone and Talc deposits of the State. There has not been time at Professor Jacobs disposal to make possible complete examination of the various deposits still less to investigate the material found in these deposits. This is now in hand and a more full report may be expected in the State Report following this. For the present Professor Jacobs has furnished the following Preliminary Report:

The talc and soapstone mined in the United States, comes almost wholly from a mineralized belt running from Georgia northeastward through the Atlantic States and in New England through Western Massachusetts, Vermont and into New Hampshire. In Vermont the talc and soapstone belts are somewhat distinct from each other, the talc running northlerly into Canada while the soapstone belt cuts across the southeastern part of the State and extends into New Hampshire.

For several years Vermont has stood second in the production of talc and soapstone, considering these minerals together, and according to the latest report of the U. S. Geological Survey for 1911, Vermont showed the largest per cent increase in quantity (14%) and the largest per cent increase in value of products (46%) of any State in the Union. The total quantity mined in Vermont in 1911 was 29,488 short tons valued at $200,015, or an average of $6.78 per ton.

The uses for talc in all its grades are constantly increasing and there seems to be a bright future for the talc industry in Vermont. The soapstone production which is much older than the talc seems to be declining and a considerable amount of the Virginia product is being imported into the State to keep up the manufacture of soapstone articles.

SOAPSTONE.

Soapstone is being mined at the present time by the Union Soapstone Co. at Chester Depot and by the Vermont Soapstone Co. at Perkinsville. The Union is mining its stone from the Davis quarry two and a half miles from the mills. It is being worked intermittently and was shut down when visited by the writer. The Vermont Soapstone Company is operating steadily and turning out its standard products of wash tubs, sinks, foot warmers, griddles, stoves, furnace linings and so forth. The new mill which replaces the old one and stands on the opposite side of the Black River was built in 1910 and is operated by water power from the river. It employs about a dozen hands. The quarries are located about a mile from the mill on the east side of Hawke

Mt. These quarries have been producing a fine quality of soapstone for over fifty years and are getting pretty well worked out. Prospecting with diamond drills has been carried on in the neighborhood of the old workings but the drill cores obtained have so far failed to reveal a good quality of soapstone. The company is therefore importing a considerable quantity of cut slabs from Virginia.

The old quarries at Grafton and Athens are idle.

TALC.

Talc is being actively mined this spring. The talc mines active and inactive extend from Waterville on the north to Windham on the south and most of these mines were visited by the writer during the last few months. At Waterville, mining operations ceased six years ago, and the mill has been partly dismantled. The teaming charges for the long six miles haul seems to have been mainly responsible for the closing of the plant. The talc deposit is of very good quality, consisting of a massive form which best lends itself to milling. and it is unfortunate that mining operations had to be suspended because of the remoteness of the mine from the railroads.

At Johnson the American Mineral Company have been working a deposit on the lower slope of French hill within a stone's throw of the railroad for the past six years. The talc is of the foliated variety and of excellent quality, some of the best in Vermont. A production of from 20 to 25 tons per day is reported.

In the northwest corner of Moretown on the farm of Mr. D. P. Deavitt a deposit has been known for over a century and small amounts of talc have been mined from time to time for foot warmers and other articles. It is reported that this deposit has been bought by Burlington parties and that it will shortly be opened up and worked commercially. The talc is massive and its quality is said to be unusually good.

An extensive talc deposit, generally called the Moretown deposit occurs in North Fayston near the Moretown line. It was opened up about twelve years ago first by the International Mineral Co. and has had a varied existence. A great deal of talc has been mined and the milling plant is very elaborate. The name of the company has recently been changed to the

American Quarry Co. The plant is closed down at the present time, owing it is said, to litigation and no information could be obtained as to further plans.

The Eastern Talc Co. of which Mr. C. F. Hollis is superintendent is conducting extensive mining and milling operations in this district. The company's old plant is located beside the railroad at East Granville and has been running since 1906. The Talc ground here is of the poor quality known as grit and is used in the manufacture of various grades of paper. The output is said to be from 20 to 30 tons per day. In the Rochester district talc is being produced from the Williams mine which lies on a mountain side east of the town of Rochester and from the Greeley mine which is near the tracks of the White River railroad seven or eight miles below Rochester. These mines were formerly worked by the U. S. Talc Corporation later called "The Standard Talc Co." The mines and milling plant were taken over by the Eastern Talc Co. two or three years ago and are now being run in conjunction with the East Granville property. The Williams mine is located as said before on the mountain side three or four miles from Rochester. The general direction of the strike is north and south, which is in fact the strike of practically all of the Vermont deposits, so far located. The dip is nearly vertical and the mine is the deepest in the State, being now bottomed at about 350 feet. Both the foliated and massive varieties of talc occur here though the massive largely predominates. The quality of the talc is exceptionally good and a large amount of it is being produced. The mineral is teamed down the mountain to the mill, located in the lower part of the town. The mill is an up to date establishment, well equipped for turning out a large amount of ground talc efficiently. Several grades of ground talc and grit are produced and about 1600 tons of material of all grades are being shipped for use in bleacheries, pulp mills, rubber works, roofing paper concerns, and for medicinal uses.

The Greeley mine the product of which is ground by the Rochester plant is opened by a tunnel running southward into the mountain side. The only commercial product of this mine is talc grit although some beautiful foliated masses occur. In the east workings some fine calco pyrite has recently been found. Its significance is as yet undetermined.

In the southern part of the state talc is being produced and ground by the American Soapstone Finish Co. of Chester Depot and the Vermont Talc and Soapstone Co., of Windham. The American Soapstone Finish Co., has obtained its material for the last six years from the Carlton quarry which is about 2½ miles from the mill. The material mined is a rather poor quality of grit talc containing considerable disseminated magnetite and mica. The material is ground and sold for the manufacture of roofing paper and for a wall finish. There seems to be an enormous amount of material at the Carlton quarry and it should keep the mill supplied for many years to come.

The deposit at Windham has in the past been mined and its material ground and teamed ten miles to Chester Depot. It has been worked in this manner for the last twelve or fifteen years. Presumably with the idea of reducing costs, a mill is now being built by the railroad track at Chester Depot just east of the Union Co's. plant. No information could be obtained from the deposit said to be at Reedville.

In addition to the above report may be given the following from a letter received from Mr. James E. Gay manager of the Reading Talc and Asbestos Company. The mine is in Hammondsville a village in Reading. There is a shaft sixty five feet deep and there appears to be a large mass of talc. Some of the talc is quite free from grit, some is not so good. There has been considerable work in the way of development, but the mine is not at present worked because of want of capital. One great obstacle is the distance, ten miles, from any railroad.

FELDSPAR.

On the road from Chester to North Springfield a large deposit of feldspar has recently been opened up by the A. L. Stone Manufacturing Co. Mr. Stone claims that he has a deposit a thousand feet wide and of naturally unknown depth which he has traced for a mile or more. A small mill has been erected for grinding the mineral which is being marketed at the various porcelain works of the country. The feldspar consists of both orthoclase and plagioclase and seems to be free from objectionable minerals.

CHESTER CHALYBEATE SPRING.

Mineral springs have long been known in Vermont. This one is located on the property of Myron W. Chandler in the northern part of the town of Chester, Windsor County, Vt, 2½ miles from Gassetts Station (Rutland R. R.). The water issues from the side of a bank in a considerable quantity at a temperature of 48° F and has long been known for its curative properties. The water is colorless and almost without taste or odor although it quickly discolors containers by its content of iron. Chemical analysis made by S. D. Hayes of Boston shows that one U. S. Standard gallon contains 6.46% of mineral matter composed of alkaline earth and iron salts.

Clays.

Aside from the use of clay for making brick and tile which far exceed in value all other clay products in this State but which do not require special discussion, clay is dug for commercial purposes in only three localities, Forestdale, near Brandon, Bennington and Rutland. Clays from which some sort of brick can be manufactured are common and in Vermont, as elsewhere, clay has been burned in the form of bricks from the days of the first settlers and tho Vermont produces only a comparatively small amount of brick, still these are about two thirds of the total value of our clay products. Formerly pottery of different kinds was produced at several localities, notably at Bennington where many years ago white ware was manufactured from kaolin, ground quartz and feldspar. All the forms of this industry have long since passed from the State and so far as I know, no pottery of any sort is now manufactured here. Bricks are made in a number of places and the total value is about $65,000 annually varying with the activity in building. At Forestdale, Messrs. Horn Crockett & Company are carrying on a thriving business. In the locality of the works of this company there are several kinds of clay differing in color and to some extent in character, but kaolin is alone worked. This is freed from the silicious sand with which it is mixed, ground and dried and shipped as a fine white powder.

At Bennington there are two firms engaged in digging and shipping, after suitable preparation, a light yellow ocher. This substance has been mined in Bennington and Shaftsbury for many years. Formerly, its main use was as a pigment but now little of it goes into paint the principal use being as a filler in linoleum. What in past years has been known as the Godfrey mine is now carried on by E. L. Sibley, who is actively working the deposit. The old drift has been abandoned and a new one

extending over two hundred feet into the bank supplies the clay which, after being freed from grit, and silica, is ground and sold. This plant sells several hundred tons annually. The deposit has been worked since 1838. Within a year what has been known as the Adams mine has been taken hold of by Mr. E. F. Rockwood and is now being refitted and all necessary preparations made for digging the ocher and putting it upon the market. As at the Sibley mine, the ocher is found in a high bank or ridge into which a tunnel has been dug. In some of the ridges about Bennington there appears to be a very large amount of ocher which is underlaid by limonite as might be expected since the ocher is itself an earthy form of iron ore. Apparently a very considerable amount of iron ore, limonite, could easily be obtained in several localities about Bennington if it could be utilized. Somewhat nearer the town than the ocher bed is a deposit of kaolin which is now worked by S. C. Lyon & Brothers. The clay is white with a little bluish cast and is found in abundance. About a thousand tons are annually sold by this firm.

As all the clay must have the silica washed out of it before it is salable and as heretofore this part of the preparation for market has been done in large basins or vats out of doors as is also done with the ocher, it has obviously been impossible to do much in cold weather, but this fall changes in the works are in process of construction which will make it possible to work thru the winter and thus greatly increase the output.

A large and increasing business in several kinds of clay products is carried on by the Rutland Fire Clay Company of Rutland. The work and buildings of this company have been described with illustrations of a part of the plant in the Sixth Report. There is little to add to this except to notice that of late the sales have rapidly increased. There are large deposits of the several kinds of clay used. This company make a fire proof wall plaster, stove lining, fire brick.

Lime.

When lime was difficult to obtain except as it could be burned from local stone there were small and rude kilns in many parts of the State. Much of the limestone used in these primitive kilns was impure and made a correspondingly poor quality of lime. Most of these have been long ago abandoned and in their place there have arisen a few large establishments located where there is stone from which good lime can be made. All but one of these are located in the western part of the State as it is here that most of the limestone best adapted to the purpose is found. These all manufacture excellent lime, tho it is not all alike. The following are the principal producers of lime in this State: The Amsden Lime Works, L. C. White Manager, Amsden; Brandon Lime and Marble Company, H. B. Huntley Manager, Leicester Marble-Lime Company, J. A. Swinington, Manager, Leicester Junction; Green Mountain Lime Company, New Haven; W. B. Fonda Lime Company, St. Albans; Swanton Lime Works, J. P. Rich, Swanton; G. B. Catlin Lime Kilns, Winooski.

Metals.

There is little to be said as to the metallic ores found in Vermont that will not repeat what has been written in former Reports. As is well known, ores of several of the metals are found in the State, but none of them in such quantity or condition that it is profitable to carry on mines. The copper ores in Vershire, Strafford,and Corinth have been worked, some of them extensively and for a time profitably, but in the long run they have not paid and at present no mines are worked. The ore, mainly chalcopyrite, in all these mines is of low grade and not easily reduced. There is some possibility that the large masses of ore which still remain may at some future time be mined by new processes and more advantageously treated. The numerous small beds of iron ore which are found in quite a number of localities in the State were in past time some of them used, but for many years there has been no iron mining in Vermont. In his article on the Strafford Quadrangle Dr. Hitchcock has discussed the copper ores of the district and in Bulletin 455 United States Geological Survey on the Copper Deposits of the Appalachian States there is the most complete account of the Vermont localities that has been published. In much smaller quantities gold, silver, lead and molybdenite are found in the State, but nowhere in anything like such amounts as to warrant mining of any sort.

Asbestos.

The only mine that produces asbestos is that at Chrysotile on the east side of Belvidere Mountain. At this place The Chrysotile Asbestos Corporation, W. G. Gallager President and Manager, has been actively engaged for several years. The previous Report contains so full an account of this locality and its mines and mill by Dr. C. H. Richardson that it needs but brief mention here. Only four States produce asbestos and only two of these produce the more useful variety, chrysotile, these are Vermont and Wyoming. Georgia and Idaho have mines of the amphibole varity. The chrysotile asbestos is not only better for all purposes, but it can be used in many ways not possible to the other form. The demand for asbestos is continually greater and there appears to be a very encouraging outlook for the business. At present two thirds of the asbestos used in the United States is imported from Canada. As the material obtained at the Vermont mine according to Dr. Cirkel "Compares favorably with that found in the Canadian mines" it is not unreasonable to expect a large growth in the business of the establishment at Chrysotile.