REPORT

OF THE

STATE GEOLOGIST

ON THE

MINERAL INDUSTRIES AND GEOLOGY

OF

VERMONT

1929-1930

SEVENTEENTH OF THIS SERIES

GEORGE H. PERKINS
State Geologist

FREE PRESS PRINTING CO., BURLINGTON, VT.

STAFF OF THE VERMONT GEOLOGICAL SURVEY
1929-1930

George H. Perkins, *State Geologist, Director,*
University of Vermont.
Elbridge C. Jacobs, *Assistant Geologist,*
University of Vermont.
Charles H. Richardson, *Assistant Geologist,*
Syracuse University.
Clarence E. Gordon, *Assistant Geologist,*
Massachusetts Agricultural College.
Miss Marion Hubbell, *Assistant Geologist,*
Brooklyn, N. Y.
Frederick A. Burt, *Assistant Geologist,*
Mechanical and Agricultural College of Texas.
E. J. Foyles, *Assistant Geologist,*
Rochester University.

CONTRIBUTING GEOLOGISTS

John E. Wolff,
Harvard University.
H. F. Perkins,
University of Vermont.
H. W. McGerrigle,
Dartmouth College.

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STATE OF VERMONT

OFFICE OF STATE GEOLOGIST

BURLINGTON

To His Excellency, John E. Weeks, Governor:

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

This Report includes a discussion of various geological features as found in Vermont, written for this volume by a number of competent geologists, as is shown in greater detail in the Introduction which follows. As heretofore in these Reports, articles of value to students of Vermont Geology are presented.

Respectfully submitted,

GEORGE H. PERKINS,

State Geologist.

DECEMBER 1, 1930.

INTRODUCTION

This is intended only as a brief summary of what is contained in the following pages. As has been noticed in preceding volumes of these Reports the geology of Vermont is for the most part exceedingly complicated and can be clearly understood only after extended and careful study. To elucidate as far as possible the history of the rocks of the Green Mountain mass as well as that of the rest of the State and to present the results and conclusions reached by such study is the main purpose of these Geological Reports, which have been issued biennially for over thirty years. As far as it has been attainable, all that could be found that helped to a good understanding of Vermont geology has been included in the volumes published.

As in most of the former volumes, so in this, the aid of students of Vermont geology has been sought and, as the contents of the volumes shows, in many cases obtained, so that in a file of these Reports most that has been published in respect of Vermont geology can be found, in most articles as original contributions, in some as reprints. "The Bibliography of Vermont Petrology," by Miss Hubbell, shows in a very useful fashion what has been written upon this subject; besides this considerable material not within the scope of Miss Hubbell's paper is yet unpublished.

As far as possible it is desired that the discussions in these Reports shall be as free from technicalities as may be so that the various papers included shall be as intelligible as they can be to readers who have little geological training. In some cases the use of technical terms is unavoidable, for none other are in existence.

In the first paper on "The Physiography of Vermont," by the Geologist, the physical features of the State, lakes, mountains, rivers, etc., are more or less fully described, the object, as indicated in the paper, being to interest Vermonters in the more obvious features of the State and to some extent to understand how they came to be as we now see them.

Connected with the surface features of Vermont, really forming an important part of them, are the altitudes of towns in the State. Some idea of the great irregularity seen in the surface of

Vermont is shown by the facts given in the second paper, by H. F. Perkins, which presents a summary of a careful study of the surface, as determined by the U. S. Topographical Survey now well towards completion.

Miss Marion Hubbell has placed all future students of Vermont geology under obligation by means of her "Bibliography of Vermont Petrology." Beds of ocher are found in several localities in the State and a very interesting and complete account of them will be found in Professor Burt's paper. Professor Wolff has kindly given permission to reprint his paper on a "Monadnock in Vermont." As a supplement to a paper on "The Rocks of Vermont," published in the last Report, the Geologist here gives a brief account of "The Minerals of Vermont." Professor McGerrigle adds to our knowledge of the geology of northwestern Vermont by his article which gives the results of his recent study of the region, the geology of which is by no means well understood, or until lately has not been. Professor C. H. Richardson continues his excellent study of Vermont geology southward into Springfield, Grafton and Rockingham. It is hoped that he may be able to carry forward his work until the Massachusetts line is reached. E. J. Foyles gives a very interesting paper on the "Geology of East Mountain." This mountain, in Mendon, presents a complex structure and is well deserving of the study of geologists.

The State Geologist gives some statement of the quarries now operated in Vermont.

PHYSIOGRAPHY OF VERMONT

G. H. Perkins

In the Eleventh Biennial Report on Vermont Geology, 1917-1918, the writer published an article having the above title. As there has been considerable demand for information upon this subject and as the volume above mentioned has for several years been out of print, it has seemed best to give in this Report a revised and enlarged republication of the former article.

The Physiography of Vermont means, in this article at least, the Surface Geology, that which most obviously appears as one looks about him and sees the mountains, hills, rivers, lakes, plains and all other natural features that may be spread before him. It is the most recent phase of the geological history of the State. But if one wishes to know why these features are what they are, how they have come to be what he sees, he will not be content with a merely superficial investigation. The why is this or that part of the landscape evidently involves vastly more than what is obvious, prominent, readily seen. The seen everywhere is related closely to the unseen, as the effect to the cause. The surface involves the deeper and more intricate parts of the structure. In its completeness, the physiography of any region must necessarily involve the cause as well as the seen effect. Vermont is as it is today because of the action of forces which have been recently, geologically speaking, in action surely, but also because of all that in past time, however remote, have been active. The physiography of Vermont more than that of many parts of this country or indeed of the world, is complex and in many cases difficult to understand. There has been great turning and overturning, placing and displacing combination of the chemical elements to form rock in one place, decomposition of older rocks in another.

In the mountainous regions and I need not add that most of Vermont is more or less mountainous, this is especially true. The record which is written in our very varied physical features may be readily interpreted in some localities, with greater difficulty in others, while in some places it seems impossible to reach a sure conclusion. From the articles on the "Rocks of Vermont" in the Report immediately preceding this and that on "The Minerals of Vermont" in this volume some idea of the vast changes which have taken place in past times may be gained. During the many ages that have elapsed since the foundations of Vermont were laid down—when? who can say. It is not difficult at least for a geologist to picture in imagination, some of the many changes, transformations, metamorphoses that have taken place in the physiography of the State. Nor is this all imagination, for we have in every ledge, mountain, valley, sand plain, gravel bank, clay deposit a more or less complete record of the changes that have been effected. What is necessary is the ability, the knowledge, the vision to read the record aright. Difficult as it often is to interpret correctly the record that we find, the difficulty is greatly increased by the occurrence in some localities of more than one transformation, so that the record of one age is much obscured by that of the next and it may be completely obliterated.

The origin and causes of many, most, of our Vermont lakes, rivers, gravel banks, sand plains, is easily discovered, but when we would find the how and why of our granites, marbles, schists, etc., we cannot be as sure. And yet, though often not shown at the surface by some of the overturnings which are so common or by the enormous erosion which in some parts of the State is very plainly indicated, or, as in case of our granite by the driving from below by volcanic action as melted material, beds which otherwise would be deeply buried. Thus it not infrequently happens that the changes by which the origin or character of the materials on the outside of our earth have been changed, below the surface all may be very puzzling.

By means of the skill, patience and untiring labor of geologists we are gradually coming to understand how Vermont came to be what and as it now is. Comparatively modern methods such as slicing the rocks and studying thin transparent sections microscopically and other methods of exploration have within the last few years added greatly to our knowledge, and the end has by no means yet been reached. It may be useful at this point to call attention to the advantage, if one is to really understand the physiography of any region, of really seeing what is presented by the physical features which may be spread out before him. Enjoy the view which is before you but if this view of whatever sort it may be, is to be fully enjoyed, it must be seen by eyes that really see, that not merely glance over what may be a charming picture.

Any fine landscape is worthy of very careful examination and study. It is often difficult, perhaps impossible, to absorb, to well understand, what we see, but it is certainly true that the more carefully and thoroughly we examine a landscape the more truly do we see with the understanding eye. And this means the more complete will be the enjoyment of what is seen. Everyone enjoys a fine prospect, but there are many degrees of the enjoyment. As has already been intimated, the delight which should come to one, to the one to whom the view has long been familiar,

to the transient guest, to the speeding tourist, is in no small degree proportional to the care which he exercises in his looking and to the understanding with which he takes it into his heart.

I am writing especially to those whose good fortune it is to live at all times surrounded by inspiring scenery, which is the case with most Vermonters, for I doubt if anywhere there is greater charm, beauty, alluring bits of landscape than are found in many parts of Vermont. (I am not a native of the State.) I use the above terms advisedly, I am not writing of scenery that is grand, overpowering, stupendous, but of that which is delightsome, fascinating, attractive. And it is not only with some hope that those who care to read these lines may in some little fashion at least, understand the natural beauty that is all around them that I am writing, but also that they may realize how much there is to see that they have perhaps never noticed. It is most true that the physiography of a region is its surface geology. It is as true that the physiography is the scenery. It goes without saying that the more completely one not only sees what is before him, but knows something, the more the better, of how this which is so attractive has come to be what it is, the greater is his delight in seeing.

If one can realize that this which so charms him has come to be what it is by the orderly action and interaction of mighty but orderly forces and that the greater his knowledge of these forces the greater pleasure he will experience as he looks at the results of their activities. In fact, for other reasons truly, but in no small degree, I am writing this article that those who look may look with not only enjoyment, but as well with knowledge as they go about in the midst of our natural attractions. It is true, as has been noticed, that while it is not yet possible that anyone, even though he be a good geologist, can tell the complete story which the physiography of Vermont may reveal, yet all can know enough to understand that there is a story and a story full of interest. A little knowledge is surely better than none at all.

Dr. James Geikie has written in a very suggestive book on "The Scenery of Scotland." The problem of the origin of the scenery of any part of the earth's surface must obviously include a consideration of the following questions:

1. The nature of the materials out of which the scenery has been produced.

2. The influence which subterranean movements have had upon these materials, as, for instance upon their displacement, fracture, plication and metamorphism and whether any evidence can be recovered as to the probable form which they assumed at the surface when they were first raised to form land.

3. The nature and effect of erosion which they have undergone since their upheaval.

4. The geological periods within which the various processes were at work, to the conjoint operation of which the scenery is to be ascribed.

Geologically Vermont is not a new area, if we go back to the times when the foundation of that which is now visible was laid. With very few and small exceptions, all the rocks which are seen are very old, as compared with many parts of the earth. They are none of them of the very oldest, but they are very ancient.

A brief review of the at present recognized geological ages that are made out in Vermont cannot fail to be helpful in understanding something about the structure of the solid foundations of the State. I do not wish to say more as to the age of the different mountains and other physiographic features of Vermont except to repeat that it is a very old land area.

All the essential data by which the age can be ascertained are so uncertain that, as it seems to the writer, an estimate given in exact figures can be only an estimate and at that may not be of much value. It must always be an estimate based on uncertain, and in some cases unknown conditions. Of much that tells us the age, etc., of our mountains and ledges we may be pretty certain, of much we are far from certain.

It is, therefore, best to use general rather than specific terms as to our rock formations. Of course when we find beds of rock one below another, lying in undisturbed order there can be little doubt that the lower beds were laid down before those above them. A relative chronology in such conditions is at least probable if not sure, but when, as in most of Vermont, we find the beds upturned, overturned, folded, crushed, what shall we think? However, notwithstanding all that is not sure, there is enough that we may well believe to be sure to make the study of our physical conditions exceedingly satisfactory. We may never go back to the beginning, but we are very sure that in our Vermont strata we can go back towards that beginning which must have been.

It is pretty certain that as the Vermonter, native or visitor, looks over Lake Champlain and sees the Adirondack Mountains, he sees rock formations older, at least mostly, than anything in this State. That is to say that land above the primeval ocean appeared earlier in eastern New York than in the area that is now Vermont. Certainly, the forces that have been mentioned in connection with the Vermont mountains must have been active for a long period or periods, in the Adirondack region, and as is true of most mountains, the rocks and beds now found are very different from those first formed. Sand is always ground rock

and sandstone is undoubtedly consolidated sand. The oldest sedimentary beds in Vermont are sandstones. Although it is not proposed to give an account of the various divisions of past time which are based mainly upon the character and changes which plant and animal life has passed through from most ancient time to the present, nor fully as to the physical changes which are indicated, in the rocks of various geological ages, yet it may be interesting to indicate the location in the geological scale occupied by the ledges, etc., which are to be seen in Vermont. As briefly as possible the different ages represented in Vermont will be taken up. As now used by most geologists, geological time is divided as follows (beginning with the latest periods before the present we have):

(Only the major subdivisions of the geological scale are here given)

	Pleistocene. Abundant in all part of Vermont.
Cenozoic	Tertiary. A small linear area in western Vermont.
Mesozoic	Not found in Vermont.
	Carboniferous. Not found in Vermont.
	Devonian. Probably granite and some other rocks.
Paleozoic	Silurian. Probably not in Vermont.
	Ordovician. Abundant in western Vermont.
	Cambrian. Abundant, especially in western Vermont.
Pre-Cambrian	Probably abundant in some of the metamorphic rocks.

By examining the above it is evident that a very large part of the State is at present occupied by Paleozoic strata, mostly Ordovician and Cambrian. That is so far as distinctly determined strata are found, but how much of the mountain masses and of the lower areas of the State, now occupied by metamorphic rocks should be placed below the Cambrian is not accurately known.

It is entirely probable that in the interior and deeper parts of the Green and Taconic Mountains there are rocks much older than any now accessible. East of the Green Mountains few fossils the sure proofs of age have been found as will be shown later, and none older than the Ordovician. Usually when the geologist can find no fossils he is compelled to be uncertain as to the age of the rocks he is studying. Still there is good reason to believe that the main rock ledges of many of our towns are older than the Ordovician and some older than the Cambrian. As anyone carefully reading this article will understand the outlines of the Champlain Valley and therefore of much of what is now Vermont were drawn millions of years ago. It is probable that in no area not larger than the Champlain Valley more satisfactory evidences of past geological history can be found. As an outline of the history which is told by this region—a mere brief outline—let us take up it in some detail. Most of this as has been noticed and as will be shown in the following pages, is very old, but the later periods bring us into the present. Indeed the end is not yet, nor will the end come while the world is as now. We speak of geological time as if it were something quite different and distinct from the times we live in but it is not so. Of course the activities of many forces may vary at different times, but their action does not cease at the close of the last geological period—the Glacial. Changes are now going forward, the world is still in the making.

Following the list of geological ages given, let us briefly examine each in its order, except that it will be better to invert the list, consider the oldest first and proceed to those that are later. When we thus study the ages as they come and go it becomes very evident that what is now Vermont, as seen in its surface features, is entirely due to what has taken place in the past. What the tourist sees now is the result of what has been in the days long since gone by, perhaps thousands of years ago, perhaps millions of years. Natural forces take no account of time; they may act quickly, more often very slowly, and it is not always easy for even a geologist to so adjust his chronology as to account for what has evidently required very long periods. Geological time cannot be measured by our present scale. I very much doubt if any of us can comprehend adequately the vastness of time or the stupendous forces that the geologist has to deal with.

As we know, there must have been a time when the foundations of Vermont were laid, but we shall never know exactly when or what they were. About all that can be asserted is that it all occurred in dimly seen and imperfectly known past ages. Nearer the beginning than very much of the earth that can be studied but by no means the beginning. But all such are not fossil bearing, and metamorphism has entirely altered the character of the rock, wholly obliterating whatever indications of past life they may have contained.

It will probably make some of that which is to follow more intelligible if we briefly review the larger geological periods as now accepted and mention some of the localities where fossils may be collected.

THE PRE-CAMBRIAN

This general title includes all that goes before the Cambrian. Taken comprehensively the name must include the unknown and unknowable era between the beginning and the known Cambrian. As to most of this era our knowledge is very indefinite and uncertain. While it is probable that in the Adirondack region immediately west of the Green and Taconic Mountains, the larger part of the rocks are older than the Cambrian, it is probable that a large part of the rocks in Vermont are later (Cambrian and Ordovician). West of the Green Mountains very few of the rocks which are seen on the surface are older than the Cambrian, but in the mountains and between them and the Connecticut River some of the ledges in many of the towns are regarded as older. As many of these rocks are metamorphic schists, etc., it is not easily determined in all cases to what age to assign them. It is pretty well established that during the immensely long period which must have elapsed between the pre-Cambrian and the Cambrian very great changes took place. There is evidence enough of this, but just what these changes were is not readily discovered. Of this Professor Coleman writes: "At present no part of the earth's history is attracting more attention than the pre-Cambrian and we are gradually disentangling obscure relationships and opening a wonderful vista into the past, which has already doubled the length of geological time and bids fair to make the post-Cambrian record only an appendage to the far more important pre-Cambrian story of the world." Imagination fails us when we attempt to comprehend and picture in our minds the convulsions, turning and overturning, upheavals, dislocations, metamorphosis of materials and all that must have been in action during this vast period. Geologists have divided this vast time before the Cambrian into several divisions and in the rocks of the later imperfect fossils have been found showing that before the Cambrian, which for a long time was supposed to be the oldest age in which life existed, some of the lower forms did live. In Vermont no fossils have been found below the Cambrian. Evidences of early life there may have been, but metamorphism has wholly obliterated all traces of them. The life of the Cambrian as shown by the numerous fossils is much of it of such a character as to compel the belief that simpler forms existed long before the beginning of that age, but as mentioned above, only more or less fragmentary specimens indicate this, and these are found only in strata which are referred to the beds nearest to the Cambrian, that is the upper beds.

THE CAMBRIAN

The oldest stratified and fossil-bearing rocks in Vermont are undoubtedly Cambrian. These are most clearly determined in western Vermont, west of the Green Mountains. The best known and most conspicuous of these beds is the red sandrock. Shales, limestone and some slate are also found in the Cambrian. It is evident to a geologist who examines western Vermont that an unknown, but very large mass of Cambrian rock has been eroded and carried away so that what is now seen is but a remnant of a great sheet that once covered much of the region between the Green Mountains and Lake Champlain. The common name of the Cambrian formation, red sandrock, sufficiently indicates its character, but while most of the beds are composed of this rock, a calcareous sandstone, more or less dolomitic, yet there are beds of dark shale, and dark gray limestones, especially in the northeastern part of the State. Parts of these beds abound in fossils, a large part is very barren. So of its present condition, some is little disturbed, some much upthrust or folded. More will be noticed of the Cambrian remnants in writing of the red sandrock hills later on. For the present it will suffice to mention Snake Mountain, Mount Philo and the cliffs at Red Rocks and Rock Point near Burlington, as examples of the Cambrian. These are all lower Cambrian, but farther north in St. Albans, and about that region there is middle and upper Cambrian, though there is much less of these than of the lower. Some of the beds of the lower Cambrian in Vermont are more calcareous, though a part of the red sandrock formation, but these "Dolomitic Marbles" are not true marbles though very handsome.

THE ORDOVICIAN

While the Ordovician beds are found, as will be seen, on both sides of the Green Mountains, the beds on the range are all more or less metamorphosed and exhibit very few fossils but along the shores of Lake Champlain and on the larger islands nearly all the periods of Ordovician limestone and shale are often well displayed and in many localities abound in characteristic fossils. There is a little sandstone but most of the rocks of this age are limestones and shale. Where there has been metamorphism on the west, marble, often in great variety of color and texture is found; all of the commercially valuable marbles being west of the Green Mountains. These marbles are all highly calcareous and by variety in the material contained, more than a hundred different colors, shades or veining are produced, though not all on sale, but they can be supplied if called for by the trade. East of the Green Mountains it was supposed for many years that no, or very little, fossiliferous rock could be found, but Dr. C. H. Richardson who has long worked on the Vermont Survey, has during the years of his investigation collected what he regards as unquestionable fossils in the partly metamorphosed schists which extend from near the Canada line south to the Massachusetts line. The fossils found are all Graptolites, identified by Dr. R. Rudeman and representing several species. From these fossils it appears

to be certain that large areas of Vermont east of the Green Mountains are occupied by Ordovician beds. It is also very probable that in the mass of rock that now composes the Green Mountains there is much Ordovician material, but highly metamorphosed.

DEVONIAN

No Devonian fossils have been found in Vermont, but beds to which one and another geologist has assigned some of the metamorphic rocks found east of the Green Mountains are of this age and many consider the great masses granite, of which more later, as the Devonian, but no fossils have been found to confirm any theory as to the real age of these rocks. A very short distance across the Canada line, north of Newport, unquestioned Devonian limestone appears on Owls Head Mountain.

It is by no means impossible that more or less of the metamorphic rocks in the southern part of Vermont may belong to this age, but as yet, proof is wanting.

The same may be said of the granites. Probably not all these intrusive masses were thrust up at the same time, but at different periods. Still, while this may be true of smaller upthrusts, it seems to be the general opinion that most of the Vermont granite was thrust up during Devonian time. Some granite is older, some younger.

No rocks in Vermont show any evidence that they should be assigned to Mesozoic time.

TERTIARY

In what is known as Cenozoic time there are two grand divisions, Tertiary and Quarternary or Pleistocene. The Tertiary is only to a small extent represented in Vermont. There is a small strip which can now be traced and which may very likely have been larger in ancient time, extending from Colchester to Bennington where clays referred to this time are well exposed. Small beds of iron, manganese, larger beds of clays of different sorts and small beds of lignite are found in this formation. There are no beds of rock and the ore beds are small and have been long since abandoned, though some were formerly worked for a greater or lesser period. To the geologist the outcropping of the clays, manganese, iron and lignite at Forestdale, about three miles east of Brandon, is most interesting. Here in a very singular mass of lignite, most of it imbedded in white clay, the only fossils have been found. This locality formerly very active, has long been abandoned except a single mill where the white clay was dug for some years. The lignite is, or has been, found in several localities in this region in well borings, but nowhere in any quantity except at Forestdale. In more than one respect this lignite is a geological puzzle. I have never seen any exposure of the lignite at the surface, nor do I find any record of an outcrop, but in digging for kaolin and other clays at Forestdale a bed of lignite was reached below the surface. At the locality named above the lignite is covered by from fifteen feet of drift down to thirty feet or more. In the fourth and fifth volumes of the Reports of the (State Geologist, 1903-1906) full accounts of this lignite illustrated by many plates will be found. In 1903 during a shortage of coal 150 tons or more of the lignite (better known as the Brandon lignite) were dug and used quite satisfactorily in and about Forestdale and Brandon. The supply appears to have been well nigh exhausted at this time and none has been taken out since, or very little, and for twenty years or more it has not been possible to find even a small piece at this locality. When taken out the lignite, which is a material about midway between soft coal and peat, abounded in excellently preserved nuts, seeds, etc., of land plants. Several hundred kinds were described, all of late Tertiary age. A few fragmentary specimens of leaves were also collected. In all, several thousand specimens were obtained. Nowhere else in Vermont have such fossils been found, and here only at the very limited locality from which the supply was soon exhausted. What has this to do with the physiography of the State? In most ways nothing, the study is for the Paleontologists rather than the Physiographer, for no elevations were formed, no physical feature, and yet by reason of the small deposit of lignite which might easily be overlooked entirely as it was for more than a hundred years, we learn that during early Tertiary time there were growing in Vermont many varieties of trees now only represented by species which grow in a much warmer climate than can be found north of the Carolinas and some not farther north than Florida. Few of the Brandon species are now found in any part of the world, though some few closely resemble some now growing.

How extensive these Eocene Tertiary forests were cannot be known, but the conditions in western Vermont we know were such before and during Tertiary time that no very large area could have been covered by these forests. But this is not all that we learn from the very perfect fossils in the lignite we know that such trees could only have grown in a moist, warm climate unlike that at present, at least a subtropical climate.

Therefore, we must see in imagination forests unlike those which we now see in western Vermont and unlike in appearance and of course the scenery was correspondingly affected. There must also have been a difference in the animal life of the Champlain Valley. What this was we cannot tell. One of the puzzling

facts is that while so many fruits and seeds have been found and beautifully preserved, not the least trace of animal life has been discovered in or near the lignite. It is not credible that no animals roamed these forests, but where are their remains?

Elsewhere the animal life of the Tertiary is abundant, large animals and small. Why do we not find some traces of it here, as we do so abundantly elsewhere? Why?

PLEISTOCENE

This age has subdivisions, but for our present purpose it will be sufficient to speak of it as the Great Ice Age. Everywhere in Vermont the effects of activities in this age are evident, even to the tops of our highest mountains. While in the early Tertiary the climate was subtropical, as we are compelled to believe, so by other and very plain evidence we must believe that during the middle and late Tertiary conditions greatly changed and the climate grew colder and over a very large area a covering of ice thousands of feet thick. Before the beginning of the Ice Age Vermont was largely finished as a part of the North American continent, the mountains had been raised and most of the physical features were in evidence, but not exactly as now for during the Ice Age the then surface of the country was more or less changed. The sands, gravels, clays, boulders, the present form of hills and mountains, the distribution of sand, gravel and any moveable material, all the present surface features of Vermont were either produced or greatly modified by the forces acting during the Ice Age. Out of the enormous masses of materials accumulated during the long past, those familiar to us were formed and distributed. It is hardly necessary to mention that most, if not all, of the processes acting during the Ice Age were more or less active in the ages which preceded this age. The physiography of Vermont was by no means made during the Ice Age, but the final, the finishing touches which have left the scenery as we now see it, came in this last age. And during the present much the same processes are going forward, except of course that the present is not an ice age and the special changes wrought by ice and cold are wanting.

How long a time had passed between the warm climate of the early Tertiary and the early Pleistocene can scarcely be guessed much less known; or what caused the change in climate. But that there was a very great change cannot be doubted. The time was probably long. Indeed, as facts in the geological history of earth are gradually discovered in one age or another we are continually compelled to conceive of longer and longer periods of time. Where in human history we deal with centuries, in geological history we are forced by discovered facts to think of millions of years. I say "compelled" because it is not possible to imagine any sort of known force that could possibly have brought about these many and vast changes in any except enormously long periods. How long we cannot fully comprehend.

The historian's day must be twenty-four hours, but the geologist's day *must* be of indefinite length. Anyone who knows what work our modern small glaciers accomplish can better imagine what glaciers of continental extent would be able to accomplish. There is abundant and certain evidence in the results as we find them today that during the Glacial Age enormous changes *must* have been made in the appearance and character of the surface of Vermont. During the Pleistocene, and probably back in the preceding age, the continental areas of both hemispheres were raised several hundred and in many regions several thousand feet. As one of many results of this elevation of the land many islands, as we now see them in different parts of the earth were parts of the mainland; such as Great Britain, Japan, the Malay Islands, etc. As the land in northern areas rose the climate grew colder and this, with other causes which cannot be discussed here, produced an Arctic climate and snow and ice accumulated in vast amount, as in the Arctic and Antarctic regions today. Great ice sheets covered Vermont and hundreds of miles farther south. Geologists are not fully agreed as to how thick the ice finally became, but at any rate it was evidently much thicker than the height of our highest mountains, as on the very top of Mansfield, for example, unmistakable scratches made by the passing of glacial ice have been found. Most of our mountains and of the higher White Mountains as well show plainly the marks left by passing glaciers. By this means the shape of all our mountain peaks must have been greatly changed and the summits of times before this greatly reduced in altitude. Other and by no means small changes in the topography of Vermont will be noticed later. It is undoubtedly true that if one could have looked over some part of the State in any of the geological ages or even in any of the periods or subdivisions of the ages, the prospect spread out before him would have been quite different from that which was before or that which came afterward, but it seems very probable that by the activities of the Pleistocene the appearance of the entire surface was more greatly changed than at any similar time before.

Slowly, gradually, the present physiography was becoming much as it now is. But not only in outward appearance was Vermont changed. By the crushing, tearing, grinding of the great ice sheet and by the great floods which came from the melting of such masses of ice when the climate was modified, as it certainly was, the foundation of most of the soil now so necessary to Vermont agriculture, was produced. No doubt that decomposition, weathering, etc. have produced and are producing the best soil we have now, but these must be upon a proper foundation. So too the present distribution of tillable soils was largely effected by these floods. It is well to remember that through all the geological ages the earth was slowly becoming what it is now, and that is to say fitted for the dwelling place of man.

In discussing lakes, rivers and mountains the work of the Pleistocene will be again referred to.

As is well known by all geologists the great glaciers originated north of the St. Lawrence. One came down over New England and south, one through the middle west, one along the Pacific Coast. Of course we have nothing in studying the area of Vermont to do with any but the eastern or Labrador Glacier.

THE VERMONT MOUNTAINS

As has been repeatedly noted the Adirondacks are considered the oldest of the mountain ranges seen from Vermont, but it was probably not a long time, geologically reckoning, before the Green Mountains began to appear. It is indeed not at all impossible that there is in the inner mass of the Green Mountains rock as old as any in the New York mountains, but if so it has long been covered by old, but later beds and none has been found at the surface.

When the Adirondacks on the west side of the Champlain Valley and the Green Mountains on the east were even partly raised the present valley was outlined. Thus this valley is one of the oldest known. In Vermont, the order seems to be first, the Green Mountains; second, the Taconics; third, the Red Sandrock Mountains; fourth, the Granite Hills. In addition to these there are a few mountains that belong to another sort—as Monadnock, in Lemington; Granite Mountain, Cuttingsville; Ascutney, Windsor; others scattered north in Canada and others east in New Hampshire and Maine. (In Professor Wolff's article, page 137 of this volume, these unique elevations are discussed.) Thus there are in Vermont four ranges of elevations of different ages, structure and appearance, and these scattered peaks. Naturally, the most prominent physical features in this State are these elevations. In order of age in Vermont, probably the Green Mountains should come first. It is not necessary to notice that these mountains as far as scenery is concerned in most parts of Vermont dominate the whole area of the State. So much is this true that many people think of these alone when thinking of Vermont. And indeed they do far exceed the other mountains in extent, size and height. Nevertheless the other elevations are by no means to be neglected. From the Canada line south through the length of the State and beyond, these are rarely out of sight of the Vermonter. As will be seen later, the other mountains and hills do not form ranges as do the Green Mountains, but are less in line, more scattered, and far fewer in number. Still all add to the picturesque scenery of the State. These mountains are well named for all except the highest are green to the very top. On the upper parts, the prevailing trees are black spruce, though few comparatively, hemlocks, balsam firs, pines, white, yellow or Norway pitch pines and a few yews are also found.

THE GREEN MOUNTAINS

As every Vermonter knows these mountains are much more extensive, higher, and except in some localities as will be seen later, most noticeable features of Vermont scenery. Throughout these mountains are, on the outside at least, built up of crystalline and metamorphic rocks—gneiss, schist, quartz, most of them metamorphosed Ordovician strata. In the northern part of the State, these mountains are somewhat scattered in two irregular ranges, but about fifty miles south of the Canada line, they are more compactly grouped and south from Johnson they form a single range, in which we may see most of the higher peaks, as Mansfield, Camels Hump, Killington, etc. The "Chin" on Mansfield is the culmination of the range, 4,393 feet above sea level; the "Nose" 4,075; Camels Hump (or Couching Lion) 4.083; Killington 4,241, etc. There are many summits throguhout the range that are over three thousand feet above sea level and quite a number, though naturally fewer, over four thousand.

In many parts of Vermont, except in narrow river valleys and elsewhere, fields that usually show that at some distant time they were under standing water, there is little or no level surface.

In latter days one hears less of the "east and west sides of the State" but formerly the more or less imaginary line between the two sides was very rigid, and it does not appear to have been wholly abandoned. This barrier was very strong politically. Physically it is not altogether imaginary, as anyone driving from one side to the other soon discovers. The Green Mountain range certainly does form a very distinct barrier in many parts of the State, and south of the Winooski River, there are not many roads where an auto can cross. Every tourist finds it very much easier to drive fifty miles, or whatever he wishes, from north to south than from east to west, especially south of the Winooski. North of this river, the mountains are more scattered and the roads can and do wind among the elevations.

The route from Burlington to Montpelier carries the traveler across the mountain in Bolton by a less steep and ascending road than is found south of this point. At the same time this is perhaps the most charming of any of the crossings. At the lowest part of this highway the road is only 350 feet above sea level, while on both sides adjacent the elevations are from 2,000 to nearly 4,000 feet. Bolton Mountain is 3,725 feet above sea level and there are numerous lesser mountains close at hand. The observing tourist will not fail to notice that for a considerable distance, as the road makes its way through the mountains there is very little room left between the river, the railroad and the highway. Other ways, either highway or railroad, as from Brandon to Rochester, Rutland to Woodstock, or near Mount Holly, cross from one side to the other, but all are more difficult than the first named, all are over 1,400 feet above sea level.

THE TACONIC MOUNTAINS

Popularly much less known than the Green Mountains the Taconic Mountains have for many years attracted the attention of geologists more than other topographic or geological features of the State. None of the peaks of the better known mountains, which have given their name to the State, has been as carefully studied as have some parts of the Taconics. As far as the scenery of Vermont goes, the Green Mountains occupy from Canada to Massachusetts, a large area in Vermont and one can rarely be out of some view of them if within the limits of the State, while the Taconics are seen only in the southern half and western border beginning in Sudbury and reaching southward to cross the Massachusetts line. The highest peaks are, Equinox in Manchester, 3,816 feet above sea level; Green Peak in Dorset, 3,185; Bird Mountain in West Rutland, 2,210; Herrick Mountain in Ira, 2,727; but there are numerous other and interesting elevations in the range. Mr. T. N. Dale has more thoroughly studied the Taconic area, or the northern part of it, than anyone else and from his publications liberal quotations follow. In the twentieth Annual Report of the United States Geological Survey, part 2, pages 9-23, there is a full account of the structure of Bird Mountain, with many illustrations. Mr. Dale tells us that "the mountain consists (mainly) of a large area of metamorphic grit and conglomerate alternating with beds of sericite schist. 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) schist and underlaid 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 these kinds 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 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 the pebbles must have come from pre-Cambrian beds, others originated in Cambrian beds and the carbonate pebbles may also be of that age." *Loc. cit.*, page 23.

In a later publication of the United States Geological Survey Bulletin 272, Taconic Physiography, Mr. Dale says, "That probably not less than eight thousand feet of rock, more rather than less at one time existed in the higher mountains of this range, though now the highest is much less than half of this. But the denudation was not only of the elevations, it included the entire region that may be called the Taconic area." As to this Mr. Dale says, "As the limestone of the valley underlies the schist, these valleys must have been originally covered with schist and therefore about a half mile of schist besides the amount of eroded limestone ought to be conceived as restored to the valley . . . . where the Cambrian limestone comes to the surface in anticlines the entire limestone formation as well as the schist ought to be added, *i.e.*, at least 3,600 and possibly 5,000 feet, leaving out the Silurian grit . . . . The synclinal mountains must correspond to original valleys and the anticlinal valleys to original mountains."

Again, "It appears that the amount of denudation has been very much greater on the once submerged portions of the Green Mountain anticline than on the Taconic synclines, although this difference is not so marked when points on the Green Mountain range in which longitudinal troughs occurred in the axis are taken for comparison. It is also evident that the general descent of the original surface westward as it emerged from the Ordovician sea was much more marked than the present surface indicates." Dale has noticed the many transverse hollows on the western side of the Taconics as one of the distinctive characters of this range, and that these are generally longer on the west than on the east side.

A very excellent view of the two ranges can be had as one rides through the Battenkill Valley from Dorset to North Bennington. Here the Taconics are on the north side and the Green Mountains on the south. A different view is to be had from the top of Killington or Dorset Mountains, and one supplements well the other and gives a very complete idea of the physiography of each range. The Taconics, as may be inferred from what has been said, present a greater variety in form and outline than do the Green Mountains. Of the lower portions of the Taconics Dale remarks, "The hill forms of the Taconic region consist generally of long narrow ridges with crests either gently sagging towards the center or else made up of short undulations with occasional rounded shoulders or dome-like masses, and obtuse angled summits with saddles or lateral benches, and ending in either somewhat steep concave or convex slopes or very gentle declivities. . . . There are also plateau-like masses with few prominences having long gentle slopes. . . . But few cliffs occur and these do not exceed 1,000 feet and usually are not 500 feet in height."

As a summary of events in the building of the Taconics, Dale gives the following: "The history of the Taconic landscape from a geological point of view is a long one. Its chief events, briefly summarized, were the accumulation in a broad arm of the ocean of arenaceous, argillaceous, and calcareous materials by erosion and by mechanical and organic sedimentation; then the formation in these stratified sediments and their crystalline basement of a series of great parallel folds, diminishing in altitude from east to west, which caused a retreat of the sea. This folding resulted in faults, metamorphism and secondary structures of several kinds. There were three periods of folding: one at the close of the Lower Cambrian, affecting the central basin, another at the close of the Ordovician, more far-reaching in its effects, and a third seems to have occurred in post Silurian time (Devonian or Carboniferous), as shown in the Rensselaer Plateau and Bird Mountain. The various materials thus collected, folded, altered and traversed by structural planes, became exposed, as great longitudinal ridges and valleys, to stream erosion, and that erosion was retarded as it approached base level or was accelerated by uplifts. The first anticlinal ridge became denuded of all its sediments, although these amounted to several thousand feet, and the ancient sea floor became exposed.

"The anticlinal ridges west of this were carved into valleys and the synclines remained as ridges, but in some instances the original form persisted with modifications. Erosion operated laterally across these anticlinal and synclinal mountains and also sculptured them on all sides into forms bearing little resemblance to their structure. Eventually, completely buried under the continental glacier which moved both southward and southeastward, the surface features became still further modified by the shattering of the ledges and the removal of blocks, the gouging and scouring action of boulders and gravel held in the ice. The melting of this vast body of ice gave rise to streams which freshly eroded the surface, scattered morainal material and formed glacial lakes. The Taconic landscape is thus the result of erosion acting on rock material of various composition and structure."

I have quoted the above at some length because it not only explains Taconic physiography, but as well with little change, the physiography of the Green Mountains. It may be added to the above that anticlinal structure is much more often found in the Green Mountains and synclinal beds in the Taconics.

The presence of magnesia, carbonate of iron and lime, both in the cement and in 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 also coarser detritus was collected. The stratigraphical relation of the schists which underlie Bird Mountain, both to the Cambrian on the west and 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 the pebbles must have come from the pre-Cambrian beds, others originated in Cambrian beds and the carbonate pebbles may have been of that age. As to the age of the Taconic Mountains there is some disagreement. Probably the final elevation of the Taconics took place at or about the same time as the elevation, final elevation, of the Green Mountains. There appears to have been an interval, it may have been of great duration, as we reckon time, between the close of the Ordovician and the beginning of the Silurian, and it was during this interval, of unknown length, that the final, and perhaps the main elevation of both the Taconic and the Green Mountains occurred. "The periodic readjustment in the earth-shell of North America is recorded by at least fourteen times of mountain making. Eight of these of lesser import, are the disturbances Green Mountains, Taconic, etc., which took place during the closing stages of as many periods." Schuchert, Historical Geology, page 979, 1915.

"The close of the Ordovician was marked by horizontal and vertical movements of considerable importance in eastern North America (Taconic deformation). During the Cambrian and Ordovician in North America sediments had been accumulating in a subsiding trough between the Adirondack land mass and a land mass in New England. . . . These sediments, after having been accumulated to a thickness of more than a mile, were subjected to a great lateral pressure which folded them and brought them above sea level to form a mountain range of which the present Taconic Mountains of western New England are perhaps rather

insignificant remnants. The folding was so intense that limestones were crystallized into marbles, of which the most famous are those of Vermont and Massachusetts; the sandstones were changed to quartzites, and schists and the muds and shales into slate and schists." Cleland, Geology, page 422, 1916.

"The most considerable (folding) was in the Taconic Mountains where both Cambrian and Ordovician systems were thick. Both were folded and lifted above the sea beneath which they had accumulated. The eroded remnants of the folds often show a complicated structure. The date of folding is known because the Silurian formations overlie the Upper Ordovician unconformably about the borders of this mountain region." College Textbook of Geology, Chamberlain and Salisbury, page 516, 1909.

Prof. T. H. Clark in an article in *Am. Jour. Science,* Vol. XXXVI, p. 158, writes as follows: "I have stated above that all we can say about the age of deformation of this region (the Taconic) is that it must be post-Upper Ordovician. We may, however, qualify this somewhat. Such metamorphism as the rocks of the Taconics and of the Green Mountains have suffered is not generally thought of as having been induced near the surface. Such metamorphism is a factor among other things, of the depth to which rocks are buried and in the opinion of the writer, the metamorphism of the rocks of the Taconics and Green Mountains could only have occurred under a cover of rock measured by thousands of feet. What this cover was we may never know but that it was not Ordovician is probable, for the Upper Ordovician is but scantily represented in eastern New York State."

Mr. Dale not only studied Bird Mountain and other Taconic peaks, but he also gave good attention to the northern part of what may properly be called the Taconic area. Of course this is involved in Taconic physiography. With the above title Mr. Dale published No. 272 Bulletin United States Geological Survey from which some of the quotations given above are taken. A few further quotations will not be out of place.

"The elevations of the Taconic range consist generally of long, narrow ridges with crests either gently sagging toward the center, or else made up of short undulations with occasional roundish shoulders or dome-like masses and obtuse-angled summits sometimes with saddles or lateral benches, and ending in somewhat steep concave or convex slopes or gentle declivities." *Loc. cit.,* page 22.

"Three well-defined topographic types stand out from a survey of the Taconic landscape. *Plateau Type.*—This includes the Green Mountain range, with its gently undulating or roundish surfaces, having few and usually not rugged elevations, its flank deeply incised. . . . *Taconic Type.*—This consists of alterating ridges and valleys. The ridges are cut by transverse and diagonal valleys and are sometimes intricately dissected or else reduced to isolated lenticular masses. *Hudson-Champlain Type.*—This is less marked in character, consisting of minor irregular elevations and depressions and yet with a series of isolated hills reaching to nearly seven hundred feet above the general surface." *Loc. cit.*, page 23.

Further as to Taconic physiography, "As approximately one-half of the denudation of the Taconic topographic belt has taken place below the two thousand-foot level part of it must have occurred during Tertiary and Pleistocene time and only an equal part during the much longer Paleozoic and Mesozoic periods. In order to restore the relations as far as possible to their condition at the time of the uplift, a depression of the present surface some 1,500 or 2,000 feet to its original base level altitude may be imagined. Such a depression would admit the Atlantic, whose waters now reach Albany and are only 101 feet below Lake Champlain, through both the Hudson and the St. Lawrence, and transform the Taconic range into an archipelago." Whether because of the Ordovician movement alone, or because of subsequent uplifts, the Taconic area has suffered a vast amount of erosion. It is a deeply dissected upland. An inspection of the map and sections will justify the estimate that the amount of denudation which has taken place between the western foot of the Green Mountain range and the western limit of the schist belt alone is not very much less than the bulk of the present schist masses. If to this be added the amount of denudation suffered by the western rim of the Green Mountain range, the total will be vast indeed. This feature is the most impressive one in the region and continued study serves greatly to increase its impressiveness." Three well-defined topographic types stand out from a survey of the Taconic landscape.

Plateau Type.—This includes the Green Mountain range with its gently undulating or roundish surfaces having few and usually not rugged elevations, its flank deeply incised.

The Taconic Type.—This consists of alternating ridges and valleys. The ridges are cut by transverse and diagonal valleys and are sometimes intricately dissected or else reduced to lenticular isolated masses.

Hudson-Champlain Type.—This is less marked in character, consisting of minor irregular elevations and depressions and yet with a series of isolated hills reaching to nearly seven hundred feet above the general surface. . . . Of the three topographic types, the plateau type may be ascribed largely to the toughness of its granular granitic or gneissic material, which offered uniform resistance to erosion. . . . The ridge and valley type is probably due to the complex structure and to the mutual relations of its soluble and schistose rocks and to the resistance of both structure and material to erosion. . . . The *Hudson-Champlain Valley type* consisting of an undulating surface with several series of low hills is traceable to the behavior under erosion of soft but insoluble rocks in small folds with occasional more resistant anticlinoria or synclinoria. Here, however, the general surface has been modified by the addition of morainal and terrace material. *Loc. cit.*, 49.

THE RED SANDROCK MOUNTAINS

Most of these elevations are more properly called hills, but two or three, as Snake Mountain, Mount Philo, and Hogback may be fairly termed mountains while Red Rocks and Rock Point, near Burlington are only cliffs on the lake. These elevations begin with Snake Mountain in Addision 1,271, and are scattered on north to Mount Philo in Charlotte, 968, Pease Mountain, 740, decreasing northward through St. Albans to low cliffs or hills. They are mostly composed of Cambrian, usually Lower Cambrian, strata, though in some there are schists and limestone, and at Snake Mountain, and a few localities north, Upper Trenton black shale, due to faulting, and overthrusting.

The Cambrian age of these elevations is not uncertain for in some localities, especially north of Burlington, there are well preserved fossils. Though mostly of Lower Cambrian strata, these also afford Middle and Upper Cambrian fossils near St. Albans and northward. All are regarded as Cambrian remnants. During Cambrian time the whole of western Vermont north of Bridport was covered by Cambrian beds, all of which have since been washed away, except these remnants. Of course, during this deposition the region west of the Green Mountains was under the sea of that time which may have been very long. A phase of the sandrock was more calcareous than most and in this at Malletts Bay and Swanton are quarries from which the stone known in trade as "Champlain Marble," a very attractive mottled stone, red, white, green, gray, olive, etc., not seldom seen in the marble floors of public buildings is taken. As this stone can be finely polished, it is also used for other interior work.

THE GRANITE HILLS

The fourth series of elevations in Vermont are of an entirely different character from those mentioned. All are east of the Green Mountains and they are wholly made up of granite and in them are situated all the many granite quarries in the State. In the other elevations there is no granite and in these nothing but granite. Granite is an igneous, volcanic, rock. All Vermont granite is the cooled mass that by internal force was pushed from below the surface as molten material. They are none of them very high, the highest, Millstone Hill is 1,700 feet above sea level and many are much less. Most are north of the middle of the State. With very small exceptions, as the granite in Newark, all Vermont granite is gray, varying from very light, as that found on Christian Hill at Bethel to very dark as some of the Barre and other quarries. In most cases, though not in all, there is schist, flanking the granite and the structure of most of the granite indicates that the once molten mass as it came up from deeper parts of the earth was cooled under pressure. From this it seems certain that the granite hills were at first not pushed through to the surface but were covered, how deeply is not known by other rock, which has since been carried off. The best known of these granite elevations are Christian Hill at Bethel, Millstone Hill at Barre (and the adjacent region), Robeson Mountain at Woodbury, but there are a number of other cliffs or ledges of granite in the State as Black Mountain in Dummerston, etc. Although most of these do not add greatly to the scenery of Vermont they certainly do add greatly to the commercial resources of the State. As to the age of the granite of Vermont, it is certain that all was not pushed up at the same time. In some of the quarries granite of a more or less different sort is found pushed up through the main mass, and is of course younger than the rest. However, as the adjacent rocks which, as has been noticed above at first covered the granite are considered as of Ordovician age it is certain that the granite, most of it at any rate, is newer than the Ordovician and on the whole the evidence seems to show that most of the Vermont granite is of Devonian age. Here and there it is possible, and in some cases certain, that small quantities were later than the larger masses.

THE MONADNOCKS

These have already been mentioned and described and those in Vermont, as well as those in Canada, Maine, and New Hampshire are enumerated in Professor Wolff's article on page 137 of this volume. Each of the three in Vermont is in many respects unlike the others and unlike other of the mountains which we have discussed on preceding pages. Ascutney is much the largest of the three, both in height and mass. Standing alone as it does Ascutney presents a very conspicuous feature in the landscape in the region of Windsor. Each of these "Monadnocks" is more complex in its structure than other Vermont mountains. And they differ from each other. The structure of Ascutney because of Professor Daly's thorough study is fully known.

I should like to quote more extensively from Bulletin 209 United States Geological Survey did space permit, but enough will be quoted to show something of the complex character of this mountain. Ascutney is 3,119 feet above sea level, but its somewhat isolated appearance makes it appear to most observers, larger and higher than if a part of a range. If Doctor Daly's conclusions are correct, as there is no reason to doubt, the mountain was not always so isolated. "The softened profiles of the mountain suggest and a study of the geological structure of the region proves, that Ascutney is a residual of erosion. It has been carved out of the Appalachian Mountain System where the sedimentary rocks of the system have been intruded by several stocks and thick dikes of igneous rocks. The relief features of the region discussed belong to the same category as the very common sugar-loaf peaks of Vermont located on intrusive granites and syenites. Ascutney itself owes its existence primarily, to a great stock of quartz syenite. The picturesque ridge of Little Ascutney is held up by a strong rib of intrusive syenite-porphyry associated with other eruptives more resistant to the weather than either the gabbro-diorite on the north or the gneiss on the south. The general feature of the residuals of erosion (an abrupt steepness of ascent along the spurs of the main mountain just above the contact between the sedimentary and the eruptive rocks) in our area may be repeatedly and clearly seen in the granite hills of New England, and might serve to dispel any doubt which remains in the minds of those students of erosion who are skeptical as to the prevailing theory of New England relief for it is doubtless true that the most illuminating treatment of New England topography finds best explanation for its mountains and higher hills in the assumption of the superior strength of their component rocks—a strength superior to that of the rock masses immediately surrounding. Ascutney like most New England mountains is a residual of erosion, a monadnock overlooking a dissected rising plateau. The relief as a whole and in its details is controlled by rock decomposition in a specially definite manner. The drainage of the region is that of an ancient mountain system. The general form of Ascutney was not greatly affected by Pleistocene glaciation. A veneer of pre-glacial weathered rock was removed and the rounding of the minor points was accomplished by the ice invasion but the pre-glacial Ascutney had practically the form of the present mountain. *Loc. cit.*, page 13.

Granite Hill in Cuttingsville.—The complex assemblage of different kinds of rock in this mountain or hill, it is 2,000 feet high, is well shown in an article by Dr. J. W. Eggleston in volume eleven of the Vermont Geological Reports, page 165 As this article has been out of print for several years, a few of the facts as found by Eggleston may well be given here. Although locally named "Granite Hill" the rock is mainly syenite, no granite is found, but several other eruptive rocks occur, about a dozen are mentioned in the article. These all differ greatly from the surrounding rocks of the locality. Several dikes cut through the earlier rocks. "The general structure is comparable to that of Mount Ascutney, not more than twenty-five miles distant, which is also a composite stock. There, biotite granite and diorite appear in addition to types which almost duplicate certain of the Cuttingsville rocks."

"The Cuttingville area takes its place as one of the known number of small intrusive bodies in the New England-Quebec region."

The third mountain of this group is that well described by Dr. Wolff on page 137 of this volume. Mr. Arthur Keith of the United States Geological Survey has published in *American Journal of Science,* February, 1913, an article which is very interesting in this connection. This is reprinted in the Fourteenth Report of Vermont Geologist. Of course it will not be possible to quote all of Mr. Keith's article here, but I will cull a few paragraphs.

"*Pre-Cambrian Disturbance.*—The earth's crust in this region has often been deformed sometimes by oscillations up and down, by revolutions sometimes which crushed and upset all previous structures. Earliest of all of which there is a record was the intrusion of granite and similar rocks into pre-Cambrian basement rocks. In pre-Cambrian time there was also enormous compression, folding, and mashing of the rocks, by which processes were formed the gneisses, and schists. Whether or not granite intrusions accompanied this deformation there is no proof at present, but some intrusions were Archean and older, while others were later and cut the Algonkian rocks. The forces that drove these great masses of molten matter into the Algonkian sediments were enormous and inevitably distorted the crust from its previous attitude. A general uplift of land resulted from these movements and sediments laid down under water were exposed and deeply worn.

Lower Cambrian Warping.—A reverse movement of depression began the sedimentation of Lower Cambrian time. This was of a broad regional nature with a moderate amount of tilting, but no compression sufficient to shorten the earth's crust in this region. The depression went on till about two thousand feet of sediment were deposited. . . . A local reversal and uplift near the end of the Lower Cambrian caused the erosion of over six hundred feet of the Malletts dolomite.

Middle Cambrian Warping.—Oscillations of this kind—broad up or down movements with some tilting—recurred during the Cambrian. . . .

Saratogan Movements.—The tilting and submergence that initiated "Saratogan" sedimentation were of similarly great importance, and great areas of eastern America received deposits of the Paleozoic sea for the first time. The submergence of broad areas west of the Lower Cambrian trough and erosion at the east indicates that the uplift as at the east and the depression was to the west. Thus was reversed the arrangement that prevailed through the Lower Cambrian, and a new distribution of the lands was begun which prevailed in a large way through the rest of the Paleozoic era, except for the submergence in the Middle Ordovician.

Middle Ordovician.—The Georgia slate and the Swanton conglomerate where present, rest on two formations of the Lower Cambrian and two of Upper Cambrian age, and contain boulders of at least one "Saratogan" formation. The erosion into and through these formations is so considerable that we must conclude that there was important tilting and perhaps even some folding in order that beds so widely separated should be brought to the same surface of erosion. . . . In this region the uplift and erosion following the "Saratogan" continued until the Middle Ordovician Beekmantown and Chazy beds are common west of the Champlain fault and are overriden by the Cambrian on the fault. They do not, however, appear east of the fault and north of Middlebury, although the younger Georgia slate is present. These facts suggest that the first uplift from which the fault developed began between the "Saratogan" and the Beekmantown.

Appalachian Revolution.—Many subsequent oscillations no doubt took place here, as in adjoining regions. The late Devonian folding that affected New Brunswick and Maine so strongly appeared only as an uplift in western New England. Nor does any record remain of any movements after the Middle Ordovician until the great deformation, which closed the Paleozoic. This is shown here on a grand scale, with all the features which characterize the Appalachian revolution. Long closed and overturned folds and thrust faults both folded, faulted and simple, are numerous and the shortening of the crust in the narrow Champlain Valley is enormous. Over large areas the forces and the reactions were so tremendous that the strength of the rocks was entirely overcome. The minerals were recrystallized, bed flowed or were torn apart and the aspects of the rocks was very greatly changed. The faults record two periods of thrusting, separated by an unknown interval of time. East of the Green Mountains great masses of granite were forced into the sedimentary rocks. The crust of the earth was jammed and piled up and its surface rose above the sea. As it rose it began to wear away, but the uplift exceeded the waste and no doubt great mountains were formed.

Triassic Faulting.—The next structural event of record is the normal faulting exhibited near the shores of Lake Champlain. The youngest beds cut by these faults are of Middle Ordovician age, so that by that criterion they cannot be separated from the thrust faults which cut the same rocks. However, the physical incompatibility of these faults—the results of the extension of the beds—with the extreme compression of the Appalachian beds. Revolution compels an assignment of them to a date after the compressive strains were satisfied or transferred to other parts of the earth. Furthermore, there is a decided difference in trend between the two fault groups. So far no normal fault has been found cutting the thrust faults, but the two sets adjoin so closely that probably such a relation will be found. The period which seems most likely for the formation of the normal faults is the Triassic. Everywhere in eastern America the Triassic period was closed by uplift with normal faulting, and no other period of normal faulting is known in the Appalachians. Some of the Triassic faults can be traced from the Triassic belt of New York into districts near to this. Accordingly, the reference of the normal faults of this region to the Triassic is reasonable.

Cretaceous Fissuring.—Scattered over western Vermont and adjoining areas are numerous dikes of camptonite, and similar rocks. These have a marked trend a little north of west and nearly vertical attitudes and they are seldom over eight or ten feet wide or an eighth of a mile long. Evidently, these dike rocks were forced when molten into a set of fissures which were formed by a regional strain. . . . There is neither direct evidence of the age of these dikes nor are similar sets known in adjacent regions. They are entirely different from the Triassic types, and they are unmetamorphosed, so that they are post-carboniferous. On general grounds, it seems most likely that they are of Cretaceous age.

Post-Triassic Oscillations.—The movements of the earth's crust thus far discussed are shown by overlapping, folding, or displacement of the rocks. Subsequent movements there were at many epochs, but their effects cannot be disentangled from far greater changes already wrought upon the rocks. The forms of the land, however, tell their story, and later uplifts and pauses are recorded at many epochs from the Cretaceous down to the present. The pauses are deduced from the plains formed nearly at sea level during a long stand of the land in one attitude and the uplifts are evidenced in the present heights of these old plains and their deep dissection by the streams into valleys and lower plains. At least seven of these pauses are known with a corresponding number of uplifts. There doubtless were many depressions as well as uplifts, but there is no present means of determining except latest.

Glacial Tilting.—One of the depressions accompanied the great invasion of ice from the north and the view is widely accepted that the weight of the ice caused the crust to bend and settle. The reverse movement of uplift accompanied the disappearance of the ice and the land nearly recovered from its great depression at the north. The tilt that it received in glacial time is now recorded in the inclined planes of glacial clay and sand and in the terraces and deltas which rimmed the margins of glacial water bodies." (Fourteenth Report, Vermont Geologist, 1924, pp. 133-136.)

The quotation as above gives in excellent summary much that geologically explains the topography of Vermont. Because of its importance and also because the article referred to is entirely out of print, it is given here. The article was first printed in *Am. Jour. of Science,* February, 1923, and is here reprinted by permission. Careful reading of the entire article is heartily recommended. It all has much explanation of our present Vermont physiography.

THE RIVERS

The north and south trend of all the Vermont elevations has often been noticed, and anyone who chanced to examine a map of the State on which no rivers were indicated would most naturally expect to find that these as well as the mountain would almost necessarily follow the same trend, but it is not found to be so in case of the larger streams. Vermonters who have not visited other parts of the country cannot well appreciate the refreshing beauty of the very numerous streams from the little mountain brooks to the largest of our rivers, nor the great charm they add to Vermont scenery, as well as to the comfort of those who pass by. Were these streams large and small, as infrequent as in drier regions, Verde-Mont could not be Verde, not only in mountainous areas, but anywhere. It is not needful to remind those who have any knowledge of geology how greatly our scenery is due to the erosion effected by our streams past and present. The more one studies the physiography of any region, the more fully is he convinced of the enormous work of streams. Probably none realize how vast this has been through the ages. Of course igneous and chemical action has done its part but more than all else, the foundations being laid, water in some of its forms has and is, accomplishing results far beyond our comprehension. Given the foundations, the roughing out of our physiography, the physical features of the Vermont we now see are mainly due to water in one form or another. Water is not only absolutely essential to the life of the body, it is as essential to the life of the spirit, at any rate to its satisfaction. To prove this it is only necessary to suggest an imaginary Vermont without water and the physical and mental conditions which would follow such a state of things. It has been noticed that Vermont is an old area and therefore it has been possible that our streams, most of them, are also very old. As every geologist well knows there is abundant evidence that many of our streams did not formerly flow just as they do now. As our elevations have changed so the courses of streams have changed, especially the older.

Still probably there has been much less of change in volume and direction of the streams here than in many regions. In case of the larger streams this change has in most cases been less than in smaller brooks, for our larger rivers are all old, even geologically, and they have, as far as indicated, always flowed in very much the same direction as now, across rather than parallel to the mountains. There are some exceptions, but in general the above is true. Otter Creek is more of an exception than any other large stream. The other rivers conform to the general rule. However, as any map of the State will show, all the larger streams flow either west into Lake Champlain or east into the Connecticut, and the brooks, however crooked may be the usual course, must be tributary to these. A few streams, small rivers flow north and empty into Memphremagog, and a few cross the State line and empty into the Hudson. In Vermont are listed by the latest authorities, over five hundred and fifty streams, large and small. It is well in such lists to remember the small area covered by Vermont, in round numbers about 10,000 square miles, else one is likely to fail to notice the relative abundance of the objects mentioned. So many are the brooks that the natives do not seem to have found very appropriate names for all. For example, there are in the State five Mill Brooks, five Dead Creeks, eight Pond Brooks and worst of all, no less than eighteen Mud Ponds.

As every Vermonter well knows, there are in the State four major streams, Missisquoi, Lamoille, Winooski and Otter. Like all streams in this region, these rivers vary greatly in volume at different seasons and also in different years, as these are rainy or dry. At different times the variation in flow is enormously variable, as those who live near any of them well know, and what is possible is shown by the flood of 1927, though fortunately, no such flood has happened before in the memory of man. A common condition is shown by one report of the United States Hydrographic Survey for April 1 and August 1, at Montpelier station. "Daily discharge, feet per second April 1, 7,460; August 1, 98." But the extremes are usually, that is in an average season, less than the above. An average variation would be April 1, 2,300 feet; September 1, 600 feet per second; this for an average year, but the figures would differ for each year. Some years much more difference, some much less.

The flow in different seasons is so different that it almost seems hardly worth while to name any figures, still these given show this variation fairly well. Briefly considering the main facts as to each of the four large streams we find:

The Missisquoi, the most northern, flows at first in Canada where it is formed by a union of a northern branch which starts in ponds near the village of Etienne in the township of Brome, Canada and flows south to unite with a shorter branch not far from the border line. It enters Vermont at East Richford and flows in a very sinuous course, but mainly southwest as far as East Berkshire, then, after a short westerly course, it turns almost directly north and finally enters Missisquoi Bay. There are few falls in this river, those at Swanton are highest, and the banks are generally low and the valley wide. It enters Missisquoi Bay by three main channels, which have been cut out through a delta. In addition to the larger mouths into the bay, there are three smaller and two which are more or less dry except when the river is in flood. In the "Geology of Vermont," 1861, Dr. Edward Hitchcock, at that time State Geologist, says, "More than half of the original width of Missisquoi Bay has been taken up by the delta. A great bend in the river south of Swanton Village encloses a higher sand flat 150 feet high which is an older delta than Hog Island. Two other sandy flats rise perhaps 40 and 80 feet in going to Highgate. The surface rises to the finest and most extensive of all the delta deposits at Highgate Center 306 feet and near its surface there are marine shells. With some variations it follows around to East Highgate and upon the town line next to Sheldon, at a curve in the river is the highest of all these sand levels 380 feet."

The Lamoille River.—Next south of the Missisquoi flows the Lamoille (of the large streams). This river may be said to rise in Greensboro, formed by the confluence of several smaller streams. The river is not as sinuous nor as long as the Missisquoi, and its volume is somewhat less. Its course in general is west from Greensboro to its entry into Lake Champlain. From its source to Milton it has cut its way through hard schists, gneiss and similar rocks, but between Milton and Lake Champlain, where beds of stone appear, many of the rocks are sandstones, shales and limestone. The valley is nowhere very wide and in many places quite narrow. The Lamoille River empties into the lake not far south of Sandbar Bridge. Here a great deal of sand has been and still is carried out into the lake and some is blown by south winds over and beyond the shore at Phelps beach. The present convenient crossing to Grand Isle is really a causeway built on the sands of an old ford, which in former times was used by teams as they went to and from the mainland. The "Bridge" is really a causeway built on the shallow ford of older time. As will be shown later, Lake Champlain was formerly much larger and deeper than now. This made more or less difference, of course, in the topography of the surrounding country. As we shall see the shores of the lake were much farther eastward than now and in this case, there was a large delta—the sand plain south of Milton, which Lake Champlain once covered. Anciently the river seems to have entered the lake by two channels, one of them, now dry, being north of Sandbar Bridge.

The Winooski River.—In the northern part of Cabot several small streams unite to form what becomes the Winooski River. From this source to its entry into Lake Champlain, about five miles north of Burlington, the course is quite irregular. After flowing through Cabot in a southerly direction it passes on south through Marshfield and Plainfield to Montpelier through which the course is northerly and westerly, sometimes due north, and sometimes due west, for over sixty miles.

Between Montpelier and the lake several considerable streams greatly augment its volume and during much of the year it carries a good deal of water, but in midsummer its volume is very greatly reduced. The principal tributaries are the North Branch, Dog River, Mad, Waterbury, and Huntington Rivers. During the years 1914-1916 the greatest amount of water measured at the Hydrographic station at Montpelier was in March when for the month the discharge in second-feet was 6,070, and the smallest discharge at the same station was in October when it was only 22 second-feet.

Most of the valley of the Winooski is narrow and in several places the river is confined within narrow gorges as at Waterbury four miles south of the village, at Bolton, and especially at High Bridge and Twin Bridges in Colchester. It finds its way through the Green Mountains in Bolton, and after leaving the mountains the valley is much wider and some of the best farms in the State are on the alluvial flats in Richmond and Essex. From its source to its mouth the scenery is attractive and often very charming. The highest fall in the river is in Bolton at the power plant, but the dam is almost wholly artificial. At Winooski there are two falls, largely natural, but modified by the dams of the American Woolen Company.

The geological history of the Winooski during the Pleistocene is in many of its phases very plainly seen as one goes along the course of the stream, and presents much that is interesting.

From Montpelier to the lake there are many old deltas from tributary streams, and water worn cliffs, and other evidences of former conditions. Some of these are related at the end of this article in quotations from Professor Fairchild's report of his investigations in this region. The wide area of sand which is familiar to all who go from Burlington to Essex or Richmond is what is left of a former great delta plain in an older Lake Champlain when the river entered the lake near Richmond. To have made such a delta the river must have flowed at a considerably higher level than now and of course the lake was much higher and very much larger. Something of the ancient history of Lake Champlain is given in the Eighth Report of this series (pp. 44-49).

As the volume mentioned has long been out of print, a résumé of "The History of Lake Champlain" in geological times will be given later on when lakes are considered. It may be well to call attention to the enormously greater volume of all the streams existing during the melting of the ancient glaciers. This greater size and of course greater power to erode and distribute ground and broken material must be taken into account when the work of streams in the past is considered. The ancient streams were long at flood level and extent, therefore their effects on the surrounding areas must have been beyond computation. More than any of the other rivers the Winooski throughout its course gives abundant evidence of the magnitude of this work. In many places this river has cut its way through schists, gneiss, etc., but at Hubbells Falls at Essex Junction it finds limestone cliffs and also at the Lime Kilns and Gorge (Lower Ordovician). At Winooski it meets some limestone and some red sandrock. Below the Lower Falls at Winooski the river flows on to the lake through flats.

Otter Creek.—This stream should be called River, as it well deserves the name. It is nowhere very wide, but it is long and deep. It is wholly west of the Green Mountains and cuts through few bodies of rock. Authorities differ as to its real source. Some call its source a pond in Dorset, others prefer to locate its source in certain brooks in Dorset, but it makes little difference as the streams flow from the pond. Therefore, the main direction of its flow is north though from Vergennes it flows west into the lake. It flows from Dorset north for many miles as a deep, rather sluggish stream, amid low meadows, which are more or less overflowed in the spring and sometimes in the fall. Near Vergennes it turns west to enter the lake about eight miles farther on at Fort Cassin. There are a few rapids and falls, which are used as water power at Rutland, Proctor, Middlebury, Beldens and Vergennes. The water is deep enough for navigating steamboats of respectable size from Vergennes to Lake Champlain. Fed as this stream is by numerous mountain brooks at first, though there are no mountains in the immediate vicinity, which in turn are fed not only by springs but by the melting snows, and flowing as it often does between low banks this stream is especially subject to great fluctuation in its volume, but this must necessarily be true of any streams in a mountainous country such as Vermont. A few of the larger streams, important in Vermont physiography, may be mentioned briefly.

There are several small rivers or large brooks which drain small areas in different parts of western Vermont, some of which should be mentioned. In Rutland County is the *Poultney River* which rises in Tinmouth, but it receives the waters flowing from several ponds and flows in a general northerly direction until it enters Lake Champlain at East Bay. The course is very winding and for a few miles it forms the boundary between Vermont and New York. The entire stream is about thirty-five miles long and its drainage area includes several lakes, chief of which is Bomoseen the outlet of which joins the river at Castleton.

The Mettawee or Pawlet River is a mountain stream rising in mountains in Dorset at an altitude given as 3,200 feet. Its course is exceedingly sinuous, at first south for a little, and then, for nearly its whole length, northward and westward to its final entrance into Lake Champlain by way of East Bay at Whitehall, N. Y. The total length is given at forty miles. The drainage area is more than half in Vermont, but over a hundred square miles are in New York. Through Wells Brook it receives the overflow from Lake St. Catherine.

The Little Otter flows north of the larger stream of the same name. This stream is wholly in Addison County. Its sources are in brooks in Monkton and New Haven, and after winding in a northward direction for sixteen miles it empties into Lake Champlain at Balls Bay in Ferrisburg. According to United States Bulletin, Water Supply, 424, the descent from source to mouth is 400 feet.

Lewis Creek enters the lake not far north of the Little Otter in Ferrisburg. It is about twenty-two miles long and has a total of 1,700-1,800 feet, but the greater part of this descent is in the mountainous region in Starksboro from which it flows.

The LaPlotte River is scarcely of sufficient size to be entitled to the name river, but it is quite a stream, flowing from Hinesburg to Shelburne Bay, about 14 miles. There are two branches, one from the northern part of the town and the other from the southeastern part. As the surplus water of Monkton Pond is carried to the lake by Lewis Creek and the water of Hinesburg Pond (the overflow) by the LaPlotte. From Monkton Pond to

the lake is about 1,100 feet fall. Most of the streams mentioned flow into Lake Champlain and are west of the Green Mountains but there are also streams east of the mountains which empty into the Connecticut.

The Connecticut River.—As stated by the United States Hydrographic Survey, this river drains nearly four thousand square miles of eastern Vermont. As the larger river depends to a large degree on its tributaries and as many of these flow into it from Vermont it drains a larger area in this State than do any of the strictly Vermont streams. Into the Connecticut from the Vermont side the tributaries are: the Nulhegan, Passumpsic, Wells, Waits, Ompompanoosuc, White, Ottaquechee, Black, Williams Saxtons, and West. The Connecticut, as is well known forms the boundary line between New Hampshire and Vermont from the Canada line at Canaan south to the Massachusetts line at South Vernon. The river offers a convenient boundary, as it seemed to the surveyors of a century ago, but this and many other convenient boundary lines have since proved very troublesome and often costly, because such "fixed" points or lines are not fixed. Rivers are always changing their course, some in small measure, some in greater and therefore no river can be considered as giving an unchanging mark. It seems to be very natural, as it is, that in time of high water a stream should take from the land on one side and carry it across to add it to the other side, which if the ownership on one side is not that of the other is likely to cause trouble sooner or later, as it has in the case of the Connecticut for many years. As the main tributaries of the Connecticut from the west are important streams, they are briefly noticed as follows:

Beginning at the north—the *Nulhegan.* This little river rises in Avery's Gore and drains the northeastern part of Vermont. It enters the Connecticut at Bloomfield. "In the main stream and on the branches the valleys are relatively wide and flat with occasional quick stretches." In general, however, the stream is not sluggish, but rather rapid.

The Passumpsic.—This river is mainly formed by the union of two branches, which meet in Lyndon. The branch which rises in Westmore flows southerly through Newark, into East Haven, then into Lyndon and on through St. Johnsbury, Waterford and Barnet to East Barnet, where it enters the Connecticut. The other branch flows south from Mount Pisgah in Westmore and Lyndon. Through much of its course this stream has a rapid current but in places it is more quiet. There are considerable falls in Barnet and Lyndon.

Wells River flows from Groton Pond and goes on through Lunds Pond to enter the Connecticut not far south of the village of the same name. The general course is southeast. It may be added that Groton Pond receives the flow from Kettle Pond and this outlet is sometimes regarded as the beginning of Wells River. This is a short river and drains only a small area.

Waits River is another of the numerous little rivers on the east side of the State. The river proper rises on Knox Mountain in Orange, but there is an important South Branch which joins the other in Bradford. This branch rises in Orange, South Branch, and Topsham, North Branch—the two uniting in East Corinth. A third branch comes in from Corinth and unites with the main stream in Bradford. The main course of the stream is southeast, but just before it reaches the Connecticut near Bradford Village, it turns north and finally east. There are smaller streams which uniting form the third branch that has its source in Washington. The length of Waits River is given as twenty miles. The current is for the greater portion of the course rapid.

The next river south is the *Ompompanoosuc* which seems to have retained its Indian name. This stream rises in Vershire and runs in a southeasterly direction to enter the Connecticut at Norwich. In Thetford the brook which carries the overflow from Fairlee Lake unites with it, and farther on another stream of some size adds its water. There is a branch which falling rapidly from the highlands in Vershire also joins the main stream in Thetford, after a descent of over 1,700 feet. A part of the Ompompanoosuc is sometimes called Brook River and a part Strafford Brook. The whole length of the river is given as twenty miles.

White River is the principal stream flowing into the Connecticut from eastern Vermont. Its course is very irregualr and several large branches increase the volume of the river at various points in its course. It is difficult to locate the precise source of such a stream as it really has no single one from which the major part flows, but derives its waters from many brooks and streams which are widely separated as to locality. In the case of the White River, we find that there are five recognized branches which, together make up the whole stream as it finally enters the Connecticut, but here, as in case of many other rivers, it is often a matter of opinion whether a given stream shall be called a branch or a tributary. According to Water Supply Paper 424, the White River "rises in Ripton, flows eastward into Granville, thence southeastward, passing across the eastern corner of Hancock, through Rochester into Stockbridge, then turns abruptly and flows northeastward into Bethel, then southeastward across Royalton and Sharon to its junction with the Connecticut River in Hartford." This takes the stream, as a whole, the length of which is given as fifty or sixty miles.

Those who are acquainted with the region indicated above will readily understand that any stream flowing through so much mountainous country must have a rapid current and often be a dashing mountain stream. This is true of the western stretches of White River, but from Bethel to the Connecticut the river is for the most part very quiet and bordered by banks which go back in level meadows and terraces, on which villages are charmingly located. It would be difficult to find anywhere more attractive scenery than is presented to one who drives from Stockbridge to White River Junction. West of Bethel, in the earlier stages of the river, the scenery is more mountainous and therefore wilder and more romantic, though with less of the quiet beauty of the lower stretches, but for the modern methods of journeying the roads are less convenient.

Several branches of this river have been mentioned and these may be very briefly considered. The West Branch comes from Hancock and joins the river in Rochester. This is perhaps less important than other branches. It is about ten miles long and has a southeasterly trend. What is known as the Second Branch of the White River has its sources in Williamstown and flows on through Brookfield, Randolph, Bethel, to North Royalton where it enters the main stream. The Third Branch rises in Roxbury and flows southward across a corner of Granville, through Braintree, across a corner of Randolph to join the river in Bethel. This and the Second Branch, each have a length of about twenty miles. The East Branch comes from Washington and goes on through Chelsea and Tunbridge into Royalton, joining the main stream in South Royalton. There is a smaller branch, sometimes called Robins Branch, which may be considered as a tributary, like many other brooks of the region, which rises in Hancock and unites with the main stream before leaving the town, having a length of not more than five miles.

In addition to what has been said of the delightful scenery of the White River Valley, it may be said that there is great enjoyment to be found in driving along the valleys of all of the branches named, especially if the somewhat rough roads in the mountainous districts are not too great a difficulty.

A few miles farther south the *Ottaquechee River* enters the Connecticut at Hartland. This river rises in Sherburne in the Green Mountains, one branch starting at an altitude of over four thousand feet. Flowing on to Bridgewater Corners, the North and South branches unite and from here the course is in the main easterly, bearing to the north for a little beyond Bridgewater Village, so that the course is northeast to Hartland, except a short distance before entering the river, it turns southerly. Necessarily the first parts of the stream are rapid, the southern branch from Killington falling over 2,000 feet in five miles. Like some of the other rivers, this gives excellent water power in wet seasons and when not reduced by drought, but the irregularity of amount of water is more or less troublesome in all Vermont mountain-fed streams.

Black River has its source in a mountainous region of Shrewsbury at a height of over three thousand feet. Naturally it is more or less turbulent in parts of its course. It joins the Connecticut in Springfield at the eastern border of that town. In passing from its source Black River drains Plymouth Ponds as well as several smaller ponds, and affords water power in Ludlow, Cavendish, Proctorsville, Perkinsville and Springfield. There may sometimes be confusion of the two streams, as there are two Black Rivers in Vermont, that which has just been mentioned and a smaller one in the northern part of the State.

Williams River is a small river which joins the Connecticut a few miles north of Bellows Falls. Several branches unite in Chester to make up the Williams River.

Saxtons River.—About five miles south of the stream just named Saxtons River flows into the Connecticut. This stream comes from Windham. At first its course is northerly, but soon it turns southeast, finally just below Bellows Falls, it bends northerly again.

West River.—The last of these little rivers to be mentioned is West River. This is rather more of a river than those just named. Its sources are mainly at Mount Holly two thousand feet up in the mountains and flowing in a generally south or southeast direction through Weston, Londonderry, Jamaica, Townshend, Newfane, Dummerston and Brattleboro the stream finally enters the Connecticut at the latter place. A few of the small rivers flow through southwestern Vermont and pass on into New York, such as the Hoosac, Walloomsac, and Battenkill. The *Hoosac* neither rises nor empties in this State. In North Adams it does receive the water of a Vermont stream and soon runs on for some miles in Vermont in Pownal. The *Walloomsac* is more largely a Vermont stream, but only in Bennington County. Rising in Glastenbury, this flows with some deviation, west into the Hoosac.

The Battenkill is about half in Vermont. It is a river of many windings and flows in every direction except east, in its onward course. So far as the name indicates its source, this is in Dorset for there it is first called Battenkill, but Mad Tom Brook which rises on Mount Tabor appears to be the beginning of the stream. From Dorest the course is southeast as far as Arlington

Village, a short distance beyond which the direction changes to northwest, then at West Arlington to nearly due west for a few miles, then southwesterly for a few more miles to a couple of miles beyond East Salem in New York. At this point the stream turns abruptly north and flows in this direction for over five miles when it turns west and flows on west and south into the Hudson. The total length is about fifty miles. It is regarded as a fine mill stream and is largely utilized throughout its course. There is also a West Branch which rises on Bear Mountain in Rupert and joins the main stream near Manchester Center. The fall of the main stream is over 2,800 feet and the branch has a fall of 1,800 feet which accounts for its value as a source of power.

As this list shows, Vermont is drained in all directions, though to a much less extent by those streams flowing, in general, north or south than by those running east and west. The reader will understand that the list here named does not pretend to include even all of the larger streams, much less the numberless smaller brooks. It is intended to show how well watered is most of the State. Of course, as has been noted, many, indeed all, of these streams are very greatly reduced in volume during a dry season, but none of those mentioned are ever entirely without water even in the driest season.

A few little rivers which flow into the St. Lawrence from Vermont may be added to those mentioned. The principal streams of this system are the Black, Barton and Clyde Rivers which flow into Lake Memphremagog, and a smaller stream, the Coaticook which comes out from Norton Pond.

Black River, which unfortunately has a duplicate name, the larger stream, as has been seen, is found in southern Vermont, rises in Eligo Pond and flows northward through Greensboro, Craftsbury, Albany, Irasburg, Coventry and Newport where it empties into Lake Memphremagog, a distance of over twenty-five miles.

Barton River has its origin in waters from what was once Runaway Pond in Glover and a stream coming through Belle Pond, the two uniting in Barton. In Barton the waters of Willoughby River, outlet of the lake, add to its volume. It flows north and enters Lake Memphremagog in Coventry. It is about twenty miles long.

The Clyde River is perhaps most important of these northern streams. It flows from Island Pond in Brighton and receives the water of Seymour Lake. The Clyde also flows through Round Pond and Salem Pond and enters Lake Memphremagog in Derby.

The Coaticook River has most of its course in Canada. There it flows into the *Massawipi* and finally into the *St. Lawrence.*

However, it rises in a pond in Norton, and therefore drains a part of Vermont.

As most of the territory through which the various streams flow contains only those kinds of rocks that are insoluble, it follows of necessity that the waters of Vermont are very free from mineral impurities and for most of the water it may be said that in general it is free from any injurious matter. This as a general rule but it is not necessary to add that this as a general rule has exceptions.

It surely is not necessary to call the attention of Vermonters to the very important addition to the scenery of the State which is contributed by the usually crystal clear, often dashing and everywhere numerous streams but it is not infrequently a surprise and a delight to tourists who now come into the State during the summer months, to note the frequently seen rivers and brooks as they drive over our roads. And the lakes and ponds so abundant as will soon be shown, complete the beauty of the innumerable and always charming waters.

LAKES AND PONDS

Abundant as are the streams of Vermont, the lakes and ponds are also very numerous and therefore are a very important feature in many a landscape. As far as the writer can discover no one has ever counted the bodies of water that may be found in the area of the whole State, but it appears to be certain that in all, large and small, there are over four hundred, and when the comparatively small area of Vermont is considered, it is evident that these must have a very important effect in the scenery of the State. In this respect, as in some others, one at all familiar with parts of Scotland cannot fail to notice much resemblance, almost identity even, in the scenery of the two countries.

A very few of our lakes are artificial, as Lake Lamoille, Lake Mansfield, but they are made in much the same way as many of the natural lakes, that is by a dam built across a stream thus imprisoning more or less of the abundant supply which comes with every spring. Nearly all our lakes are glacial, that is mainly or wholly formed by the action of a great glacier in Pleistocene time. Often the glacier has done more than build a dam across some valley, but also the ice mass in crossing a softer area of soil or soft rock, has scooped out a basin, which when the ice melted was filled with water. In some few lakes or ponds a landslide from a nearby slope has dammed a valley which filling with water makes a lake. A few of the so-called lakes are not more than small ponds, as Lake of the Clouds on Mount Mansfield, but most are well worthy the name. Since tourists began to visit Vermont, and summer boarders, most of our once-named ponds have come to be lakes. Such bodies of water although scattered over the whole State are more numerous in the northern and eastern portions than west of the Green Mountains. Naturally the distribution of water is by no means uniform. In some of our towns there are no ponds while in some there are many, as in Woodbury where there are twenty, and Eden which includes twenty. The prettily illustrated pamphlets "Lakes of Western Vermont" and "Lake of Eastern Vermont" published by the Bureau of Publicity, edited by Mr. Walter H. Crockett, give one a very excellent knowledge of our lakes. But as always, verbal descriptions cannot do more than call attention to what must be seen to be appreciated. So many lakes could not find place in an area as small as that of Vermont if most were not of moderate size, that is from two to three miles long and usually less broad, but some are larger. As everyone knows, our only lake which can be called large is Champlain, more than half of which belongs to Vermont. Memphremagog is also worthy to be called a large lake, but only a small part of this lake is in Vermont, most of its area being north of the Canada line. A more extended account of Champlain will be given later.

Wholly within the State, the largest lakes are Willoughby, Dunmore, Bomoseen, St. Catherine, Seymour, these are larger than others but Caspian, Crystal, Fairfield, Fairlee, Franklin, Groton, Island Pond, and Morey are all listed as over a thousand acres in extent and a number of others are put at a thousand acres or nearly as much. The interested reader is referred to the pamphlets mentioned above for further details. These pamphlets are obtained by application to the Secretary of State. As would be expected in a mountainous country a very considerable number of the Vermont lakes are several hundred and in some cases thousands of feet above sea level. Highest of these are Lake of the Clouds on Mansfield, 3,800; Bear Pond, 3,500; Sterling Pond, 3,060; Fairfield Pond, 3,000; Haystack Pond, 2,660; Lake Pleiad, 2,120; Noyes Pond, 2,286; Gilmore Pond 2,040. One hundred and forty are over a thousand feet in elevation. This does not include the portion of the State as yet unsurveyed. The above figures, as it may be added, all given in this article, are those found by the United States Topographical Survey and are therefore more accurate than any heretofore obtained. I need not add to the above that these higher ponds are all small, really they are mountain tarns.

As has been said, most of the Vermont lakes and ponds are the result of glacial action, but not all. Most of them have not been carefully studied, but there is little reason for doubting that nearly all are glacial lakes. When anyone thinks of the lakes of

Vermont, of course Lake Champlain comes to mind at once. This lake, though it cannot be called a Vermont lake, in that it is not wholly included within the boundaries of the State, is nevertheless of such importance in every way to the State that it cannot be omitted from a consideration of the lakes of Vermont. Moreover, it has a geological history more interesting than that of any of the truly Vermont lakes, or as to that more complex and involving more geological changes than most lakes the world over. In the Eighth Report on the Geology of Vermont, published in 1912, the writer attempted to give a somewhat detailed history of Lake Champlain, this is too long to be repeated in this article, but as the volume to which reference is given above has long been out of print, as brief a summary of its contents as is possible may well be included here.

Lake Champlain.—As the reader of earlier pages has seen, the Champlain Valley has a long history, outlined in early geologic time by the Adirondacks on the west and the Green Mountains on the east and the valley was early more or less filled by the lake. Indeed, Lake Champlain must be one of the very ancient bodies of water. Quiet as this valley has been in recent geologic time there is abundant evidence that during immensely long periods it was the region of many changes, changes which involved nearly all known in geological history. Just what some of these changes were is not certain, but many are very plainly indicated. The story of the beginning and development of the valley and the lake is not to be rehearsed here, only its plainest outlines, and these must be regarded as only outlines; the complete picture probably cannot be drawn with certainty. The geologically later features are pretty sure but the earliest are more uncertain and probably always will be more or less indistinct. Of course the earliest records of the Champlain Valley have been more changed during the succeeding ages. Some have undoubtedly been entirely obliterated, some greatly altered, many can be inferred by what is now found although very unlike their former condition. The valley was probably in some measure outlined as a long and narrow depression before Cambrian time. Later, after the Ordovician it was definitely marked out.

At the close of the Ordovician, if not before, there was a stream of some sort, or it may be, an ocean current, which for a long time flowed through the depression and eroded a canon-like channel where even now is the deepest part of the lake. Through the several ages, Silurian, Devonian, Mississippian, Pennsylvanian, Permian, Triassic, Jurassic, Cretaceous, Tertiary, there do not seem to have been great changes, but an immensely long period of apparent quiet. At last came the Pleistocene when the record is pretty clear. Now, in the Champlain Valley as elsewhere, came

not quiet, but unrest of every sort. Long before the incoming of the Pleistocene, the ocean waters from what is now New York Bay had flowed north to connect with the Greater St. Lawrence Gulf and thus for many, many, millions of years New England was an island. This ocean river, or current, could not have been very wide between the two mountain ranges which have been briefly considered. Now in the early Pleistocene, the land sank over an extensive area at the north and the waters of the St. Lawrence Gulf came in and flooded the land. This depression extended far west affecting the Great Lakes, but this cannot be discussed here. In the marine fossils now found in many parts of the Champlain Valley, some in banks five hundred feet above the present sea level, as well as in the beds of clay and sand lower down we see proofs of all this. In the earlier years of the Pleistocene, as has been mentioned before, great ice sheets, one after another came from the north and at times filled the Champlain Valley. Then, as the climate grew warmer, the ice front would melt and recede. Probably this recession and new advance of the ice took place several times, it certainly did in the middle west, how it was in the Champlain Valley is not very plainly shown as the later advance of the ice effaced earlier records. Most probably there was more than one glacial period, but the proofs of the last only are abundant and certain. Passing several intermediate steps in the land and water formations we come to what has been named Lake Albany. It may be noticed that before this time there was what has been called "Lake Hudson-Champlain." This lake occupied the Hudson Valley and northward covered the land of the divide which now separates Whitehall and Troy, that is the Hudson Valley from the Champlain Valley, through which now runs the canal by which boats may pass from one place to the other. How far north this lake reached was determined by the gradual melting of the ice in the Champlain Valley. When the then St. Lawrence Gulf and the then Lake Champlain were free from ice, they were continuous. For a time according to Professor Woodworth, "Lake Albany" existed above and below where Albany is now located. Woodworth says further, "That Lake Albany with the melting of the ice in the Champlain district became confluent with the glacial lake stage of that district is borne out by the extension of clays from one district to the other and by the extension of the water levels of the Lake Champlain area into the upper Hudson Valley through Wood Creek pass." 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 through the narrow defile of Wood Creek united with a glacial lake which was extending northward in the valley of

Lake Champlain as the ice melted in that valley." "With the draining of the waters over the Albany district, a divide partly of glacial materials and partly of rock was revealed between the nascent glacial lake over the Fort Edward basin and in the Champlain Valley and the region on the south, and waters began to spill over this barrier west and south of Schuylerville. Thus Lake Vermont was born consisting on the south of two mountainous ridges between which Lake George lies, a shallow lake over the Fort Edward district and a constantly increasing body of water to the north." "The water level was now about a hundred 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 two hundred feet lower than sea level. (The lake which is called Lake Vermont in this quotation, most geologists call Glacial Lake Champlain.) Somewhere about this time Glacial Lake Champlain reached its full volume, and was much larger than now and much deeper. At the Canada line its width was at least twenty miles. At Plattsburg the old shore line was ten miles farther west than now. As very ancient cliffs form the western shore at Port Kent, the old lake could not have been wider than now on the west, but south of this town in places it was wider, in places not. But on the east, or Vermont, side the width was much greater from Canada to Orwell, especially from Burlington south to Benson. Franklin County was under water west of the Central Vermont R. R. Chittenden County as far east as the foot hills of the Green Mountains. For a long time (historically long) the lake was salt water, practically an arm of the sea. The ancient shores are well defined in many places and are often known by (as mentioned above among other proofs) deposits of marine shells, clams, mussels, etc. Some of these beds of shells are several hundred feet above the present level of the lake. Several of the sand plains as in Colchester, Essex Junction, etc., have been mentioned. Most of these are delta formations in ancient Lake Champlain made when the rivers were larger than now and the land at a different level. Fort Ethan Allen is built on one of these sand deposits. It is easily understood that when the enormous masses of ice finally melted at the close of the Pleistocene the changes in the land and water surfaces must have been beyond imagination.

The changes in water levels, height of land, character and direction of the streams, tearing of ledges, and mountains, grinding rock to sand (for all sand is ground-up rock), moving and depositing all movable material, all these and more activities that moulded, formed and transformed the surface of Vermont during the thousands of years of Pleistocene time are surely beyond

comprehension. These have only been outlined here perhaps too briefly.

Vermonters surely need no measurements of so well known a lake as Champlain, but it may not be out of place if a few figures are given here. From St. Johns in Canada to Whitehall the length is 126 miles. Of this a little more than a hundred are along the shores of Vermont. It is wide at the north but a little south it is in some measure occupied by islands and the large peninsula of Alburg. Opposite Burlington is the widest clear water, thirteen miles. Of course the water in the lake varies at different seasons. For convenience the United States Topographical Survey consider the surface as a hundred feet above sea level. Actually, the height varies from a hundred and three or four feet in very high water in spring to ninety-two in a very dry summer.

In this connection the writer would like to quote from a paper published in the Tenth Report Geology of Vermont. I think that no geologist has studied the water levels of Pleistocene time, here and in New York State as carefully or as successfully as has Professor Fairchild. His conclusions as to these features are therefore authoritative. Only those paragraphs which discuss Lake Champlain can be quoted here.

"The waters of the Champlain Sea extended southeast up the narrow Winooski Valley to beyond Montpelier and the terraces of the deposit on the valley walls is abundant and often conspicuous from the moving train. We have here a narrow valley . . . . deeply flooded by sea-level waters, abundant inwash of detritus by tributary streams, and the benching of deposits by wave erosion of the lowering waters. One conclusive proof is the occurrence of finely laminated clays. A good example is seen at Waterbury. The electric line to Stowe climbs up the face of clay for more than a hundred feet. At least seventy are exposed. Similar deposits are found in all the deeper valleys and constitute the bulk of all the lower plains of the Hudson, Connecticut and Champlain Valleys. The Winooski River may be regarded as beginning at Montpelier in the junction of several streams. Many small streams dissect the valley walls. The crystalline rocks of the Green Mountains and the glacial drift supplied abundance of material for delta construction while the stream flow concentrated it in this section. But the existing terraces are only small remnants of the original delta for with the lifting of the land the vigorous rivers eroded the deposits and swept the detritus westward down the stream to build plains at lower levels even as far as Burlington. The broad stretches of sand plains on both sides of the Champlain Valley and conspicuous in Vermont are clear evidence of standing water at levels far above Lake Champlain. Marine fossils found in large numbers up to a level of over three hundred feet on the parallel of Burlington leave no doubt as to the level of the lower plains. In the Champlain Valley deltas are found on all the streams which flow westward. It should be understood that the earlier waters flooded all the valleys of Vermont to a height correlating with the open Vermont and Connecticut Valleys and the evidences of the highest water will be found far up the tributary valleys. The heavy streams now tributary to Lake Champlain were, during the postglacial submergence represented by deep estuaries or inlets, and the deposits of the flowing streams lie far inland, far east of the Champlain Valley."

The above quotations are of especial importance, since usually the terraces have been regarded by all investigators as having been wholly the result of stream activity, whereas Professor Fairchild, correctly as it seems to the writer, accounts for them by the action of the receding sea waters. Changes in the elevation of the adjacent land are certainly not to be forgotten in this connection. That such changes took place time and again cannot be doubted by anyone who studies the region.

In looking carefully over many a landscape in Vermont, the observer cannot fail to notice the recurrence of level fields, at one or several altitudes, some high up on a hillside, some lower down. Usually these are old water levels, places where the ancient Champlain sea was held for a time, it may have been long, until the deposits brought by the water had made the floor of some water body level. As the level of the land rose, or more often, in this case, the waters were lowered, the old level was left and newer levels formed. The often seen plains, such as have been noticed as delta plains must not be confused with those water levels just considered. The delta plains are always sand brought down by stream flow. The old water levels are less sandy and often fine soil.

Usually, in a mountainous or long, irregular country, such as Vermont has always been since anything that could be called Vermont existed, neither deltas nor water levels can be of large size, a few acres at most, but a few, especially deltas, are larger, as has been shown. Much of the above may be thought out of place in this connection but the writer has thought that it would be most conveniently used in this part of the article.

Lake Memphremagog.—The only other lake, partly in Vermont, and partly, and in this case mostly, outside of the State, is Memphremagog, located on the northern border. As all Vermonters know, only a small part, the southern end of this lake extends into Vermont. The entire lake is over thirty miles long and affords

charming scenery throughout its borders. About a third in length of the lake is on the Vermont side of the line. In the Eighth Report, Vermont Geologist, Prof. C. H. Hitchcock says, "Glacial Lake Memphremagog (soon after the melting of the great ice sheet) discharged through the Elligo outlet into the Lamoille and the glacial Lamoille discharged into the Winooski through the Stowe strait and even this latter stream poured though Williamstown Gap into the White River and eventually into the Connecticut. This condition of things could prevail only when the ice filled Lake Champlain so high that there was no chance for the water to be discharged except through the eastern outlet."

While all observers would not agree with the above reading of the evidence, it is quoted here, to show how different geologists may differently interpret the present indications. And though the writer does not agree with this, it may have been for a short time. It is not at all probable that Glacial Lake Champlain at any time flowed into the Connecticut.

If the reader will recall that there are over four hundred lakes and ponds in Vermont it will be evident that only a few can be even mentioned, two or three in addition to those mentioned above, are all that can be taken up here. Several years ago Mr. T. N. Dale wrote in one of the Bulletins of the United States Geological Survey—of Lake St. Catherine in Poultney as follows:

"It is bounded on the west by a slate ridge and on the east by a schist ridge. As the boundary between the two formations crosses the lake diagonally, and the slate is probably anticlinal in structure, the hollow in which it lies has been eroded." The same geologist says of Bomoseen, "Lake Bomoseen lies entirely in a region of small folded slates, etc., which crop out along its shores. The general trend of the lake corresponds approximately to the strike of the folds. But there is a cut through which the outlet of Glen Lake flows into Lake Bomoseen, and the shore of Lake Bomoseen west of Cedar Point is in line with this cut. The parallelism of this cut and this shore line to some of the joints, and also to a camptonite dike which crosses the lake a mile north of Cedar Point, indicates structural relations between them. In other respects this lake is to be attributed to erosion and to glacial and stream deposits."

So of Lake Dunmore, "Lake Dunmore seems to lie in a southward pitching syncline of quartzite with overlying dolomite, the dolomite having been largely eroded." Of Silver Lake Mr. Dale says: "Silver Lake, 670 feet above Dunmore, lies in a narrow syncline of dolomite underlaid by quartzite. . . . The lake is retained in its syncline by glacial gravel. Both of these lakes are thus associated with rock structure," *Willoughby Lake* is discussed at some length in the Report of the Vermont Geologist, Volume XII, page 230. A few quotations from this article by Prof. E. C. Jacobs follow:

"The lake may be likened to the section of a giant calabash gourd, with its broad end lying in the relatively open country and its curving neck penetrating and forming a gap in the mountain range at its southern extremity."

"Lake Willoughby lies 1,169 feet above sea level. From the southern end an easy trail leads to the summit of Mount Pisgah whose elevation is given as 1,654 feet above the lake level. . . . From the opposite shore Mount Hor rises 1,000 feet above the lake. This lake is deeper than most, just how deep has not been ascertained. Dean H. E. Hawkes of Columbia University . . . . has made careful soundings." From the data obtained by Dean Hawkes it is found that "the water deepens rapidly to about two hundred feet, and that about a third of the distance across there is a gorge in the bottom ninety-six feet deep and fifteen to twenty rods wide which has been traced about three miles north. Willoughby is a glacial lake and lies directly in the watershed between the Memphremagog and the Connecticut drainage basins. The most striking feature of the whole region is the great trough in which Lake Willoughby partly lies. As the traveler passes over the divides on the way from Lowell to Newport or from Orleans to Westmore or as he approaches the lake from West Burke, he sees in the distance a great notch in the mountain barrier, a huge U-shaped trough such as is unique in Vermont topography, but is often observed in the Rocky Mountains. The fantastic form of Mount Pisgah, rising 1,654 feet above the lake, forms the northern half of the trough while the great whale's head of Mount Hor 600 feet lower, makes the southern half. The two summits are perhaps three-quarters of a mile apart and are nearly in an east-west line."

As the result of his study of the Willoughby region Professor Jacobs offers the following summary:

"The present study has shown: 1. That Willoughby is a glacial lake 1,169 feet above set level. 2. That it lies partly in a glacier-fashioned trough between Mount Pisgah and Mount Hor. 3. That these Mountains are composed of phyllite and limestone strata of Ordovician age uplifted and injected by granite. 4. That the granite is a quartzmonzonite. 5. That the pre-glacial stage of the glacial trough could not have been a stream cut valley but was probably a trough-fault or 'Graben.' 6. That the gorge in the bottom of the lake was caused by glacial cutting." Report, Vermont Geologist, 1919-1920, pp. 280-298.

The above quotations are included here because the lake studied is unique in several respects among Vermont lakes and

because this lake has been more carefully studied, as reported in Professor Jacobs' article and because the volume referred to has long been out of print. The volume will be found in many of our public libraries and for the full account of the lake the entire article should be consulted.

It is very plain from what has been told of the story of the formation of Vermont that to bring the surface features, even those most readily seen as one looks over any of our landscapes clearly before one, well nigh if not quite impossible forces have been in action and as incomprehensible formation and transformation has been effected. Try as we may to tell this story, I do not suppose that it can be half told, I do not think that the best imagination among us can fully recreate what has taken place since Vermont began to be. Not years nor centuries nor tens of centuries, but hundreds must have been required to bring all that we see into the shape in which we now see it.

Although it is partly a repetition of what has been already noticed, it cannot be superfluous if attention is called to the character of the activities which we know to have been engaged in the making of this little state.

The main facts as they have been well established are beginning as far back in geological time as we can, of course no one knows, no one can ever know with certain knowledge what was in the beginning or anywhere near the beginning, we can imagine somewhat, probably only somewhat, the great confusion, the vast convulsions, and whatever else that language fails to express, that occurred before the earth had form and solid substance. Beginning with a solid earth as it was, say in the ages immediately preceding the Cambrian, an earth with rock of various kinds, with atmosphere, water and subject to the action of many forces but no vegetation, no life of the higher kinds, nothing as we have seen it, we may start at the Cambrian (see list of ages on page 5 of this volume). Since this age what has been going on here in Vermont? How has Vermont come to be what it is?

The foregoing pages have been an attempt partially to reply to such an enquiry. What are the instruments by which nature has through the ages accomplished so great results? They have all been repeatedly enumerated in one way or another. Look at the list once more. No repetition can make it too plain.

Taking only the last of the geological ages—a very small bit of geological time, what are the great instruments which were in action during this most recent of age. It may be well to call the attention of the reader to the great number and vast extent of the changes that took place during ages before the last Pleistocene. Look again at the list of past ages and remember that the Pleistocene is only the last enumerated and also that it was undoubtedly one of the short ages. Probably in the ages between the Cambrian and the Pleistocene similar changes were going on at all times, more or less violently.

Could one have looked over the landscape of Vermont at any period of the long time mentioned be would see a different, perhaps very different, view from that before him. We should imagine the area which is now Vermont as continually changing as the ages came and went. Certainly there were many physical features in all the later ages that were the same or similar, but the ensemble was undoubtedly more or less changed from age to age. During the Pleistocene then the forces acting to produce change were:

1. The weathering and decomposition of rock masses, very rapid in some kinds, very slow in others.
2. Action of frost whenever the temperature was lowered below freezing.
3. The various effects of streams both in wearing down rock masses and in transporting all loose material.
4. When instead of a flowing stream there was a river of ice, a glacier, there must have been enormous work done in tearing, grinding, moving rocks.
5. During the latter part of the Pleistocene, the greatly increased volume of all streams must have caused greatly increased and therefore more rapid work.
6. Wide areas of the land were raised or lowered sometimes hundreds of feet and this raising or lowering of the land must have greatly aided in carrying on the above changes. As the immediate result of these activities the conditions which prevailed in the more ancient times were brought into the state which we now see. Probably the greatest change from ancient to modern times came as the result of the forces mentioned above. The great glacier has been called "The old Vermont Plough" and undoubtedly, to its action and the results which necessarily followed its melting very much of the physiography of the Vermont which we see is due, our soil from ground rock, the rounded shape of many of our mountains, the distribution of our sands and gravels, indeed everything in our present Vermont.

Of much which does not concern our present discussion, about all that can be said is that in the Green Mountain axis there are masses of rock the origin of which undoubtedly goes back of the known fossiliferous strata of the Ordovician. How far below the surface rocks of the State these should be placed is not well determined, but that they are very old is certain. Probably these rocks will be found throughout the Green Mountain range, but they have been determined thus far only in a few limited localities, as on Killington and elsewhere in Rutland County.

The oldest rocks are hard, crystalline, and mostly wholly destitute of any indications of fossils, but in some localities they do contain fragmentary fossils. The oldest strata in this region that contain readily recognized forms are Cambrian. Although these for the most part are not fossiliferous, yet some of the strata are well filled with clearly defined specimens. The rock is largely sandstone, often of a red color and, as has been noticed the more conspicuous headlands of Lake Champlain and the nearest elevations such as Snake Mountain, Mount Philo, etc., are examples of Lower Cambrian beds. Farther north in Swanton and St. Albans, there are beds of a hard limestone and in Georgia, shale of this age, and in these some exceedingly interesting fossils are to be found. Cobble Hill and Snake Hill in Milton are examples of conspicuous elevations of Cambrian shale, but nearly all the hills near the lake on the Vermont side are of red sandstone.

In the geological series the Cambrian is immediately followed by the Ordovician. As the Cambrian was a time of shallow water and beach formation, the Ordovician was for the most part a time of deep seas and still water, abounding in lower forms of life. There is Cambrian rock east of the Green Mountains, but so far as is known, the beds are not of great extent, and probably a large part of Vermont is occupied by Ordovician strata, and it is very likely that other beds whose position geologically is not yet ascertained, will be found to belong in some of the Ordovician beds.

Not only are there numerous strata of limestone and shale in the Champlain Valley of this age, but in eastern Vermont, as has been conclusively shown by Prof. C. H. Richardson, during the last few years, widely distributed beds of slate and limestone have been examined and found to contain graptolites of Ordovician age and the schists and conglomerates of eastern Vermont are most of them if not all, of the same age. On the Vermont side of the lake, the Ordovician beds are nowhere raised into cliffs of much height, those at Thompson's Point are as bold as any, but all the gray limestones and black shales which border the lake are of this age.

With few exceptions the linear north and south arrangement mentioned above and which appears to have been fixed when the Champlain Basin and the Green Mountain uplift took place is more or less owing to the effects of the Pleistocene Age. The plan according to which all was long ago outlined, is carried out in the beds of rock, for on both sides of the mountains they are long and narrow from Canada to Massachusetts. West of the mountains these beds are limestone and sandstone mainly. East of the mountains they are mainly schists, though there are some rather extensive limestone areas. In the mountains all the rock, and east of them much of it is metamorphic—gneiss, quartzite, schist, slate.

The shape of hills and mountains, all the outlines of each landscape if not determined by the character of the outcropping or underlying rock is more or less influenced by it. For this reason the landscapes of Vermont, though certainly greatly modified by the surface drift, are such as they are because the rock of the country is what it is.

It were tedious to take up the different belts of rock running through the State in too minute detail, but some general statements may not be uninteresting Commencing at the eastern border of the State and going west, the rocks are roughly arranged in about a dozen north and south bands, some of them very narrow, some several miles wide, some extending through the length of the State, some only a short distance. Scattered over the eastern part of the State are the granite areas, and in the Champlain Valley, the marble belt of Rutland County, and the slate belt of the western part of the same region. Besides these are beds of other rocks which occur in small masses here and there.

On the northern border there is a band of schist which, of very variable width and with several wide breaks, runs south to Bellows Falls. West of this is a narrow band of slate some of which was used years ago for roofing, but nothing has been done with it for many years. This, nowhere more than a mile or at most two miles wide, extends from Burke south to the Massachusetts line, in some places bordering the Connecticut River, elsewhere separated from it by schist. West of this is a belt of schist, the "Calciferous Mica Schist" of Hitchcock, including sericite, phyllite and several other varieties. This is the most extensive of all the areas of similar rock. In it are located the most important granite areas of the State. Beginning at the Canada border, this schist belt reaches beyond the southern limits of the State and through more than half of its length it is twenty or more miles wide, but below Hartford it narrows to a few miles and at the southern limit of Vermont it is about twelve miles wide, though for a considerable distance north it is only three or four. A large part of this schist area has not been carefully studied and, while it is probably Ordovician in age, this remains to be proved.

West of this is another narrow band of dark, compact slate much like that first named. This runs from Lake Memphremagog through to Bethel. This belt is widest about Lake Memphremagog where the width is over three miles but south of this region it is narrower, sometimes not more than one mile and then it again, in the vicinity of Montpelier, widens to two or three

miles and fades out at Bethel. West of this slate strip there is a much greater belt of schist which at the Canada border is thirty miles wide, but it is soon divided by a band of gneiss and gneissoid rock into a major part which is nearly fourteen miles wide at first and continues as far south as Pittsfield and Bethel. From these towns it grows narrower until at the Massachusetts line, in Halifax, it unites with the schist which has come down farther east, being only about three miles wide where it enters Halifax. The western part of this schist area at the Canada border is over fifteen miles wide, but it gradually narrows as it goes southward until it fades out in Lincoln.

As has been repeatedly shown, the Green Mountain mass is mainly composed of gneiss or gneissoid rock and forms a belt from one edge of the State to the other, of varying width, starting very narrow and reaching a breadth at the Massachusetts line of over fifteen miles. East of this main band of gneissoid rock there is a smaller, lens-shaped one, which begins in Hartland and rapidly widens, remaining some six or eight miles wide, until at Townshend it narrows and fades out near the southern edge of the State, its total length being about sixty miles.

West of the gneiss and schist comes, in the northern half of the State, a long, narrow outcrop of conglomerate. This extends from the Canada line south as far as Ripton and in patches still farther south. In the eastern part of the State is a conglomerate which does not appear to be the same. This from its exposure in Irasburg, Doctor Richardson has named Irasburg Conglomerate and his description of its occurrence will be found in the Fifth, Eighth, Ninth and Tenth Reports of this series. West of the first mentioned conglomerate is a belt of gray limestone, often highly silicious, though in places very pure calcium carbonate from which excellent lime is made. This rises in large masses here and there and altogether is an important member of the series of Vermont rocks. This bed, the old "Eolian Limestone" in which were included several widely different beds of different age, though all Ordovician, extends through the State and into Massachusetts. Hitchcock's name is no longer used and the former Eolian Limestone has been split up into several groups, some of them very silicious, some very calcareous, some pure marble and others still different, and the ages of different beds are as different as are the rocks.

The true silicious limestone ends in Monkton not far beyond the south line of Hinesburg and though few fossils have been found is most probably of Lower Ordovician (Beekmantown) age. This limestone often heavily outcropping, especially in the town of Hinesburg, and is extremely unfossiliferous, but in part of the outcrop, in Colchester, in what appears to be a part of the general mass, distinctly Beekmantown fossils have been found and thus far I have seen no reason to doubt that the more strongly exposed southern ledges in South Burlington, Shelburne, and Hinesburg are of the same age. It is possible that here as elsewhere more extended investigation would necessitate some modification of the above, but I do not think it probable.

There is a great portion of Vermont of which the same could be properly said, for much of the State has never been carefully examined geologically. The Champlain Valley and that portion of the State which Doctor Richardson has explored, that in Orange, Washington, Caledonia and Orleans Counties, wholly or in part, and parts of Rutland County, which United States Geologists have studied with more thoroughness and care than has been bestowed upon any other part of the State, Prof. C. H. Hitchcock's work in Windsor, Orange and Chittenden Counties, Professor Gordon's in Bennington and the work of the State Geologist in Grand Isle and Chittenden Counties and elsewhere in the western part of the State, is about all that has been published of late years on Vermont geology so far as the rock structure is concerned. But to the above should be added the very interesting and valuable article by Prof. H. L. Fairchild on some of the features of the surface geology in the Report immediately preceding. All the above has been published either in full or in abstract in the biennial Reports of the State Geologist. Indeed all of the work except that of the United States Geological Survey, was done by the Vermont Survey.

West of the silicious limestone is a yet more extensive outcrop of the Lower Cambrian. Incidentally it may be worth while to notice that very small exposures of Middle and Upper Cambrian rocks have been located but these are very insignificant stratigraphically as compared with the large area of the Lower Cambrian. Repeated notice has already been made of this formation. It consists of shales and sandstone, largely the latter, and some silicious limestone. The Cambrian enters Vermont from Canada and is found for about ten miles along the western end of the border line. From this it extends southward through western Vermont in a belt of very unequal width, into New York. Nowhere very far from the shore of Lake Champlain it is seen in cliffs, which are the shore, from the northern part of St. Albans Bay to the southern end of Shelburne Bay, a distance of about thirty miles. Were it not for the Cambrian elevations, and all the elevations near the lake are Cambrian, the scenery of the lake region back several miles from the shore would be far less interesting than now. On the lake shore all the rock within this thirty miles belongs to the Red Sandrock series.

Elsewhere along the lake, often between this and the sandrock is a usually, though not always, thin bedded black shale, Upper Trenton. This is the rock of the shore from the Canada line to St. Albans Point and from the south side of Shelburne Bay to Charlotte. It also is the rock of Alburg, North Hero and most of Grand Isle. South of Charlotte this shale does not come to the shore of the lake except at Larabees Point, but it continues a short distance inland to the New York border which it crosses. From the middle of Charlotte to the middle of Shoreham the lake is borderèd by limestone, mostly Chazy and Trenton, with some Beekmantown and Upper Trenton. The larger islands in Lake Champlain are all of one or another or several of these rocks. For example North Hero is entirely Upper Trenton, Grand Isle is two-thirds Upper Trenton, but on the western shore are several beds of Chazy, through the middle is an uplift of Trenton and here and there, on shore and inland, are heavy beds of Black River from which the picturesque stone houses, formerly a conspicuous part of an island view, were built. Isle La Motte also is composed of the same Ordovician strata, though the Chazy predominates.

I wish to add here a word of qualification of some of the terms used lest there be misunderstanding. In speaking of belts or outcrops of schist, slate, etc., I do not intend to limit that of any given area to one species or kind, but simply to indicate the prevailing or more evident kind, that which really gives character to the part of the State under consideration. This is especially to be remembered when the northern or eastern parts of Vermont are discussed. Thus, schist belts have been often mentioned between the Green Mountains and the Connecticut River. These belts exist, but they are far from homogeneous, nor is the schist all of the same kind. Taking the area as a whole it may be that it is best characterized as covered by schist, but in many parts there will be found heavier masses of limestone than of schist and where there is schist this is often sericite in part and phyllite in part with perhaps smaller outcrops of chlorite and hornblende schist.

To give definite examples, in Lunenberg which is in the schist belt near the eastern border, there are outcrops of sericite, phyllite, chloritic, and hornblendic schists, besides other rocks. In Woodbury and Hardwick there are sericite, and phyllite schists, slate, limestone, and great masses of granite, so of many of the eastern towns. Sericite and phyllite schists and limestone are common all through the schist areas. More thorough investigation of the schists is needed to determine the geological period to which each should be referred. It is improbable that they were all deposited at the same time, though it is very possible that from the original rock they became schist during the disturbances that attended the Green Mountain uplift after the close of the Ordovician, as all of them have been changed in a greater or less degree from their original condition. Some of them have been supposed to be pre-Cambrian, others may be Cambrian, others and I think most, may be Ordovician. West of the Green Mountains, especially in the neighborhood of Lake Champlain, the rocks are more uniform and in the immediate vicinity of the lake they are unaltered stratified beds.

It may relieve some perplexity which arises if the older reports on Vermont geology are consulted, notably the large Report of 1861. The attention of the reader is called to numerous changes which must be made in the old names given to various geological divisions. The geological map in tne second volume of this Report is very misleading. From what has been said it will be understood all the land now included in what we call Vermont was raised above the ancient sea in very early time at least by the close of the Ordovician time. It will also be understood that its outward appearance has greatly changed during the past period since that time. There was ample time for the great changes herein enumerated to take place. The only disturbance which has left definite record of its activities was the rise of the great granite masses of the eastern part of the State. As many geologists believe, it may very probably be that much of the upheaval of the granite of Vermont came during Devonian time. Some may have come later, certainly it did not all at once rise from deeper in the earth's masses. It appears to be very certain that the activities which have during the ages so changed the character of the surface of the earth as well as far below it were not altogether quiet during the tremendous interval between the Ordovician and the Pleistocene, though little record remains to prove it.

In closing let me ask those who read this article to the end to remember what has already been written that this article is not so much for geologists as for those who desire an untechnical account of how Vermont came to be the Vermont of today.

A few repetitions will be noticed. These are intentional, in order to emphasize the facts stated. Most of the technicalities which are met in course of reading the preceding pages are explained before the close of the chapter.

A STUDY OF ALTITUDE AREAS IN VERMONT

H. F. PERKINS

LEVELS OF LAND AND LEVELS OF LIVING

Altitude alone, unless it is very low or very high, does not greatly affect the levels of civilization in a community. Hills and valleys do make a great difference. In a mountainous state the industries of the people depend a great deal on the topography of the country.

A marked change in this respect is observable since the pioneer days. It did not seem to make a great deal of difference to early settlers whether their "claims were staked" in a valley or high up on a mountain side. Later on, however, a large number of the higher farms began to lose their inhabitants. The land reverted to forests, the roads were choked up and lost, the buildings fell in ruins. This was due to some obscure group of causes which made people rather suddenly shun the higher levels, and doubtless one important cause was the desire for more social life. A concentration in hamlets, then in villages and finally cities, becomes increasingly apparent as one approaches this present day.

Obviously agriculture is considerably affected by the topography of the country. The rich bottom land along the rivers and lakes contrasts sharply with the rocky hillsides on which, to be sure, the pioneer Vermonters managed to eke out some sort of an existence. But since this is not an agricultural article, the conclusions to be drawn from careful study of these high, low, and intermediate regions are left to others who are qualified to consider them. It is hard to leave the subject, however, without pointing out that many of the achievements of the early settlers have perhaps been due to the topography of the State, or at least related to it. Also that the deserted farms, the cellar holes, and the abandoned roads of the mountain sides of Vermont are not necessarily an indication of decadence. Readjustment, especially to the mind of the believer in evolution, inevitably involves apparent waste. We may well question whether the pioneers who struggled so hard to make a living on these rugged Vermont mountain-slopes in the seventeen nineties and early eighteen hundreds would now, if they were to come into the State for the first time in the year nineteen thirty, occupy the high ground, sparsely scattered over a large area of the State, or whether they would now congregate more closely along the valleys. The factors that determine where a family will establish itself—on what soil, in what proximity to neighbors and trading centers—seem to have become greatly changed.

Improvements in transportation, even the development of high-powered motors, do not seem to have turned back the trend of migration that has been going on for half a century or more from high land to low land.[1]

RELIEF MAP OF VERMONT

To see the elevations and the depressions of the whole State at once by studying an accurate relief map is to know the State better and grasp its possibilities and its problems more quickly. Next to traveling over the State in an airplane it gives the best notion of its hills, valleys and infrequent plains that can be had.

In the prosecution of the Comprehensive Survey of Rural Vermont, now in its third year of activity, the Vermont Commission on Country Life through its committee on Basic Geographical Features has undertaken the production of such a relief map of the entire State. Professor E. C. Jacobs heads this committee.

The Commission interested itself in this undertaking because of the conviction that the "lay of the land" has a great deal to do with all human activities. Steep, uneven fields are hard to cultivate and harvest. Roads are more costly to maintain among the hills, and people are easily discouraged from gathering for recreation, worship, schooling or voting when and where travel is difficult. But valleys sometimes suffer from floods and land in lower sections is apt to cost more.

Unfortunately it is impossible to include with this article a picture of the map. A fire has destroyed the model, practically completed, and a new one must be made. We shall speak for a place in the next report for the photograph of our map.

In planning this large relief map of the State of Vermont, it was noticed that some of the towns in Vermont consisted almost entirely of low-lying territory, others had almost no land lower than one thousand feet, while in still others there was considerable range as if the town had been located on an inclined plane reaching from zero to the highest land in the State. The question inevitably arose: What effect does the altitude of the land, including steep hills, winding roads, and other difficulties, exert upon the industries and other activities of the inhabitants?

Through cooperation between the State Geological Survey and the administrative office of the Vermont Commission on Country Life, an attempt has been made to analyze and then tabulate the areas of the one hundred and sixty-nine Vermont

[1] Goldthwait, J. W., "A Town That Has Gone Down Hill," *Geographic Review*, October, 1927.

towns and cities as they lie between various levels. Unfortunately funds were not available for the production of certain diagrams and graphs that might have helped to visualize these altitude areas, but a study of the accompanying table will perhaps serve to convey an idea of the relative amount of low land in the various towns and to show how much land of medium altitude and how much very high ground lies within the limits of the several Vermont towns.

In the calculations for the making of the large relief model, the United States Topographic Survey sheets were used as far as they were available. The altitudes given in this paper are based upon these maps and the areas were ascertained by computing the number of square miles between the contour lines.

For this work a planimeter was used, very kindly loaned to the writer by the American Geographical Society of New York.

This instrument, as most readers know, automatically registers numbers on a dial when its point is caused to trace along a line, and the number represents area measurements, not linear. It is then translated into square miles by use of a factor which is easily found from the scale to which the map is drawn. Thanks are due and are cordially given to Dr. John K. Wright, Librarian of the American Geographic Society, for much painstaking and wise assistance in this undertaking.

In earlier reports, the State Geologist himself contributed articles on the altitudes of a long list of points in very many of the towns of Vermont. It seems not inappropriate then to add this small contribution to our knowledge of the altitudes of the State. In this instance the extent of areas between certain altitude levels are considered rather than the measurements of certain specific points.

SURVEYED AREAS

At this time it is impossible to get complete altitude data for Vermont. The altitudes of many points in the State outside of the surveyed areas are known[1] but it is impossible to tell much about the area of land included in the different levels unless the town has been surveyed by the United States Geological Survey, Topographic Service. The accompanying map of Vermont (Figure 1) shows the areas that have been completely surveyed, the towns that have been partly included in the survey quadrangles (in light shading), and (unshaded) the towns in which no measurements have been made by the Government workers. About four-fifths of the State has been completely covered by the published topographic sheets. The forty-three towns that are lightly shaded on the map are tabulated in a second list, but the figures

[1] See Sixteenth Report of the State Geologist of Vermont, 1928-1929.

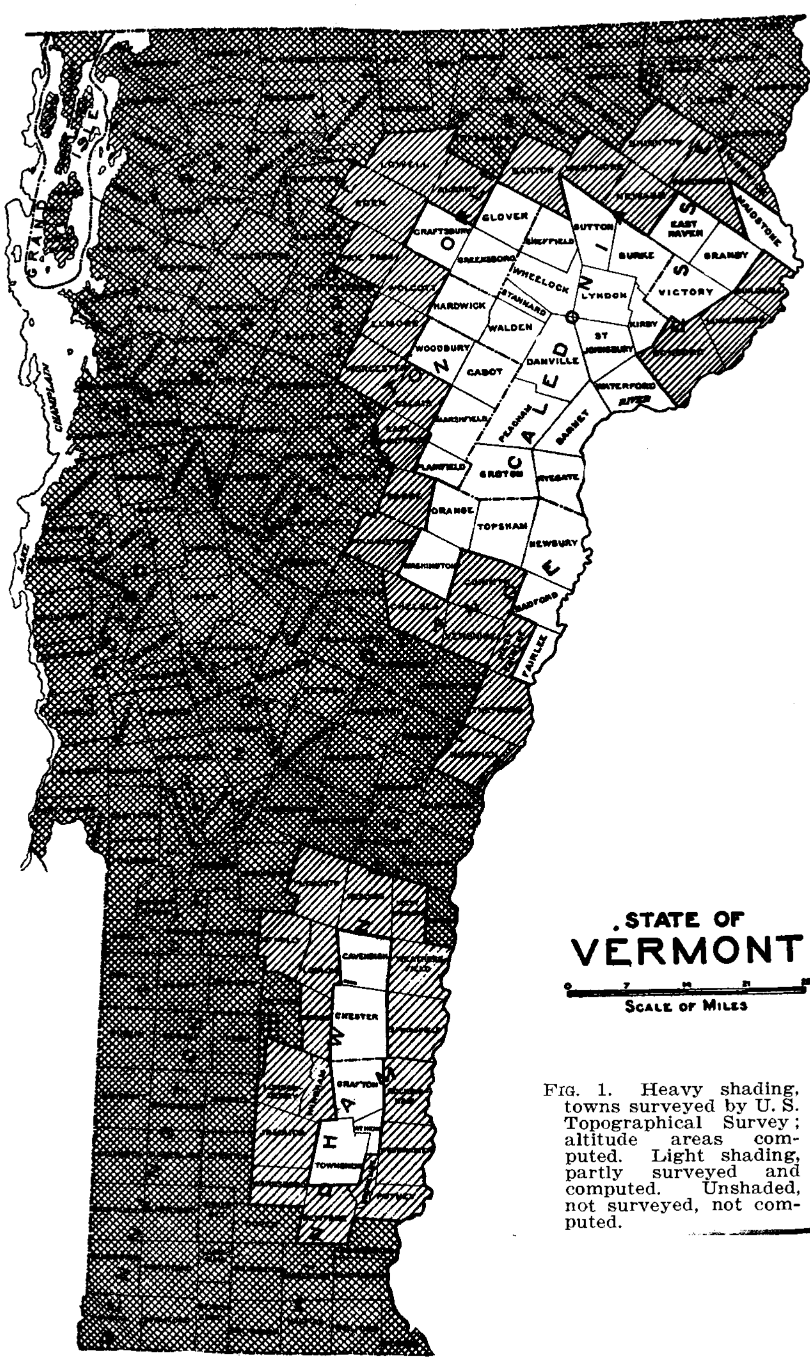

FIG. 1. Heavy shading, towns surveyed by U. S. Topographical Survey; altitude areas computed. Light shading, partly surveyed and computed. Unshaded, not surveyed, not computed.

are lower than they will be when the surveys are complete, and therefore seem to show a smaller area for each of these towns than it actually covers.

The Committee on Basic Geographical Features, Professor E. C. Jacobs, Chairman, was able by a considerable amount of research work, to secure additional data from various sources which was sufficiently accurate to use in the construction of the map. Thus the areas that are shown in white on the accompanying figure because they were not covered by the United States Geological Survey topographic sheets, were filled in on the relief map in accordance with this additional information. In order to make the necessary observations in the northeastern part of Vermont, mostly in Essex County, Professor Jacobs and a representative of the map makers, Ward's Natural Science Establishment of Rochester, New York, spent several days in that territory making records by means of the barometer, the camera, and the notebook.

HIGH, LOW AND INTERMEDIATE TOWNS

In the absence of diagrams illustrating the relative amounts of high ground in each town as well as of intermediate and low lying territory, the following list has been compiled indicating the natural grouping under the three headings. The division points are arbitrary, the purpose being to divide the one hundred and sixty-nine surveyed towns into three equal groups.

It will be interesting, as soon as the government surveys are all done and the maps available for study, to make a composite diagram of the entire State to show how much of the total land in the State belongs within the limits of each of the four altitude levels. It would not be wise to attempt this estimate until the figures are at least more nearly complete than they are today.

TOWNS HAVING NO LAND BELOW 1,500 FEET

Searsburg, Somerset, Stratton, Warner's Grant.

TOWNS HAVING NO LAND BELOW 1,000 FEET

Averill, Avery's Gore,[1] Avery's Grant, Canaan, Dover, Glastenbury,[1] Goshen[1], Holland, Landgrove, Lemington,[1] Lewis, Morgan,[1] Norton, Peru, Readsboro, Ripton,[1] Sherburne, Shrewsbury, Stamford, Tinmouth,[1] Warren's Gore, Weston, Whitingham, Wilmington, Winhall,[1] Woodford.[1]

TOWNS HAVING NO LAND HIGHER THAN 1,000 FEET

Addison,[2] Alburg, Bridport, Burlington, Charlotte, Colchester, Cornwall, Fairfax,[2] Fair Haven, Ferrisburg, Franklin,

[1] Very small amount below one thousand feet.
[2] Very small amount higher than one thousand feet.

Georgia,[1] Grand Isle, Highgate, Isle La Motte, New Haven, North Hero, Orwell, Panton, Shelburne, Sheldon,[1] Shoreham, South Burlington, South Hero, Vergennes, Waltham, Whiting.

COMPLETED TOWNS

	Total area Sq. mi.	Below 1,000′ Sq. mi.	1,000′-1,500′ Sq. mi.	1,500′-2,000′ Sq. mi.	Above 2,000′ Sq. mi.
Addison	44.89	44.62	.27	.....	.....
Alburg	30.40	30.40	.....	.....	.....
Arlington	43.08	17.23	11.89	7.63	6.33
Averill	38.56	.....	.76	17.74	20.06
Avery's Gore	9.18	.06	1.74	3.11	4.27
Avery's Grant ...	21.57	.....	.08	5.30	16.19
Bakersfield	40.70	28.71	10.90	1.09	.....
Barnard	50.11	1.56	21.06	22.57	4.92
Belvidere	36.96	2.90	13.39	11.67	9.00
Bennington	43.43	25.57	10.61	5.85	1.40
Benson	48.36	48.33	.03	.....	.....
Berkshire	43.20	42.31	.89	.....	.....
Berlin	38.04	17.75	18.16	1.85	.28
Bethel	46.47	15.41	22.81	6.46	1.79
Bloomfield	39.78	2.08	18.48	14.98	4.24
Bolton	43.89	9.41	11.37	9.52	13.59
Braintree	38.72	7.81	18.98	8.91	3.02
Brandon	40.70	35.63	4.47	.41	.19
Brattleboro	33.72	24.72	7.15	1.85	.....
Bridgewater	52.27	3.41	14.94	24.40	9.52
Bridport	47.71	47.71	.....	.....	.....
Bristol	40.80	27.02	5.55	5.28	2.95
Brookfield	42.89	5.51	24.28	13.10	.....
Brownington	29.30	1.55	26.17	1.58	.....
Burlington	11.01	11.01	.....	.....	.....
Cambridge	64.69	37.87	11.60	6.74	8.48
Canaan	33.78	.....	17.91	15.53	.34
Castleton	43.66	38.42	4.92	.31	.01
Charleston	40.09	.29	31.06	8.58	.16
Charlotte	42.79	42.79	.....	.....	.....
Chittenden	77.01	.38	13.79	26.85	35.99
Clarendon	32.59	23.57	7.76	1.09	.17
Colchester	40.09	40.09	.....	.....	.....
Cornwall	29.52	29.52	.....	.....	.....
Coventry	28.34	21.80	6.39	.15	.....
Danby	42.99	4.90	15.71	13.19	9.19
Derby	59.03	25.58	31.95	1.50	.....
Dorset	47.28	10.08	17.23	9.96	10.01
Dover	36.96	.....	4.29	12.24	20.43
Duxbury	45.57	9.27	12.12	10.90	13.28
Dummerston	31.14	23.61	7.07	.46	.....
Enosburg	49.97	39.36	7.86	1.94	.81
Essex	40.46	39.76	.70	.....	.....
Fairfax	41.82	41.80	.02	.....	.....
Fairfield	69.36	65.60	3.76	.....	.....
Fair Haven	18.57	18.57	.....	.....	.....
Fayston	37.26	1.83	13.44	12.55	9.44

[1] Very small amount higher than one thousand feet.

	Total area Sq. mi.	Below 1,000′ Sq. mi.	1,000′-1,500′ Sq. mi.	1,500′-2,000′ Sq. mi.	Above 2,000′ Sq. mi.
Ferrisburg	51.31	51.31	.....	.....	.....
Fletcher	39.17	26.15	11.13	1.89	.....
Fort Ethan Allen	1.24	1.24	.....	.....	.....
Franklin	42.42	42.42	.....	.....	.....
Georgia	41.44	40.92	.52	.....	.....
Glastenbury	46.54	.03	1.58	3.94	40.99
Goshen	23.55	.02	4.20	12.35	6.98
Grand Isle	16.63	16.63	.....	.....	.....
Granville	51.90	2.88	7.71	20.35	20.96
Guilford	35.58	14.73	20.47	.38	.....
Halifax	41.21	4.23	17.64	16.77	2.57
Hancock	38.62	1.16	5.14	12.46	19.86
Hartford	48.03	38.64	9.35	.04	.....
Hartland	46.55	25.03	20.17	1.35	.....
Highgate	54.57	54.57	.....	.....	.....
Hinesburg	41.85	32.36	8.82	.67	.....
Holland	39.66	.....	19.72	18.79	1.15
Hubbardton	29.64	20.79	8.16	.63	.06
Huntington	43.88	11.72	21.48	1.48	9.00
Ira	23.37	4.72	10.10	6.46	2.09
Irasburg	41.89	20.06	17.86	3.38	.59
Isle La Motte	8.05	8.05	.....	.....	.....
Jay	34.90	5.10	12.43	8.69	8.68
Jericho	37.20	30.05	6.31	.84	.....
Johnson	62.09	29.77	18.49	9.55	4.28
Landgrove	9.22	.....	3.29	5.78	.15
Leicester	22.59	18.61	2.89	1.09	.....
Lemington	36.03	.30	7.45	15.14	13.14
Lewis	38.27	.....	18.40	15.71	4.16
Lincoln	44.15	.80	17.60	14.90	10.85
Manchester	42.67	18.00	8.33	5.24	11.10
Marlboro	42.31	1.55	8.59	28.70	3.47
Mendon	35.43	2.16	6.08	13.92	13.27
Middlebury	40.15	34.42	3.52	2.14	.07
Middlesex	40.77	13.65	19.42	5.55	2.15
Middletown	23.64	4.97	12.73	5.74	.20
Milton	54.62	53.20	1.42	.....	.....
Monkton	38.27	35.62	2.43	.22	.....
Montgomery	55.94	16.36	21.69	8.80	9.09
Montpelier	10.02	9.76	.26	.....	.....
Moretown	41.63	17.20	18.86	4.93	.64
Morgan	33.74	.04	16.13	16.27	1.28
Morristown	65.21	35.87	19.68	3.47	6.19
Mt. Tabor	45.87	4.40	2.92	12.45	26.10
New Haven	43.36	43.36	.....	.....	.....
Newport	52.33	32.03	17.14	3.07	.09
Northfield	46.26	7.54	22.65	12.26	3.81
North Hero	14.14	14.14	.....	.....	.....
Norton	40.10	.....	14.56	23.72	1.82
Orwell	48.95	48.95	.....	.....	.....
Panton	16.80	16.80	.....	.....	.....
Pawlet	44.74	26.73	14.88	2.90	.23
Peru	40.28	.....	4.37	16.69	19.22
Pittsfield	20.44	2.04	7.14	6.12	5.14
Pittsford	45.05	33.72	8.89	2.44	.....

	Total area Sq. mi.	Below 1,000′ Sq. mi.	1,000′-1,500′ Sq. mi.	1,500′-2,000′ Sq. mi.	Above 2,000′ Sq. mi.
Pomfret	40.75	7.33	23.50	9.92	.....
Poultney	21.34	9.48	9.36	2.31	.19
Pownal	48.49	14.81	20.39	7.40	5.89
Proctor	7.68	7.13	.55	.....	.....
Randolph	48.83	20.84	26.54	1.45	.....
Readsboro	34.59	.....	6.88	6.87	20.84
Richford	43.87	20.88	11.75	5.08	6.16
Richmond	33.73	28.76	4.80	.17	.....
Ripton	53.56	.24	10.62	24.74	17.96
Rochester	59.20	5.12	17.33	24.27	12.48
Roxbury	42.23	1.09	15.16	19.27	6.71
Royalton	42.14	22.83	19.31	1.74	.....
Rupert	45.94	10.15	19.31	10.08	6.40
Rutland	28.43	27.24	1.19	.....	.....
St. Albans	39.80	37.32	2.48	.....	.....
St. George	3.79	3.52	.27	.....	.....
Salisbury	30.14	24.10	2.00	2.86	1.18
Sandgate	43.53	4.70	15.67	14.73	8.43
Searsburg	20.32	.....	.....	4.67	15.65
Shaftsbury	43.38	19.71	18.06	4.83	.78
Sharon	41.28	14.32	21.43	5.53	.....
Shelburne	26.08	26.08	.....	.....	.....
Sheldon	40.43	39.87	.56	.....	.....
Sherburne	50.30	.....	5.53	15.31	29.46
Shoreham	45.44	45.44	.....	.....	.....
Shrewsbury	51.95	.....	8.64	19.10	24.21
Somerset	27.12	.....	.....	2.19	24.93
South Burlington	17.15	17.15	.....	.....	.....
South Hero	14.97	14.97	.....	.....	.....
Stamford	43.57	.....	5.39	10.19	27.99
Starksboro	44.96	11.43	14.96	15.42	3.15
Stockbridge	47.55	18.22	6.57	18.28	4.48
Stowe	78.73	17.90	28.35	17.05	15.43
Strafford	44.96	2.44	24.06	18.23	.23
Stratton	50.37	.....	.....	11.30	39.07
Sudbury	23.11	22.04	1.07	.....	.....
Sunderland	48.17	9.82	3.72	4.46	30.17
Swanton	50.74	50.67	.07	.....	.....
Tinmouth	29.59	.11	17.33	8.35	3.80
Troy	36.99	30.46	6.53	.....	.....
Tunbridge	46.52	11.80	25.52	9.05	.15
Underhill	52.76	15.49	21.93	8.29	7.05
Vergennes	2.75	2.75	.....	.....	.....
Vernon	20.67	19.70	.97	.....	.....
Waitsfield	26.58	10.11	10.02	3.91	2.54
Wallingford	44.07	12.54	10.58	12.05	8.90
Waltham	8.95	8.95	.....	.....	.....
Warner's Grant	3.29	.....	.03	2.21	1.05
Warren	42.72	1.80	14.03	15.79	11.10
Warren's Gore	12.15	.....	4.33	4.53	3.29
Waterbury	51.60	26.96	14.70	6.20	3.74
Waterville	18.98	8.14	7.86	2.65	.33
Wells	24.34	15.49	7.11	1.66	.08
Westfield	40.53	8.38	11.49	10.69	9.97
Westford	40.57	34.05	6.43	.09	.....

	Total area Sq. mi.	Below 1,000′ Sq. mi.	1,000′-1,500′ Sq. mi.	1,500′-2,000′ Sq. mi.	Above 2,000′ Sq. mi.
West Haven	29.45	29.41	.04	.....	.....
Weston	37.00	.....	8.36	17.43	11.21
West Rutland	17.80	12.58	3.52	1.65	.05
Weybridge	17.67	17.55	.12	.....	.....
Whiting	14.07	14.07	.....	.....	.....
Whitingham	39.76	.....	4.80	31.70	3.26
Williston	31.87	31.77	.10	.....	.....
Wilmington	42.96	.....	1.19	32.89	8.88
Windsor	20.30	13.98	4.42	.77	1.13
Winhall	44.42	.02	10.02	19.01	15.37
Woodford	48.92	.03	3.57	7.67	37.65
Woodstock	44.31	12.56	24.08	6.75	.92

Incomplete Towns (Not yet entirely surveyed)

	Total area surveyed to 1931 Sq. mi.	Below 1,000′ Sq. mi.	1,000′-1,500′ Sq. mi.	1,500′-2,000′ Sq. mi.	Above 2,000′ Sq. mi.
Albany	11.35	3.45	6.76	1.03	.11
Andover	3.81	.....	.06	1.01	2.74
Barre	25.35	8.01	16.70	.64	.....
Barton	27.51	8.02	17.04	2.34	.11
Brighton	52.89	.....	31.13	15.47	6.29
Brookline	1.84	1.30	.49	.05	.....
Brunswick	7.90	.15	5.77	1.95	.03
Calais	8.93	2.04	4.85	2.04	.....
Chelsea	29.53	2.52	14.06	12.33	.62
Concord	.45	.22	.23	.....	.....
Corinth	2.88	.02	2.58	.28	.....
E. Montpelier	21.01	5.99	14.72	.30	.....
Eden	58.54	4.28	36.71	13.21	4.34
Elmore	28.55	.06	18.82	7.43	2.24
Ferdinand	16.53	.....	16.31	.22	.....
Guildhall	1.45	1.00	.45	.....	.....
Hyde Park	50.11	22.92	23.82	3.37	.....
Jamaica	42.71	10.48	16.88	13.88	1.47
Londonderry	35.59	.66	30.29	3.14	1.50
Lowell	53.62	4.23	27.34	13.65	8.40
Ludlow	1.85	.....	.....	.....	1.85
Lunenburg	29.46	7.85	19.20	2.41	.....
Mount Holly	45.30	.....	7.84	26.05	11.41
Newark	2.00	.....	.....	1.69	.31
Newfane	34.29	13.28	16.60	4.41	.....
Norwich	43.18	20.08	20.45	2.65	.....
Plymouth	35.88	.41	10.56	15.38	9.53
Putney	23.84	18.09	5.18	.57	.....
Reading	19.72	.....	4.20	11.37	4.15
Rockingham	27.44	24.86	2.58	.....	.....
Springfield	33.59	27.99	5.60	.....	.....
Thetford	22.48	14.07	7.52	.89	.....
Vershire	36.23	1.03	12.56	17.99	4.76
Wardsboro	27.70	.45	7.44	16.53	3.28
Weathersfield	32.05	20.42	10.79	.63	.21
West Fairlee	4.41	2.38	2.03	.....	.....
Westminster	24.92	23.82	1.10	.....	.....
Westmore	25.04	.....	5.97	9.11	9.96

	Total area surveyed to 1931	Below 1,000′	1,000′-1,500′	1,500′-2,000′	Above 2,000′
	Sq. mi.	Sq. mi.	Sq. mi.	Sq. mi.	Sq. mi.
West Windsor ..	18.84	5.16	10.46	2.51	.71
Williamstown	37.62	3.55	19.44	14.50	.13
Windham	3.48	.....	.82	1.36	1.30
Wolcott	6.28	2.89	3.39	.....	.....
Worcester	39.42	5.87	15.84	7.31	10.40

LIST OF LOW, INTERMEDIATE, AND HIGH TOWNS

Low: Addison, Alburg, Benson, Berkshire, Brandon, Brattleboro, Bridport, Bristol, Burlington, Castleton, Charlotte, Colchester, Cornwall, Enosburg, Essex, Fairfax, Fairfield, Fair Haven, Ferrisburg, Franklin, Georgia, Grand Isle, Hartford, Highgate, Isle La Motte, Leicester, Middlebury, Milton, Monkton, Montpelier, New Haven, North Hero, Orwell, Panton, Proctor, Richmond, Rutland, St. Albans, St. George, Salisbury, Shelburne, Sheldon, Shoreham, S. Burlington, S. Hero, Sudbury, Swanton, Troy, Vergennes, Vernon, Waltham, Westford, West Haven, Weybridge, Whiting, Williston.

Intermediate: Arlington, Bakersfield, Bennington, Berlin, Bloomfield, Braintree, Brookfield, Brownington, Cambridge, Charleston, Danby, Derby, Dorset, Fletcher, Guilford, Hartland, Hinesburg, Hubbardton, Huntington, Ira, Irasburg, Jericho, Johnson, Manchester, Middlesex, Middletown, Montgomery, Moretown, Morristown, Newport, Northfield, Pawlet, Pomfret, Poultney, Pownal, Randolph, Richford, Royalton, Rupert, Shaftsbury, Sharon, Starksboro, Stockbridge, Strafford, Tinmouth, Tunbridge, Underhill, Waitsfield, Waterbury, Waterville, Wells, West Rutland, Windsor, Woodstock.

High: Averill, Avery's Gore, Avery's Grant, Barnard, Belvidere, Bolton, Bridgewater, Canaan, Chittenden, Dorset, Dover, Duxbury, Fayston, Glastenbury, Goshen, Granville, Halifax, Hancock, Holland, Jay, Landgrove, Lemington, Lewis, Lincoln, Marlboro, Mendon, Morgan, Mt. Tabor, Norton, Peru, Pittsford, Readsboro, Ripton, Rochester, Roxbury, Sandgate, Searsburg, Sherburne, Shrewsbury, Somerset, Stamford, Stowe, Stratton, Sunderland, Wallingford, Warren, Warren's Gore, Warner's Grant, Waterbury, Waterville, Wells, West Rutland, Windsor, Woodstock.

Glastenbury and Somerset are the two highest towns in Vermont although Glastenbury runs down to a small corner that is below the one-thousand-foot level.

Manchester is one of the most evenly sloping towns having 18.0, 18.33, 5.25, and 11.10 square miles, respectively, in each of the four columns. Stowe is similar with 17.90, 28.35, 17.05, 15.43, total 78.73.

ANNOTATED BIBLIOGRAPHY OF VERMONT PETROLOGY

Marion Hubbell

INTRODUCTION

From time to time lists of publications dealing with the geology of Vermont have been prepared. The Bibliography of Geologic Literature on North America[1] includes all references published between the dates 1785 and 1918, but of the lists concerned solely with the State the best are those in the State Geologist's Reports for 1902 and 1904.[2]

So far as has been determined, none of the lists available are annotated, and there is no means of knowing the character of the published material, except by consulting each report. It was felt, therefore, that it might be an advantage to students of Vermont geology to have access to information that will enable them to gauge the utility of a given reference for their particular needs, and the following list was prepared with the idea of partially filling this need. An annotated bibliography of all publications on Vermont geology would be a greater task than time or space permitted in the present paper. As indicated in the title, it lists articles on one branch of Vermont geology only, namely, Petrology.

The selection of the reports which have been included was difficult, and many references were consulted which do not appear in the Bibliography. The definition of terms which governed the acceptability of papers for such a list was based upon the definition of petrology given by Pirsson and Knopf: "It comprises our knowledge of the rocks forming the crust of the earth, the results of our studies of the various component materials that form them, the different factors that have led to their formation, and the laws governing them, and of their behavior under the action of the agencies to which they have been subjected; it also endeavors to classify the kinds into orderly arrangement."[3]

Many references found in this list naturally contain in addition to petrologic information, material which must be classified under the headings Paleontology, Physiography, Stratigraphy, and

[1] Nickles, John M., Geologic Literature on North America, 1785-1918. U. S. G. S., Buls. 746, 747 (1923).
[2] Perkins, George H., List of Reports on the Geology of Vermont: 1845-1900; List of Publications on the Geology of Vermont. Vt., St. G., Rp. 3: 14-21 (1903); List of Works on the Geology of Vermont. Vt., St. G., Rp. 4: 16-21 (1905).
[3] Pirsson, Louis V., and Knopf, Adolph, Rocks and Rock Minerals. John Wiley & Sons, New York, 1926, p. 2.

Historical Geology. Reports which deal with these phases of geology exclusively have not been included, for it was felt that these branches of the science are distinct enough to merit separate treatment.

The comments on each article are not intended to give an abstract of the contents, but to indicate the subject matter of the paper and the kind of treatment which it receives. Abstracts, unless very lengthy, would not satisfy the varying needs of all persons consulting the bibliography, and for this reason no effort was made to furnish them. An evaluation of the utility of each report is not attempted for it would vary according to the demands of the reader; an effort has been made to indicate the thoroughness of the author's treatment when it could be judged.

An attempt has been made to make the list complete, but it is possible that some articles, especially among those which have appeared since the last of the North American bibliographies was issued (1926), have been inadvertently overlooked. It is probable, also, that there are some publications which deal with Vermont petrology more or less incidentally that have escaped notice. Nickles' Bibliography, Perkins' lists of publications, bibliographies included in the various works on Vermont, and footnote or text references in the reports have constituted the principal sources of bibliographic information.

The arrangement of titles which seems most convenient is a list, alphabetical by authors, and chronological for each author. Where there is more than one reference under a single date, the order is alphabetical by titles. The date has been placed in the margin so that it can be seen at a glance how recent the publication is and consequently how nearly up-to-date the information it contains is likely to prove. Each article is numbered to facilitate the use of the index lists. An enumeration of the rock types, ages, counties, and petrographic work involved cannot be given conveniently in each annotation, therefore, indices of the subjects have been prepared and are to be found at the end of the paper.

The form of abbreviation employed for publication, volume, and page references is, in general, the same as that in Bulletin 746. For example, Am J Sc (3) 29:205-222, 437-443; 33:270-276 stands for American Journal of Science, series 3, volume 29, pages 205 to 222, 437 to 443, and volume 33, pages 270 to 276. A list of the publications and the abbreviations for each follows:

LIST OF PUBLICATIONS AND ABBREVIATIONS USED

Ac N Sc Phila, Pr: Academy of Natural Sciences of Philadelphia, Proceedings.
Am As, Pr: American Association for the Advancement of Science, Proceedings.

Am G: American Geologist. Minneapolis.
Am J Agr: American Journal of Agriculture and Science. Albany, N. Y.
Am J Sc: American Journal of Science. New Haven, Conn.
Am Mus N H, B: American Museum of Natural History, Bulletin. New York.
Am Nat: American Naturalist. Salem, Mass., and elsewhere.
Archives of Science of Orleans Co (Vt) Soc N Sc, Tr Archives of Science and Orleans County (Vt) Society of Natural Sciences, Transactions. Newport, Vt.
Boston Soc N H, Pr; Mem: Boston Society of Natural History, Proceedings; Memoirs.
Can M Inst, Q B; J: Canadian Mining Institute, Quarterly Bulletin; Journal. Montreal.
Can Nat: Canadian Naturalist and Geologist and Proceedings of the Natural History Society of Montreal.
Eng M J: Engineering and Mining Journal. New York.
G Mag: Geological Magazine. London.
G Soc Am, B: Geological Society of America, Bulletin. Rochester, N. Y., and elsewhere.
G Soc London, Q J: Geological Society of London, Quarterly Journal.
J G: Journal of Geology. Chicago, Ill.
Lyc N H N Y, Pr: Lyceum of Natural History of New York, Proceedings. Later New York Academy of Sciences.
M Mag: Mining Magazine. London.
Middlebury Hist Soc, Papers and Pr: Middlebury (Vt) Historical Society, Papers and Proceedings.
N Y Ac Sc, An; Tr: New York Academy of Sciences, Annals; Transactions.
N Y St Mus, B: New York State Museum of Natural History, Bulletin. Albany.
Science: Cambridge, Mass., later New York (n s new series).
Soc G France, B: Société géologique de France, Bulletin. Paris.
Soc Minér France, B: Société minéralogique de France, Bulletin. Paris.
U S G S, An Rp; Mon; Min Res: United States Geological Survey, Annual Report; Bulletin; Monograph; Mineral Resources.
Vt Historical Gazetteer: Vermont Historical Gazetteer.
Vt Soc Eng, Pr: Vermont Society of Engineers, Proceedings.
Vt, St G, Rp: Vermont, State Geologist, Report. Rutland.
Vt, St G, Rp: Vermont, State Geologist, Report. Burlington.
Wash Ac Sc, J: Washington (D. C.) Academy of Sciences, Journal.

BIBLIOGRAPHY

Adams, Charles Baker

1 1845 First annual report on the geology of the State of Vermont. 92 pp, Burlington.

This first annual report of the work of the State Geologist includes a description of the common minerals, of the stratified and unstratified rocks and a section on economic geology which gives the distribution and occurrence of the useful minerals. Under Scientific geology the ages of the rocks are discussed. An appendix contains letters from several geologists on topics pertaining to Vermont.

2 1846 Second annual report on the geology of the State of Vermont. 267 pp, Burlington.

The report, which might have been used as a textbook, is arranged in five divisions. Part I on Elementary geology discusses the geologic agents and the history of the earth. A brief list of mineral localities and a lengthy dissertation on concretions comprise the contents of Parts II and III. The Scientific geology of Part IV treats the age problems of Vermont geology, and Part V describes the economic phases of the subject.

3 1847 Third annual report on the geology of the State of Vermont. 32 pp, Burlington.

The granite, limestone, and marble industries receive attention, and the reports of other workers and a history of the survey complete this brief report.

4 1847 On the Taconic rocks (with discussion by E. Emmons). Am J Agr 6:212 (260); Am J Sc (2) 5:108-110 (1848); Can Nat 6:324-325 (1860).

The degree of metamorphism and correlations of the sedimentary and metamorphic rocks from the Taconic series (Cambrian) to the "Lower Silurian" (Ordovician) system in Addison County are the topics for a short paper.

5 1848 Fourth annual report on the geological survey of Vermont. 8 pp, Burlington.

The only geologic information in a report on the progress of the survey is the chemical analyses of limestone, iron ore, and clays.

Allen, Jonathan A.

6 1821 On the question whether there are any traces of a volcano in the West River Mountain (Vt.). Am J Sc 3:73-76.

No evidences of volcanic activity were discovered, but the rock sequence and mineral localities of the vicinity were noted.

Alling, Harold L.

7 1929 Porphyritic Monzonitic Bostonite in Vermont. Vt, St G, Rp 16:290-291.

Microscopic examination of a specimen from a dike in North Ferrisburg proves the rock to be a Bostonite, a type of rock not previously noted in the region. This very brief discussion presents valuable material in concise form.

Bain, George W.

8 1927 Contact metamorphism and related changes in composition. Vt, St G, Rp 15:242-263.

The changes in composition, the behavior of the primary waters in igneous rocks, and other results of contact metamorphism were deduced from chemical and petrographic studies of specimens from Ontario, which are similar to those in the Green Mountain section.

9 1927 Geologic history of the Green Mountain front. Vt, St G, Rp 15:222-241.

Under the headings of "gathering the materials," and "mouldings," and "sculpturing" them are presented the types of outcrops, their distribution, and the geological and erosional history of the region. Emphasis is upon the general relationships rather than upon detailed study of the rock types.

Balk, Robert

10 1927 A contribution to the structural relations of the granitic intrusions of Bethel, Barre, and Woodbury, Vt. Vt, St G, Rp 15:39-96.

General description of the rocks, the structure, and relations of the intrusive bodies to each other and to the country rock are treated by townships in this well organized article.

Barker, George F.

11 1861 Report (on rocks of Vermont). In Report on the geology of Vermont (Hitchcock) 2:706-711.

Chemical analyses of rocks of Vermont made by the author form a section in Hitchcock's extensive report.

Billings, Elkanah

12 1862 On the age of the red sandstone formation of Vermont. Am J Sc (2) 32:232; Can Nat n s 6:322-323 (1872).

The calciferous sandrock of the Canada-Vermont boundary receives slight treatment in this paper, but more detail in the following report.

13 1862 Further observations on the age of the red sandrock formation (Potsdam group) of Canada and Vermont. Am J Sc (2) 33:100-105, 370-376, 421-422.

Although the material is mainly paleontologic in character there is some discussion of the metamorphic and sedimentary rocks of northern Vermont. A controversy over priority in dating the red sandrock series is reviewed.

14 1872 Note on the discovery of fossils in the "Winooski marble" at Swanton, Vt. Can Nat n s 6:351; Am J Sc (3) 3:145-146.

This brief statement of the discovery of fossils at Swanton gives the stratigraphic relationships of the rocks of the region.

Brainerd, Ezra

15 1885 The geological features of the marble belt (of western New England). Middlebury Hist Soc, Papers and Pr 1 pt 2:9-21.

This paper was written with the purpose of presenting briefly the geological views which had obtained with respect to the marble district and of indicating those more recently established. The origin and history of the marble and associated rocks in all of western New England are given, but the belt in Vermont is most fully discussed.

16 1891 The Chazy formation in the Champlain Valley. G Soc Am, B 2:293-300.

Vermont localities are mentioned and the lithologic characteristics of outcrops described.

Brainerd, Ezra, and Seely, H. M.

17 1888 The original Chazy rocks. Am G 2:323-330.

This article was written as a preliminary to one which was to deal with the same subject for western Vermont. Descriptions of localities and fossil content of the rocks are given for the New York area in which the rocks are represented.

18 1890 The Calciferous formation in the Champlain Valley (with discussion by C. D. Walcott and C. H. Hitchcock). G Soc Am, B 1:501-513; Abst, Am J Sc (3) 39:235-238. The Calciferous formation in the Champlain Valley. Am Mus N H, B 3:1-23.

A thorough study of the strata between the Potsdam sandstone and the Chazy limestone was undertaken and every important exposure on the Vermont side of Lake Champlain was visited and maps and cross sections made. A discussion of each section is given in the report.

19 1896 The Chazy of Lake Champlain. Am Mus N H, B 8:305-315.

Even though references to localities in Vermont are infrequent, the paper gives a short description of the rocks and the fossil content of a formation which is prevalent in the State. Such a reference should have a place in the geologic literature on Vermont, although it deals mainly with occurrences of the formation in New York.

Burt, Frederick A.

20 1929 The origin of the Bennington kaolins. Vt, St G, Rp 16: 65-84.

The principal concern is the kaolin deposits, but pages 67-72 give considerable information concerning the physiography, structural geology, and microscopic character of the rocks of the section.

Dale, Nelson Clark

21 1919 Provisional report of the areal and structural geology of the western flank of the Green Mountain range. Vt, St G, Rp 11:194-199.

An indication of the treatment to be used in the final report is given, and the topics of areal geology, stratigraphy, and age receive some attention.

22 1921 Notes on the areal and structural geology of a portion of the western flank of the Green Mountain range. Vt, St G, Rp 12:43-56.

The more complete report deals with the general, areal, and structural geology, microscopic examination, and relationships of the igneous and metamorphic rocks in the

lower half of the Middlebury and Burlington quadrangles. This is a good treatment and more thorough than might be supposed from the title referring to it as "notes" on the subject.

Dale, Thomas Nelson

23 1892 On the structure and age of the Stockbridge limestone in the Vermont Valley. G Soc Am, B 3:514-519.

The areal geology and relations of metamorphic rocks as well as the structural and age details of the sediments of the sections of the valley from Rutland south to Danby Hill are treated in a concise manner.

24 1894 On the continuation of the Rensselaer grit in Vermont. U S G S, An Rp 13 pt 2:337-340.

Similar rock types and structural relationships are found at Bird Mountain, Vermont, and on the Rensselaer plateau. This similarity and a study of microscopic slides are the basis for the supposition that the formation continues into Vermont.

25 1894 On the structure of the ridge between the Taconic and Green Mountain ranges in Vermont. U S G S, An Rp 14 pt 2:525-549.

The work of previous investigators and the petrographic determinations of Wolff are included in the discussion of the relations of the bordering schists to the quartzite anticline.

26 1896 1902 Structural details in the Green Mountain region and in eastern New York. U S G S, An Rp 16 pt 1:543-570 (1896); U S G S, B 195: 22 pp (1902).

General structure is discussed rather extensively with specific examples from Vermont on pages 556-570 of the Annual Report. Bulletin 195 is a second paper which adds a few details, but is written with the same intention and manner as the previous study.

27 1899 The slate belt of eastern New York and western Vermont (with note on dike rocks by Florence Bascom). U S G S, An Rp 19 pt 3:153-300.

An excellent, thorough treatment of the subject of the slate belt between the Taconic range and Lake Champlain includes detailed rock descriptions, areal distribution, bibliography, and map. Miss Bascom contributes a petrographic study of the dike rocks of the region.

28 1900 A study of Bird Mountain, Vt. U S G S, An Rp 20 pt 2:9-23.

More details of the geology of Bird Mountain are given than in the report on the Rensselaer grit (see 24). A petrographic study of the conglomerate and a description of the gross structure are included.

29 1904 The geology of the north end of the Taconic Range. Am J Sc (4) 17:185-190.

The structure of the Taconic range continues over into Vermont, almost to the Addison-Rutland county line, and the account of the sediments and metamorphics is pertinent to Vermont geology.

30 1905 Note on the geological relations of the Brandon lignite deposit. Vt, St G, Rp 4: 163-165.

The relationships of the metamorphic rocks from which the associated kaolin and lignite are derived are briefly sketched.

31 1909 The granites of Vermont. Vt, St G, Rp 6:58-75 (1909);
1911 U S G S, B 404:138 pp (1909); Vt, St G, Rp 7:78-197 (1911).

An abstract of the study is given in volume 6 of the Vermont Report, and volume 7 is a reprint of the United States Geological Survey, Bulletin 404. The proposed treatment was not to give an exhaustive work, but with an economic purpose to locate, describe, and classify all the known granites. Tests and analyses were applied and there are descriptions of specimens of which thin sections were made. The age, history, and geologic features and relations of the marble are discussed at some length. The report seems most complete and is a very good one.

32 1910 The Cambrian conglomerate of Ripton in Vermont. Am J Sc (4) 30:267-270.

The "Talcose Conglomerate" of Hitchcock and Hager, and adjoining formations in a section of Addison County are given fairly detailed consideration.

33 1912 The commercial marbles of western Vermont. U S G S, B 521:170 pp. Abst, Wash Ac Sc, J 3:152 (1913).

This detailed report contains a section on the general features of marbles, a bibliography, and a thorough discussion of the Vermont marble belt, with maps, sections, structure, details of the quarries listed by towns, tables, economic classifications, and other topics.

34 1912 The Ordovician outlier at Hyde Manor in Sudbury, Vt. Am J Sc (4) 33:97-102 (1912); 36:395-398 (1913).

Microscopic investigation of specimens obtained by core drilling establishes the age of the outcrop, and the geologic history is reconstructed. The second article confirms, from the evidence of further work, the conclusions already reached.

35 1915 The calcite marble and dolomite of eastern Vermont. Vt, St G, Rp 9:224-276; U S G S, B 589:67 pp; Abst, Wash Ac Sc, J 5:518-519.

The stratigraphic and petrographic character, and the geologic age and economic possibilities of the marbles are treated according to county and township divisions.

36 1916 The Algonkian-Cambrian boundary east of the Green Mountain axis in Vermont. Am J Sc (4) 42:120-124.

The origin, composition and structure of the metamorphics for a section of southern Vermont are presented in moderate detail for a short article.

Dale, Thomas Nelson, and Eckel, E. C.

37 1906 Slate deposits of the United States. U S G S, B 275:51-125.
1914 (And others.) Slate in the United States. U S G S, B 586:
1915 220 pp (1914); Abst, Wash Ac Sc, J 5:25-26 (1915); (Revised ed. of B 275 [1906]).

Bulletin 586, a revised edition of the earlier bulletin, contains some more recent information, but there is no change in the Vermont section except in figures and dates. Pages 89-110 of Bulletin 275 and pages 120-146 of Bulletin 586 discuss the geologic and geographic distribution and structure of the varieties of slate in Vermont. Because concise form was employed the salient points about Vermont slate have been well presented in a few pages.

Daly, Reginald Aldworth

38 1903 The geology of Ascutney Mountain, Vt. U S G S, B 209: 122 pp.

This excellent bulletin gives the geology and petrography of the eruptive igneous rocks and the surrounding metamorphics which make up Mt. Ascutney. The phyllitic, schistose, and gneissic series are described in general terms, following a discussion of the physical geography of the region. Contact metamorphism and a comparison of metamorphic effects are adequately treated. The most thorough study is given to the eruptive rocks; the main syenite stock is treated in detail, and a table of the rock types which resulted from the eruptions is given in the sections. A chapter of theoretical conclusions on the manner of intrusion of stocks completes the report.

Dana, James Dwight

39 1873 On the quartzite, limestone, and associated rocks of the vicinity of Great Barrington, Berkshire Co., Mass. Am J Sc (3) 4:362-370, 450-453; 5:47-53, 84-91; 6:257-278.

A brief comparison of similar rocks in Vermont and Berkshire County is made in the references, volume 4, pages 362-370, and volume 6, page 272. The balance of the work is a general discussion and describes localities in Massachusetts.

40 1873 On staurolite crystals and Green Mountain gneisses of the Silurian age. Am Nat 7:658-660; Am As, Pr 22 pt 2:25-27 (1874); Abst, Can Nat n s 7:163 (1874).

The age of the limestones and metamorphic rocks of the Green Mountains receive brief attention in these abstracts.

41 1877 An account of the discoveries in Vermont geology of the Rev. Augustus Wing. Am J Sc (3) 13:332-347, 405-419; 14:36-37.

The towns of central and southern Vermont are taken up separately in the discussion of the age and structure of the metamorphic and sedimentary rocks.

42 1877 Note on the Helderberg formation of Bernardstown, Mass., and Vernon, Vt. Am J Sc (3) 14:379-387.

The lithologic character and origin are given consideration in this study of the schists, gneisses, quartzites, and limestones of the two sections.

43 1877 On the relations of the geology of Vermont to that of Berkshire. Am J Sc (3) 14:37-48, 132-139, 202-207.

The age of the Berkshire rocks is reconsidered on the basis of the findings of Reverend Wing. The stratigraphic relations of the metamorphics and Vermont Valley limestone had already received some attention in a previous report. (See 41.)

44 1880 Note on the age of the Green Mountains. Am J Sc (3) 19:191-200.

A good account is given of the extent, deformation, and crystallization of the rocks which form the Green Mountains.

45 1882 Geological age of the Taconic system. G Soc London, Q J 38:397-408; Abst, Am J Sc (3) 24: 291-293; G Mag (2) 9:281-282.

The paper was occasioned by the author's disagreement with a statement made by T. S. Hunt before the Society on November 16, 1881. Dana puts forward the findings of other geologists as well as his own to show that the schists and limestones of the Taconic range are conformable and of "Lower Silurian" (Ordovician) age.

46 1885 On Taconic rocks and stratigraphy, with a geological map of the Taconic region. Am J Sc (3) 29:205-222, 437-443; 33:270-276, 393-419 (1887).

Although the discussion concerns the general features of the rocks in several states, there are sufficient specific references to Bennington County in Vermont to warrant the inclusion of the paper here. The references in Volume 33, up to page 406 relate to Vermont; pages 412-419 include Emmons' views on the Taconic system.

Dewey, Chester.

47 1822 Notice of crystallized steatite and ores of iron and manganese (Bennington, Vt.). Am J Sc 5:249-251.

This brief and very early account mentions the occurrence of the mineral content in the mica slates and limestone about Bennington, Vt.

Diller, Joseph Silas

48 1911 The types, modes of occurrence, and important deposits of asbestos in the United States. U S G S, B 470:507-512; Can M Inst, Q B 13:45-48; J 14:92-106 (1912).

In Bulletin 470, pages 507-512, the geological setting of the asbestos deposits in the Lowell region of Vermont is described.

Edson, George E.

49 1907 Historical sketch of the Cambrian age as related to Vermont geology. Vt, St G, Rp 5:117-132.

Part I is mainly a compilation of information on the Cambrian rocks of Vermont, published in various periodicals. A table of the formations belonging to the Cambrian system concludes Part I of the paper.

50 1907 The geology of St. Albans and vicinity. Vt, St G, Rp 5: 133-154

With the general preface given in the previous section, Part II presents local details of Cambrian geology of one district of Vermont. Descriptions of the rock composition, the areal distribution, and the paleontology of the various formations are the important phases of the subject dealt with.

51 1909 The geology of the town of Swanton. Vt, St G, Rp 6: 210-220.

A short account of the outcrop localities, the fossil content, and chemical composition, together with a small geological map, furnishes information about the Utica shale, Intraformational conglomerate, Noah Parker horizon, Winooski marble, and Chazy limestone.

Eggleston, Julius Wooster

52 1910 The complex of alkaline igneous rocks at Cuttingsville, Vt. Abst, Science n s 32:220; G Soc Am, B 21:785-786.

A stock-like intrusion into gneiss and its attendant dikes are briefly described. A discussion following the paper compares the section with the Monteregian Hills of Canada.

53 1918 Eruptive rocks of Cuttingsville, Vt. Am J Sc (4) 45:377-410; Vt, St G, Rp 11:167-193 (1919).

The field relations of the country rocks and the eruptives, and petrographic descriptions and chemical analyses of the rocks are given in this well organized and comprehensive article. The paper as published in the Vermont Report has a few changes in the map and text based on additional field work after publication of results in the American Journal of Science.

Elliott, Arthur H.

54 1885 The colored marbles of Lake Champlain (with discussion by J. S. Newberry). N Y Ac Sc, Tr 3:100-102.

Only the discussion following the paper is recorded, and it includes descriptions of marbles from several localities.

Emmons, Ebenezer

55 1844 The Taconic system; based on observations in New York, Massachusetts, Maine, Vermont, and Rhode Island. 65 pp, Albany.

The paper is a general discussion of the subject and makes occasional references to various rock types in Vermont, but there is very little direct treatment of Vermont geology.

Finlay, George Irving

56 1901 The granite of Barre, Vt. Abst, Science n s 13:509; N Y Ac Sc, An 14:101-102 (1902).

This is a brief summary of a paper read before the Geological and Mineralogical section of the New York Academy of Sciences.

57 1903 The granite area of Barre, Vt. Vt, St G, Rp 3:46-60.

A reasonably complete discussion which includes the petrography of the schists and granites, as well as a description of localities in which granite occurs, is given here.

Foerste, August Frederick

58 1893 New fossil localities in the early Paleozoics of Pennsylvania, New Jersey, and Vermont, with remarks on the close similarity of the lithologic features of these Paleozoics. Am J Sc (3) 46:435-444.

Pages 441-444 deal with Vermont. The author concludes from similarities in the characters of the sedimentary rocks that New Jersey, Pennsylvania, and the southern half of Vermont probably belong in the same petrologic province.

Foye, Wilbur G.

59 1919 A report of the geological work within the Rochester, Vt., quadrangle. Vt, St G, Rp 11:76-98.

The information given concerning each group of rocks is organized under the following headings: A. Geographic distribution; B. Physical description; and C. Geological relations. A review of Whittle's work and of the relations of the Rochester area to the Champlain Valley rounds out the discussion. Petrographic and chemical analyses of the various types of sedimentary and metamorphic rocks add to the thoroughness with which the work has been done.

Foyles, Edward J.

60 1923 Preliminary report on the Ordovician formations of Vermont. Vt, St G, Rp 13:71-86.

The paleontology and correlation problems of the formations receive especial attention in this report. The area along Lake Champlain was investigated, and the distribution of the rocks was determined. A review of previous studies and a comparative table of the rocks described by Brainerd and Seely in 1890, and by the author in 1922 furnish the historical background.

61 1925 Geology of Shoreham, Bridport, and Fort Cassin. Vt, St G, Rp 14:204-217.

The author outlines the facts bearing on the Beekmantown formation in the Champlain Valley by giving the physiography, the structural and stratigraphic details, and the paleontology of representative sections.

62 1927 The stratigraphy of the townships of Addison, Panton, and southwestern Ferrisburg, Vt. Vt, St G, Rp 15: 111-120.

This paper is the third in the series of reports which attempt to determine the age of the rocks called Beekmantown by mapping and describing the geology of the townships along Lake Champlain. The fauna and age of each horizon are given, but only meager descriptions of the rocks.

63 1929 Rock correlation studies in west-central Vermont. Vt, St G, Rp 16:280-289.

Structure, specific descriptions of the rocks, and the relation of fossils and igneous intrusions to progressive metamorphism are discussed in an attempt to determine the relationship of the Green Mountain rocks to those of the Vermont and Champlain Valleys. The data are made available in concise form in a correlation table at the end of the paper.

64 1929 The stratigraphy of Ferrisburg, Vt. Vt, St G, Rp 16:275-279.

The description and mapping of the Cambrian and Ordovician sediments in Addison County are continued in this brief paper. The age as determined by the fossil content, the structure, and distribution of the formations are presented concisely.

Gordon, Clarence E.

65 1915 Notes on the geology in the vicinity of Bennington, Vt. Vt, St G, Rp 9: 337-371.

Brief field study of the western third of the Bennington quadrangle furnished the data for a moderately complete treatment of the geology and topography. The association of limestones and schists is considered at some length. A geologic map and a cross-section show the structure and geographic occurrence of all the rocks.

66 1921 Ancient rock deformations and their present expressions in western Vermont. Abst, G Soc Am, B 32 no. 1:88-89.

Compressional deformation in western Vermont and the resulting interrelations of the rock formations involved are tersely presented in this abstract.

67 1921 Studies on the geology of western Vermont. Vt, St G, Rp 12:114-279. Abst, Science n s 55:208 (1922).

The general plan of this paper, the first of three, is to present (1) brief description of the principal physiographic divisions and of the various rock formations, and (2) a discussion of the author's observations, particularly upon the subject of secondary deformations. The terranes of western Vermont are reviewed, and the separate townships are treated in detail. Various studies and theories of structural deformation are carefully set forth.

68 1923 Studies on the geology of western Vermont. Vt, St G, Rp 13:143-285.

A general description of the rocks, their structure, and age is given for each township. The work done by others is reviewed, and the observations of the author are added under each topic. This second paper follows the outline of the first, but includes less theoretical exposition.

69 1925 Studies on the geology of western Vermont. Vt, St G, Rp 14:219-259.

The same organization of material as in the two earlier reports is employed in telling of the field relations of the rocks in the Taconic range and of those in the foothills in Bennington and Rutland Counties. Petrographic analysis of the conglomerates is an added feature. A general summary completes a good article.

70 1927 Notes on the geology of the townships of Bristol, Lincoln, and Warren. Vt, St G, Rp 15:272-318.

A careful treatment of the physical geography, physiographic history, areal geology, and strucuture, supplemented by microscopic studies, and reviews of previous work, are given for the three townships embraced in the report.

Hager, Albert David

71 1858 The marbles of Vermont. 16 pp, Burlington.

Each of the five classes of marble are treated separately. Analyses are given, and the utility of the marbles is discussed, a large part of the paper being devoted to the economic features of the industry. The structural relationships of the marble and associated rocks are described, particularly in Dorset and Tinmouth mountains.

72 1861 Economical geology of Vermont. *In* Report on the geology of Vermont (Hitchcock) 2:733-870.

This section of the Hitchcock report describes the occurrences of granite, gneiss, marble, and slate in the State and gives the location of some of the quarries.

Hall, S. R.

73 1861 Geology of northern Vermont. *In* Report on the geology of Vermont (Hitchcock) 2:719-730.

As one of the geologists on the Hitchcock survey, Hall contributed this report on the field work done on the Ordovician metamorphic and sedimentary rocks in Essex, Orleans, and Caledonia Counties.

74 1871 Geology and mineralogy of Orleans Co. (Vt.). Archives of Science (Orleans Co [Vt] Soc N Sc, Tr) 1:71-78.

An informal manner of presentation marks this good article on the rocks and minerals in the county. The geology is chiefly metamorphic; the mineralogy, non-economic.

Hayes, Augustus Allen

75 1855 On the so-called verd-antique marble from Roxbury, Vt. Boston Soc N H, Pr 5:260-263, 339-341 (1855-6).

An account of the character of the rock as determined from analyses of specimens is supplemented by some commercial information.

Hitchcock, Charles Henry

76 1859 Lithology of Vermont. Abst, Can Nat 4:296.

The abstract reports the reading of a paper on the "so-called talcose schists of Vermont." Analyses of specimens from Pownal were made by Hunt and Barker.

77 1860 On distorted pebbles in the conglomerate of Vermont. Boston Soc N H, Pr 7:208. (In error attributed to E. Hitchcock, Jr.)

A Vermont occurrence of pebbles first noticed in a Rhode Island conglomerate receives brief mention.

78 1860 Rocks of Vermont as related to the Taconic system. Boston Soc N H, Pr 7:426-427.

The fossil content and general characteristics of the rocks which lie stratigraphically above and below the Taconic system in New York and eastern Vermont are discussed briefly.

79 1861 Azoic rocks. *In* Report on the geology of Vermont (Hitchcock) 1:452-558.

Parts of this section of the report are the work of Edward Hitchcock, Sr. and Jr., but most of the facts about the geographic range, thickness, mineral constituents, structure, and age of the gneisses, schists, and serpentines are furnished by the author.

80 1861 Notes on the geological sections. *In* Report on the geology of Vermont (Hitchcock) 2:595-682.

As a commentary on the thirteen structure sections drawn across the state and covering its entire length, this report describes the localities represented, as well as the rocks, their structure, and topography.

81 1861 Report on the chemistry of the survey. *In* Report on the geology of Vermont (Hitchcock) 2:690-712.

A tabulation of the analyses of marbles, limestones, marls, and clays gives the name of the analyst, date, specimen locality, and chemical percentages.

82 1868 The geology of Vermont. Abst, Am As, Pr 16:120-122.

A study of the unstratified (igneous and metamorphic) and the Paleozoic rocks is given in abstract, with the reasons for the probable "Eozoic" age of the Green Mountain gneiss included in the discussion.

83 1868 The Winooski marble of Colchester, Vt. Abst, Am As, Pr 16:119; Am Nat 1:621.

Very brief notice is given of a dolomitic rock of the same age as the red sandrock of Burlington. A peculiar feature of the rock is its nodules of calcite enclosing quartz.

84 1870 The geology of northern New England (contains Geology of Vermont 5 pp).

The work of the survey and its several geologists is reviewed, and the reports are used as the basis for a table which presents the order of formations adopted by the author together with the formations recognized by earlier workers. A description of each lithologic unit, giving the type of rock, locality, and previous work upon it, follows the table and helps to make this a valuable reference.

85 1876 Stratigraphical structure of the Cambrian and Cambro-Silurian rocks of western Vermont. Boston Soc N H, Pr 18:191-193.

Emmons' views and those of Hitchcock are briefly compared in an attempt to straighten out the geology of the Taconic Region.

86 1884 Geological sections across New Hampshire and Vermont. Am Mus N H, B 1:155-179; Also, with title, Description of geological sections crossing New Hampshire and Vermont, 33 pp, Concord, N. H.

The object of the sketch was to record the most important facts connected with the explorations made by the survey and those made to obtain illustrative material for the American Museum of Natural History. The types of rock and the structure are designated on the sections.

87 1884 Identification of the Green Mountain gneisses in eastern New England. Abst, Am As, Pr 33:396-397 (1885); Science 4:327 (1884).

The age of the gneisses in the White Mountains and in Vermont is discussed, and a comparison shows the similarity of their lithologic characteristics in both states.

88 1892 The Green Mountains' anticlinal. Science 20:328.

In the limited space of an abstract, a comparatively thorough review of the relationships of the metamorphic rocks of Hoosac Mountain is achieved, and the studies which others have made on the subject are carefully considered.

89 1895 Gotham's cave; or fractured rocks in northern Vermont. Abst, Am G 16:248; Am As, Pr 44:133 (1896).

The abstract is a very brief account of some caves formed by fracture in a mass of mica schist.

90 1897 Note on the stratigraphy of certain homogeneous rocks. Abst, G Soc Am, B 8:389-390; Science n s 5:86.

Short comments are made on the metamorphic rocks of northern Vermont.

91 1913 Geology of the Strafford quadrangle. Vt. St G, Rp 8:100-145.

A geologic map, several cross sections, microscopic determinations, and rock descriptions comprise the essential features of this report, which includes observations on a large sector in New Hampshire.

Hitchcock, Edward

92 1823 Geology, mineralogy, and scenery of the regions contiguous to River Connecticut, with a geological map and drawings of organic remains. Am J Sc, 6:1-86, 201-236; 7:1-30.

This extensive report includes occasional references to mineral localities in Vermont, but gives little material of geological value, except to the student of the development of science.

93 1846 Notes on the geology of Vermont. *In* Adams, C. B., Second annual report on the geology of the State of Vermont: 247-252.

A letter from Hitchcock to Adams, telling of a rapid trip through Vermont, is given in an appendix to the latter's report (see 2). It mentions gneiss and slate, drift features, kaolin deposits, and the local problem of the economic geology of Bennington.

94 1852 On the geological age of the clay slate of the Connecticut Valley in Massachusetts and Vermont. Am As, Pr 6: 299-300.

A discussion of the age, with inadequate notes on the character, of the rocks extending from Bernardston to Guilford constitutes this abstract.

95 1853 Description of a brown coal deposit in Brandon, Vt., with an attempt to determine the geological age of the principal hematite ore beds in the United States. Am J Sc (2) 15:95-104.

As there are no igneous or metamorphic rocks near the deposit, the discussion is confined to the brown coal and its associations, as well as the age problem mentioned in the subtitle.

96 1857 Report on the geological survey of the State of Vermont. 12 pp, Montpelier.

The report tells of the construction of structure sections of the State and of fourteen hundred specimens exhibited in the State Cabinet. A notation of the work still to be done is included.

97 1858 Report on the geological survey of the State of Vermont. 13 pp, Burlington.

This brief article summarizes the fuller report which was published in 1861 (see 101).

98 1859 Devonian granites and Taconic rocks. (Abst with discussion) Can Nat 4:298.

Sir William Logan was called upon for his opinion of a short paper on the relations of the fossiliferous limestones to the granites and slates in Vermont. He tells of similar occurrences in Canada.

99 1860 On distorted pebbles in the conglomerate of Vermont. (With discussion by C. T. Jackson) Boston Soc N H, Pr 7:353-354.

This reports a discussion by Hitchcock and Jackson on the subject, previously presented by Charles Hitchcock (see 77), of quartz conglomerate associated with gneiss.

100 1861 On certain conglomerated and brecciated trachytic dikes in the Lower Silurian rocks of Shelburne, in Vermont. Am As, Pr 14:156-158.

Description of the dikes, a discussion of their manner of formation, and a chemical analysis of the rock by G. F. Baker constitute this concise report.

Hitchcock, Edward, and Barker, G. F., Hager, A. D., Hall, S. R., Hitchcock, C. H., Hitchcock, E., Jr., Thompson, Z.

101 1861 Report on the geology of Vermont; descriptive, theoretical, economical, and scenographical. Vol 1, 558 pp. vol 2, pp. 559-982, Claremont, N. H. Résumé and summary by E. Billings. Am J Sc (2) 33:416-420 (1862).

These volumes were compiled to include the reports of several geologists, and their individual contributions are reviewed elsewhere under their names. Parts I and II of Volume 1 and Part IV of Volume 2 are the work of Edward Hitchcock, Sr., but there are occasional additions by the others. He has also contributed to the sections written by Hager, Hall, and Hitchcock, Jr. Part I covers the alluvial and Tertiary rocks, erosion of the earth's surface, and concretions, and Part II treats the "Hypozoic" (term used to indicate metamorphic rocks below all strata which contain organic remains) and Paleozoic rocks. The igneous or "unstratified" rocks and the dikes of Chittenden County receive detailed attention in Part IV. The whole work is a thorough treatment of general geologic principles as they apply to Vermont, and it earned the commendation "one of the best published on this continent." An appendix to the work contains Billings' description of some little-known species of Ordovician fossils.

102 1861 Localities of minerals in Vermont. *In* Report on the geology of Vermont (Hitchcock) 2:683-689.

An alphabetical list of towns tells the minerals occurring in each. A catalogue of the specimens in the State Cabinet indicates their quality by a system of italics and exclamation marks.

Hovey, Edmund Otis

103 1894 Note on the petrography of certain basaltic boulders from Thetford, Vt. N Y Ac Sc, Tr 13:161-164.

An account is given of the microscopic determination of boulders, having a conglomeratic appearance, as olivine basalt.

Hubbard, George D.

104 1925 Geology of a small tract in south-central Vermont. Vt, St G, Rp 14:260-344.

The descriptive geology of the metamorphic and igneous rocks, their structure, and the geologic history of the region are the main topics of the paper. The report is well organized and is a comprehensive survey of the territory.

Hunt, Thomas Sterry

105 1868 On some points in the geology of Vermont. Am J Sc (2) 46:222-229.

The red sandrock of northern Vermont and its relation to associated rocks furnishes the subject of the paper.

Jackson, Charles Thomas

106 1856 Chemical analysis and comparison of serpentine marbles known under the name of verd antique. Boston Soc N H, Pr 5:314-318, 341-343 (1856); Am J Sc (2) 23:123-126 (1857): M Mag 6:410-413 (1856).

This brief report supplements chemical analyses and comparisons of specimens with pertinent geological information.

107 1867 On the gold regions of Vermont. Boston Soc N H, Pr 11: 243-244.

Very brief mention is made of the presence of gold in the talco-micaceous slates of Plymouth and Bridgewater.

Jacobs, Elbridge Churchill

108 1915 Talc and the talc deposits of Vermont. Vt, St G, Rp 9:382-429.

The purpose of the report is to provide, for the information of those engaged in the industry, facts about the mineral properties, commercial uses, and occurrences of talc, and statistics of production for the world, the United States, and Vermont. The treatment is thorough and well executed.

109 1917 The talc and verd antique deposits of Vermont. Vt, St G, Rp 10:232-280.

Chemical analyses, the results of microscopic examination, and discussion of occurrences and production, mines, and prospects give the main facts of the subject. Each locality is treated separately and in detail.

110 1921 The geology of Lake Willoughby. Vt, St G, Rp 12:280-298.

The petrography, mineralogy, and structure of the region and the factors in the origin of Lake Willoughby are considered at moderate length.

111 1923 Geology of Westmore, Brownington, and Charleston. Vt, St G, Rp 13:93-108.

The relations of the sedimentaries and metamorphics to the granite bathylith, the petrographic study of the rocks, and the economic aspects of the region comprise the outstanding topics treated.

Jones, Daniel J.

112 1917 The physiography of Greensboro, Hardwick. and Woodbury, Vt. Vt, St G, Rp 10:74-99.

The primary interest of the article is in the physiography, but stratigraphy and petrology are included as they affect the topographic features.

Jones, Robert W.

113 1918 The manganese deposits of South Wallingford, Vt. Eng M J 105:779.

Strictly geologic information about the locality is very brief; a description of the opening of the deposits is the main item.

Keith, Arthur

114 1913 Further discoveries in the Taconic Mountains. Abst, G Soc Am, B 24:680.

The slate and the surrounding limestone at the north end of the Taconic Mountains receive attention in this study.

115 1914 A pre-Cambrian unconformity in Vermont. Abst, G Soc Am, B 25:39-40.

The interrelation of sedimentary and metamorphic rocks on the western border of the Green Mountains provides evidence of the unconformity reported in this summary.

116 1922 Cambrian succession of northwestern Vermont. (Abst, with discussion by C. E. Gordon.) G Soc Am, B 33 no 1:123-124.

The abstract enumerates the number of formations and the rock types in the Cambrian of the Champlain Valley.

117 1925 Cambrian succession in northwestern Vermont. Vt, St G, Rp 14:105-136.

This report is a full account of the formations sketched in the abstract of 1922. It gives the detailed stratigraphy and historical geology of the Cambrian and Ordovician rocks.

Kemp, James Furman

118 1894 On some camptonite dikes in the town of Quechee, Vt., near Thetford. N Y Ac Sc, Tr 13: 164-165.

A general review of the camptonite dikes of the Green Mountain region is given, and examples in Quechee Gulf are cited, specimens having been sent by C. H. Hitchcock.

119 1901 Notes on the occurrence of asbestos in Lamoille and Orleans Counties, Vt. U S G S, Min Res 1900:862-866.

As part of the section on asbestos, compiled by J. H. Pratt, Kemp describes the geology of the serpentine and asbestos deposits of Belvidere Mountain. The character of the asbestos and the current developments of the property are also discussed.

120 1901 A new asbestos region in northern Vermont. Abst, Science n s 14:773-774; Am G 28:330; N Y Ac Sc, An 14:140-141 (1902).

The rocks associated with the serpentine in which the asbestos of Belvidere Mountain occurs, and theories as to the origin of the serpentine are concisely presented in this abstract.

Kemp, James Furman, and Marsters, Vernon Freeman

121 1893 The trap dikes of the Lake Champlain region. U S G S, B 107: 62 pp.

A tabulation of the dikes furnishes information concerning the locality, width, strike, wall rock, and type of component rocks, all of which were examined microscopically. A review of the classification of basic dike rocks precedes the tabulation. The table makes the material available in a concise form which enhances the general excellence of the paper.

Kroustschoff, K. de

122 1885 Note sur le granite variolitique de Craftsbury en Amérique. Soc Minér France, B 8:132-141; Abst, Am Nat 20:275-276 (1886).

The abstract reports the microscopic work done by the author on the variolitic granite from Craftsbury, first mentioned in Hitchcock's Report of 1861.

Marcou, Jules

123 1881 Sur les colonies dans les roches taconiques des bords du lac Champlain. Soc G France, B (3) 9:18-46; Criticism by J. D. Dana. Am J Sc (3) 22:321-322.

The original article, in French, describes occurrences of the Taconic rocks in the townships along Lake Champlain, and it attempts to determine the age of the formations. The reference in the American Journal of Science is a summary in English.

124 1888 The Taconic of Georgia (Vt.) and the report on the geology of Vermont. Boston Soc N H, Mem 4:105-131.

A discussion of the recognized Taconic rocks about Georgia, Vt., is followed by a criticism of the Hitchcock "Report on the Geology of Vermont." An historic classification of the Georgia formation and a dissertation on the use of the name "Georgian" are included, together with some paleontological notes and tables of the several horizons.

Marsters, Vernon Freeman

125 1895 Camptonite dikes near Danbyborough, Vt. Am G 15:368-371.

Microscopic study of specimens from the dikes proves them to be camptonite, but of an abnormal variety. The geologic conditions under which the dikes occur are treated briefly.

126 1905 A preliminary report on a portion of the serpentine belt of Lamoille and Orleans Counties. Vt, St G, Rp 4:86-102.

The topography of the area studied and the discovery of asbestos within it are the introductory topics to an exposition of the structure and rock types, the genesis of the asbestos, its varieties and composition. The latter has been ascertained by microscopic study and chemical analyses.

127 1905 Petrography of the amphibolite, serpentine and associated asbestos deposits of Belvidere Mountain, Vt. G Soc Am, B 16:419-446; Abst, Science n s 21: 426; Am G 35:194-195; N Y Ac Sc, An 17: 573-574 (1907).

The general distribution, character, structure, and age of these associated rocks are indicated on a map and outlined in the discussion. A detailed account of the asbestos, including its occurrence, varieties, microscopic character, composition, and mode of origin, makes this a valuable reference.

McCormick, Calvin

128 1886 The inclusions in the granite of Craftsbury, Vt. Ac N Sc Phila, Pr 1886:19-24.

A history of the work done on inclusions in granite prefaces a description of the internal structure and the relations between inclusions and rock mass. For a short paper this is a comprehensive handling of the subject.

Merrill, George Perkins

129 1924 The first one hundred years of American geology. New Haven pp 205, 246-249, 350-353, 594-614.

An account of Jackson's survey of New Hampshire, which includes some references to strata in Vermont, is found on page 205. Pages 246-249 give a review of the work done by C. B. Adams in Vermont in 1844, and a sketch of his assistant, Zadock Thompson. Hitchcock's Geology of Vermont (1856-1861) is summarized and an estimate given of the accuracy and value of the work, on pages 350-353. Chapter XII, pages 594 and following, presents a history of the Taconic controversy. A summary of the views of each participant and an evaluation of their conclusions are given. This is a valuable digest, for use in conjunction with the original works which present the subjects.

Merritt, John Wesley

130 1921 Structural and metamorphic geology of the Hanover district of New Hampshire. Vt, St G, Rp 12:1-36.

Though the paper deals with a New Hampshire area, a a goodly part of the section surveyed lies in Vermont, and the detailed discussion of the rocks and their metamorphism is applicable to the rock types on both sides of Connecticut River.

Nason, Frank Lewis

131 1889 A new locality of the camptonite of Hawes and Rosenbusch. Am J Sc (3) 38:229-230.

This summary describes a camptonite dike cutting the quartzites and gneisses in the Green Mountains near Summit.

Newberry, John Strong

132 1870 Marble beds of Vermont. Lyc N H N Y, Pr 1:62-63.

The geology of the marble outcrop at Middlebury is mentioned in the course of a discussion regarding specimens exhibited at a meeting of the society.

Perkins, George Henry

133 1885 The Winooski or Wakefield marble of Vermont. Am Nat 19:128-136.

The entire outcrop of sedimentaries and metamorphics which includes the variegated "marble" receives consideration. The varieties and the places where the dolomite marble occurs are described.

134 1898 Report on the marble, slate, and granite industries of Vermont. 68 pp, Rutland.

A description of the rocks, of the quarries and their development, together with analyses by Richardson, make up this report.

135 1900 Report of the State geologist on the mineral industries of Vermont, 1899-1900. 83 pp, Burlington.

The report is intended in some measure to supplement the preceding one, but is not full because of the lack of funds to carry on the work. Information on the metallic products of the State is added to current facts about the marble, slate, and granite industries. Some geologic facts are furnished in the section on slate, but the remainder is economic in character.

136 1903 The geology of Grand Isle. Vt, St G, Rp 3:102-173.

The paper was designed to furnish a general account of the geologic features which would strike a visitor to the island. The rock types, structure, and paleontology at each locality, listed by the bays along the island's shore, and the geologic history comprise the main topics.

137 1905 Geology of Grand Isle Co. Vt, St G, Rp 4:103-143.

The author continued the preceding study, and this paper takes up in a similar manner the geology of the other islands of the county.

138 1905 Mineral resources of the State. Vt, St G, Rp 4:22-66.

Financial and production statistics, a list of operating companies, descriptions of localities, and an account of microscopic work provide the most important items of information given on the subject.

139 1907 Mineral resources, building and ornamental stones. Vt, St G, Rp 5:1-62.

The organization and content of this report are similar to the others, but some additional material is included. References are given to papers dealing with the geology of the deposits, and parts of Marsters' report on asbestos, which did not appear in the Vermont publication, are reprinted from the Bulletin of the Geological Society of America, 16, pages 417-444.

140 1909 Mineral resources. Vt, St G, Rp 6:1-57.

Descriptions of varieties of marble and accounts of special work on granite and clays by petrographic and analytic methods constitute noteworthy additions to the routine statistical report.

141 1909 Preliminary report on the geology of Chittenden Co. Vt, St G, Rp 6:221-264.

The writer takes up the distribution and relations of the formations and discusses their fossil content and geologic age.

142 1909 Preliminary report on the geology of Franklin Co. Vt, St G, Rp 6:189-209.

An historical sketch of the work already done, quotations from the publications of other writers, and treatment of the distribution and characteristics of the rocks are the main points covered.

143 1911 Geology of the Burlington quadrangle, Vt. Vt, St G, Rp 7:249-257.

Plates and a geologic map help clarify the study of the eruptive, metamorphic, and sedimentary rocks. The megascopic character of the rocks in this part of Addison County is presented.

144 1911 Mineral resources. Vt, St G, Rp 7:331-352.

A list of companies engaged in the marble, granite, and slate industries, and a map showing the outcrops of each rock and mineral of commercial importance are of value, especially to the economic geologist.

145 1913 A general account of the geology of the Green Mountain region. Vt, St G, Rp 8:17-99.

Prepared for teachers, the paper gives the distribution of rocks from Pre-Cambrian to Pleistocene, discusses fossils, outlines the geologic history of Lake Champlain, and contains abstracts from works on Vermont geology. This report should be of considerable value to those who desire a non-technical exposition on an important area.

146 1913 Mineral resources of Vermont. Vt, St G, Rp 8:247-269.

The marbles of Swanton receive particular attention in this biennial record of mineral production.

147 1917 The geology of western Vermont. Vt, St G, Rp 10:200-231.

The author's object was to present a general and, as far as possible, comprehensive account of the geologic formations exhibited in the outcrops in the townships west of the Green Mountains, as an aid to the geologically inclined visitor. The account has been well developed, and the reference is a very useful one.

148 1920 The geology of Mill Stone Hill (Barre, Vt.). Vt Soc Eng, Pr Oct. 8, 1920:6-10

The geological history of a typical rock section is presented in a popular vein.

149 1921 A detailed study of the Trenton beds of Grand Isle. Vt, St G, Rp 12:77-89.

The beds were carefully studied, a fossil collection made, and data obtained on the principal sections of the Trenton series in the area. There is a brief résumé of the formations of Grand Isle County, and a bibliography of previous geological work.

150 1921 Mineral resources. Vt, St G, Rp 12:299-326.

The addition of extra geologic data characterizes this report, which is similar in outline to the previous papers on the State's mineral resources.

151 1925 Geology of Grand Isle Co. Vt, St G, Rp 14:63-71.

Earlier reports are reviewed, and the formations in Alburg, on North Hero Island, Isle la Motte, and Cloak Island are treated in this final paper of the series.

152 1929 The rocks of Vermont. Vt, St G, Rp 16:85-106.

Written for the layman, this dissertation gives a description of the megascopic character of the rocks and of the principal localities in which they are found. It is the type of articles of which there is great need, for so few publications on the subject are non-technical. Another value of the report is to be found in its concise tabulation of the most important rock types in the State.

Perry, Elwyn L.

153 1927 Summary report on the geology of Plymouth and Bridgewater, Vt. Vt, St G, Rp 15:160-162.

The principal rocks of the two contiguous townships, a series of metamorphosed sediments, are featured in this very short article.

154 1929 Geology of Plymouth and Bridegwater, Vt. Vt, St G, Rp 16:1-64.

The full report of the area gives the areal distribution, lithology, structure, probable origin, and history of the formations. Previous work is shown in the correlation table. The material is carefully arranged and well presented.

Perry, John Bulkley

155 1868 Queries on the red sandstone of Vermont and its relation to other rocks. Boston Soc N H, Pr 11:16 pp.

Five questions seeking to determine the relationship of the formations are propounded, and data for the answer are offered under each.

156 1868 The red sandstone of Vermont and its relations. Am As, Pr 16:128-134, 158.

The same information as in the preceding paper is found here in slightly different form.

157 1869 A point in the geology of western Vermont. Am J Sc (2) 47:341-349.

The series of sedimentary rocks in the Lake Champlain basin were studied in an attempt to discover their age and relations to the associated metamorphics.

158 1871 The natural history of the counties of Chittenden, Lamoille, Franklin, and Grand Isle. Vt Historical Gazetteer 2 No 12: 21-88. Burlington, Vt.

Section I outlines the geologic divisions of the rocks of the earth for those unacquainted with the science. The general divisions of each of the rock groups and a synoptical table of the rocks of the globe follow. Section II discusses the geological development of the Lake Champlain Valley, and Section III is a detailed exposition of northwestern Vermont. Although some of its terminology is obsolete, this is a good, thorough paper, and especially useful to the layman.

Richardson, Charles Henry

159 1898 The Washington limestone in Vermont. Abst, Am As, Pr 47:295-296; Science n s 8:469-470; Am G 22:257-258.

The name "Washington" is proposed for the more calcareous member of the calciferous mica schist of Hitchcock.

160 1903 The terranes of Orange Co., Vt. Vt, St G, Rp 3:61-101.

Maps and geologic sections; rock descriptions, structures, localities, chemical analyses, and economic utility; and paleontology are the outstanding topics of the paper. Many rock types are treated in detail, and the report seems most complete.

161 1907 The areal and economic geology of northeastern Vermont. Vt, St G, Rp 5:63-116.

The structure, relationships, and history of the pre-Cambrian and Devonian formations and of the eruptive rocks are discussed. Chemical analyses and tests to determine the commercial value of the granite are included. A section on paleontology and one on unsolved problems conclude the work.

162 1909 The geology of Newport, Troy, and Coventry. Vt, St G, Rp 6:265-291.

The report covers the subjects of topography, glaciation, lakes and, under geology, the distribution, characteristics, relationships, and structure of the rocks. A section on clays is a special feature. The economic geology and paleontology of the region are considered briefly.

163 1911 Asbestos in Vermont. Vt, St G, Rp 7:315-330.

A study of the interrelation of sedimentaries and intrusives is a preliminary to the detailed treatment of the asbestos-bearing rocks and of their economic exploitation. Discovery, types of fiber, composition, milling, uses, and other details are presented.

164 1913 The terranes of Craftsbury, Vt. Vt, St G, Rp 8:162:183.

Following the usual outline and method of treatment, this report makes a particular point of the age of the intrusives.

165 1917 The geology of Calais, East Montpelier, Montpelier, and Berlin, Vt. Vt, St G, Rp 10:111-149.

The distinguishing feature of this paper, which continues the author's series, is the paleontology, including an especially good "find" of graptolites. The Cambrian metamorphosed sediments receive some especial attention also.

166 1919 The Ordovician terranes of central Vermont. Vt, St G, Rp 11:45-51.

This paper departs from the usual form; the rock descriptions, distribution and structure are more concise, and attention is turned to the geologic history of the region. The chief events of each period are summarized.

167 1919 The terranes of Roxbury, Vt. Vt, St G, Rp 11:120-140.

Serpentine and verd antique, of which eleven quarries are described, received especial consideration in this report.

168 1925 The terranes of Bethel, Vt. Vt, St G, Rp 14:77-104.

The study of 100 petrographic slides with detailed descriptions of the specimens, and of the areal extent and structure of each type of rock distinguish this paper, which is part of the systematic study of Vermont geology.

169 1927 Geology and petrography of Barnard, Pomfret, and Woodstock, Vt. Vt, St G, Rp 15:127-159.

The emphasis upon petrography and the list of rock localities give this report some variety, but in other respects the mode of presentation is similar to the others.

170 1929 Geology and petrography of Reading, Cavendish, Baltimore, and Chester, Vt. Vt, St G, Rp 16:208-248.

A study of field relations served as the basis for determining the stratigraphy, because fossils were few. Chemical analyses form a topic in addition to those covered in the majority of the reports.

171 1929 Petrography of the Irasburg conglomerate. Vt, St G, Rp 16:107-110.

This short article describes the results of microscopic study of five phases of the conglomerate which was discovered in 1904.

Richardson, Charles H., and Brainerd, Arthur E., Jones, Daniel J.

172 1915 The geology and mineralogy of Hardwick and Woodbury, Vt. Vt, St G, Rp 9:294-336.

With the assistance of several workers, the sections in a continuous belt were systematically examined. Descriptions of rock slides and a full discussion of the intrusives are outstanding topics in this report.

Richardson, Charles H., and Cabeen, C. K.

173 1921 The geology and mineralogy of Braintree, Vt. Vt, St G, Rp 12:57-76.

The presence in this region of a large number of basic intrusives invited careful petrographic study of both sedimentary and intrusive rocks, and provided an additional reason for selecting the township for study.

174 1923 The geology and petrography of Randolph, Vt. Vt, St G, Rp 13:109-142.

New microscopic examinations of the rocks, from which conclusions as to origin and mineral composition are drawn, and the description of a rock new to the United States distinguish this generally excellent report.

Richardson, Charles H., and Camp, Samuel H.

175 1919 The terranes of Northfield, Vt. Vt, St G, Rp 11:99-119.

The study of an area continguous to those of the previous reports and in which the erosional unconformity between the Ordovician and pre-Ordovician rocks continues, follows them in outline, but includes analyses of many

rock slides. The discovery of slate conglomerate in this locality is important, and the fossils which place the stratigraphic position of the terranes are the most important contribution of the work.

Richardson, Charles H., and Collister, M. C.

176 1913 The terranes of Albany, Vt. Vt, St G, Rp 8:184-195.

The same plan followed in the series of reports by Richardson is carried out in this account of another locality.

Richardson, Charles H., and Conway, E. F.

177 1913 The terranes of Irasburg, Vt. Vt, St G, Rp 8:146-161.

The expressed purposes of the work are to determine the nature and extent of the rock formations, their age and stratigraphic position, and to make a study of mineral resources. These aims are well executed in the manner common to all the reports.

Richardson, Charles H., and Turner, Homer G.

178 1915 The terranes of Greensboro, Vt. Vt, St G, Rp 9:277-293.

The relationships of the terranes, their distribution, structure, and characteristics receive the same treatment as those of the other sections studied by Richardson.

Ries, Heinrich

179 1896 The limestone quarries of eastern New York, western Vermont, Massachusetts, and Connecticut. U S G S, An Rp 17 pt 3:795-811.

The character of the various limestones in the quarries in several Vermont localities are concisely described.

Rogers, William Barton

180 1860 On the geology of western Vermont. Boston Soc N H, Pr 7:237-239; Can Nat 6:326-328.

The sedimentary series east of Lake Champlain are described and their ages discussed.

Ruedemann, Rudolf

181 1921 Paleontologic contributions from the New York State Museum. N Y St Mus, B 227, 228:63-130. Black shales of Champlain Valley.

Chiefly of paleontologic interest, the section on pages 108 to 116 treats the age of the black shales of the Lake Champlain region.

Schroeder, Rolf A.

182 1921 A contribution to the geology of Essex Co., Vt. Vt, St G, Rp 12:37-42.

The discussion of the area adjacent to Averill Lakes gives details about a region previously considered only by Hitchcock in 1861 and Richardson in 1906. Economic geology dominates the report.

Seely, Henry Martyn

183 1885 The marble fields and marble industry of western New England. Middlebury Hist Soc, Papers and Pr 1, pt 2: 23-52.

Descriptions of the marbles and some of their structural features are included in the treatment of each of the quarries, many of which are located in Vermont. A history of the methods of working marble, as well as the economic aspects and condition of the industry, are the other items stressed in the report.

184 1901 The geology of Vermont. The Vermonter 5 (6), no 7: 53-67.

A history of the early geologic studies in the State and a review of the general geologic agents and processes preface a description of the rocks, which have been arranged according to the time schedule. A comparison of the Vermont series with the world succession, and bibliography complete the paper.

185 1907 Beekmantown and Chazy formations in the Champlain Valley; contributions to their geology and paleontology. Vt, St G, Rp 5:174-187.

With the object of explaining the character of the "Eolian limestone of Wing," the author considers the localities, special characteristics, relationships, and paleontology of the Beekmantown and Chazy formations in the Champlain Valley.

186 1911 Preliminary report of the geology of Addison Co., Vt. Vt, St G, Rp 7:257-314.

Although designated a preliminary report, it is a relatively comprehensive study. Previous work is reviewed, and measurements of the Chazy and Beekmantown, fossil lists, and rock descriptions are given under each township.

Seely, Henry M., and Brainerd, Ezra

187 1886 Notice of geological investigations along the eastern shore of Lake Champlain. Am Mus N H, B 1:293-300.

The paper summarizes the results obtained from detailed study of the geologic structure along the Vermont border of Lake Champlain and on the islands.

Shimer, Hervey Woodburn

188 1903 Columbia University geological department excursion. Am G 32:130-131.

A résumé is given of the work done in the summer course on the rocks in the Ticonderoga quadrangle. The section embraces types ranging from Archean to Utica.

189 1903 Petrographic description of the dikes of Grand Isle, Vt. Vt, St G, Rp 3:174-183.

As a supplement to Perkins' report on Grand Isle, this short paper gives detailed descriptions of the rocks based upon a microscopic examination of one specimen from each dike.

Silliman, Benjamin

190 1839 Marble and serpentine in Vermont. Am J Sc 35:390.

A brief description of some tablets of serpentine and serpentine marble sent from Windsor County by the agent of the Black River Marble and Manufacturing Co. is presented.

Smith, George Otis

191 1904 Quartz veins in Maine and Vermont. U S G S, B 225: 81-88.

Pages 85 to 88 give a short discussion of the gold-bearing veins and the associated rocks in Plymouth and Bridgewater.

Smyth, Henry Lloyd, and Smith, Philip Sidney

192 1904 The copper deposits of Orange Co., Vt. Eng M J 77:677-678.

Though written for the mining engineer, the article gives a fairly concise account of the rocks, metamorphic features and ore bodies.

Snyder, W. H.

193 1896 Preliminary report on the Stamford gneiss. Abst, Science n s 3:143-144.

The abstract gives a concise description of the gneiss and surrounding rocks in southwestern Vermont.

Thompson, Zadock

194 1842 Geology and mineralogy of Vermont. *In his* History of Vermont: 222-224, Burlington.

A short description of the rocks and interesting mineral localities is given in a section of the book.

195 1848 Geography and geology of Vermont. 220 pp, Burlington.

The author's object was to enable the youth of Vermont to acquire a knowledge of his own State. Because of the general neglect of geology, a goodly portion of the book was devoted to it, and pages 13 to 88 furnish the geologic information, which is presented in three sections; namely, Physical geology, Geology and mineralogy, and Climate and meteorology. The section on geology was further subdivided to cover the Quaternary, Secondary, Primary, and Igneous rocks. The book was written for the layman, but adequately explained technical terms are used. Though much of the terminology is out of date, some sections of the report are still useful, and it must have been a very valuable book at the time it was written.

196 1850 Natural history of Vermont. Address before Boston Soc N H, 32 pp. Reprinted at Burlington.

Pages 6 to 12 of this address present the history of the Vermont geological survey and a discussion of the rocks belonging to the Taconic system.

197 1853 Geoology of Vermont. *In* Appendix to Thompson's Vermont: 40-58.

A moderately detailed discussion of the types, uses, quarries, localities, and fossils of the Champlain and Taconic rocks, and a list of igneous rocks are published in this paper.

198 1861 Dikes of Chittenden Co. *In* Report on the geology of Vermont (Hitchcock) 2:579-583.

Thompson contributed a short section on the trap dikes in the Hitchcock report, giving their localities, width, classification, and offering a theory of their origin and structure.

Van Hise, Charles Richard

199 1896 Pre-Cambrian rocks in the Green Mountains. U S G S, An Rp 16:827-829.

The summarized results of Whittle's studies constitute the section about Vermont in this report on the "Principles of North American Pre-Cambrian Geology."

Vermont Marble Co.

200 1925 The book of Vermont marble. 69 pp, Proctor.

The pamphlet is designed to give the general geology of marble, its chemical composition and physical properties, and a few references to individual types in Vermont.

Walcott, Charles Doolittle

201 1883 Investigations in the Champlain Valley. Science 2:633-634.

Sections of the Winooski marble and of the overlying slates were examined by Marcou at Highgate Springs, Swanton, St. Albans, and Georgia, and a summary of the results is presented in this brief article.

202 1888 The Taconic system of Emmons, and the use of the name Taconic in geologic nomenclature. Am J Sc (3) 35:229-242, 307-327, 394-401.

The results of Walcott's study of the Taconic area and his conclusions about the system are given under the headings: (1) Taconic area and geologic work within it; (2) geology of the Taconic area as known at the present time; (3) geology of the Taconic area as known to Doctor Emmons; (4) comparison and discussion; (5) nomenclature. The work of others on the problem is reviewed critically. There are only occasional direct references to Vermont, but the Taconic problem concerns the geology of a section of the State, hence the reference is pertinent.

Weed, Walter Harvey

202 1904 Notes on the copper mines of Vermont. U S G S, B 225: 190-199.

The general character of the deposits and of the ores and a comparison of mining geology in the eastern part of the Green Mountains with mining geology in other regions are the main topics treated. The metamorphic schists, slates, and the intrusive granites receive some attention.

Whitney, Josiah Dwight

204 1850 On fractured strata at Guilford, Vt. Boston Soc N H, Pr 3:226.

Professor Hitchcock suggested in a brief comment on this article that the impact of a floating ice mass might have caused the break in the slate of the Bruce quarry at Guilford.

Whittle, Charles Livy

205 1892 An ottrelite-bearing phase of a metamorphic conglomerate in the Green Mountains. Am J Sc (3) 44:270-277.

The physical and petrographic characteristics of the rock are given, and the genetic order of mineral development is discussed.

206 1894 The general structure of the main axis of the Green Mountains. Am J Sc (3) 47:347-355.

Structural and stratigraphic information derived from the author's observations of the Green Mountain range between Chittenden and Stratton follows a review of work done by others.

207 1894 The occurrence of Algonkian rocks in Vermont and the evidence for their subdivision. J G 2:396-429.

The main problem is stated as a study of the metamorphic sediments between the conglomerate and quartzite series in the area from Stratton to Rochester. Petrologic, structural, and microscopic evidence for referring the rocks to the Algonkian is adduced.

Wigglesworth, Edward

208 1915 The serpentines of Vermont. Boston Soc N H, Pr 35:95-107; Vt, St G, Rp 10: 281-292 (1917).

Distribution, petrography, analyses, origin, and age receive detailed attention. An account of the relations of serpentine and steatite, and comparison of these occurrences with others in the United States and Canada complete the report.

Wolff, John Eliot

209 1891 On the Lower Cambrian age of the Stockbridge limestone (with discussion by J. F. James). G Soc Am, B 2:331-337.

The discovery of fossils, and conclusions as to the structure of the Rutland Valley limestones and the metamorphic rocks to the east are discussed.

210 1894 The geology of Hoosac Mountain and adjacent territory. U S G S, Mon 23:41-118.

The structure and relations of the metamorphic rocks of Hoosac Mountain are the same in western Massachusetts and Vermont. The discussion, therefore, is applicable to the southern part of the state.

211 1922 Mount Monadnock, Vt., a Monteregian hill. · (Abst, with discussion by F. D. Adams, and others.) G Soc Am, B 33: 127-128.

A brief description of the syenite mass which intrudes the quartzite and schist country rock and is cut by camptonite, aplite, and bostonite dikes is given. The discussion following the presentation of the paper is reported.

212 1929 Mount Monadnock, Vt., a syenite hill. J G 37:1-15.

A study of the minerals and rocks, detailing their microscopic characteristics, distribution, and similarities with occurrences at other localities, expands the subject of the previous report.

Woodworth, Jay Backus

213 1905 The Brandon clays. Vt, St G, Rp 4:166-173.

Although the article is concerned chiefly with clays, some information about the relationships of the rocks and the occurrences of the clays is included.

INDICES

The following indices have been prepared to facilitate the selection of references pertaining to specialized subjects within the larger field of Vermont petrology. The subjects which have been indexed are Age, Counties, Rock Types, and Petrographic Work. The lists can be used as cross indices; for example, a reader wishing to secure reports on petrographic work on Camptonite from Washington County, can look for the numbers listed in the petrographic index, which occur in both the index of Igneous Rocks under "Camptonite," and in the County index, under Washington. These numbers refer directly to the titles in the preceding list, which contain the desired information.

INDEX OF AGE

The era, period, and epoch names which have featured in the reports are listed in alphabetical order in the following index. The terms used are those sanctioned by the United States Geological Survey in Bulletin 769.[1] Names encountered in the reports but not accepted by the Survey are put in quotation marks, and they have been translated into their equivalents in the Survey's list. For example, references to the Taconic System have been placed under the Cambrian and Ordovician periods. In cases where "Lower Silurian" was used for the present term Ordovician, the references are listed as Ordovician. The reference numbers have been arranged under era headings only, except in the cases of Paleozoic and Proterozoic. The references for the Paleozoic and Proterozoic periods are so numerous that periodic listing is necessary for purposes of utility. Articles which refer to the Paleozoic or Proterozoic eras and do not specify the periods have been listed under the era headings. In other cases, the era under which references to periods and epochs may be found has been indicated.

[1] Wilmarth, M. Grace, The geologic time classification of the United States Geological Survey compared with other classifications. U. S. G. S., Bul. 769: 138 pp. (1925).

INDEX OF ERAS, PERIODS, AND EPOCHS

INDEX OF COUNTIES

An index of all the towns mentioned in reports would have been excessively long, and a county index seemed sufficient. Where specific towns have been studied, they are usually named in the title, and sometimes they are mentioned in the annotation. The heading "General" at the end of the alphabetical list of Counties covers those articles in which reference is made to a section of the state or to the state as a whole, but not to specific counties.

Washington

10, 31, 33, 35, 56, 57, 70, 75, 80, 86, 90, 106, 108, 109, 112, 135, 144, 148, 160, 161, 165, 167, 171, 172, 175, 208.

Windham

6, 26, 31, 35, 37, 42, 58, 80, 86, 87, 92, 94, 104, 108, 109, 144, 202, 204, 206, 207, 208.

Windsor

4, 10, 26, 31, 35, 36, 38, 52, 53, 58, 59, 63, 71, 72, 76, 80, 86, 87, 88, 91, 107, 108, 109, 130, 144, 152, 153, 154, 160, 168, 169, 170, 190, 191, 202, 206, 207, 208, 212.

General

1, 2, 3, 9, 11, 12, 15, 18, 21, 22, 26, 27, 29, 37, 40, 41, 43, 44, 45, 46, 49, 54, 55, 67, 71, 72, 76, 78, 79, 80, 82, 84, 85, 86, 87, 88, 90, 93, 96, 97, 99, 101, 102, 104, 105, 108, 109, 114, 115, 116, 117, 121, 129, 132, 134, 135, 138, 139, 140, 144, 145, 146, 147, 150, 152, 156, 157, 163, 166, 171, 179, 180, 181, 184, 185, 187, 194, 195, 196, 197, 199, 200, 203, 209.

INDEX OF PETROGRAPHIC WORK

Some of the reports and articles contain brief or full accounts of microscopic work done in connection with the study. For the benefit of those who are particularly interested in this phase of the subject, a list of the papers in which such work is published follows:

Petrography

7, 8, 20, 22, 24, 25, 26, 27, 28, 31, 32, 33, 34, 35, 38, 46, 53, 56, 57, 59, 61, 63, 65, 69, 70, 91, 103, 104, 108, 109, 110, 111, 121, 122, 125, 126, 127, 130, 138, 139, 140, 145, 154, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 178, 182, 189, 205, 207, 208, 210, 211, 212.

INDEX OF ROCK TYPES

The rock varieties which are treated in the reports have been classified according to the three chief divisions, Igneous, Metamorphic, and Sedimentary. Under each of these headings the rock names have been listed alphabetically. The numbers, given in sequence, that follow each type are those of the preceding references in which that type is discussed. Some indication of what kind of information the reference contains may be obtained by consulting the notation accompanying it.

IGNEOUS

Analcitite

27.

Aplite

38, 53, 167, 169, 170, 172, 175, 178, 211, 212.

Basalt

1, 11, 27, 74, 82, 92, 97, 100, 101, 103, 125, 141, 152, 158, 160, 162, 187, 195, 198.

Bostonite

7, 121, 124, 141, 211, 212.

Camptonite

27, 38, 52, 53, 56, 57, 91, 118, 121, 125, 131, 141, 153, 154, 160, 166, 168, 174, 189, 192, 206, 211.

Dacite

170.

Diabase

8, 22, 32, 63, 91, 118, 121, 131, 153, 154, 160, 161, 162, 163, 164, 166, 167, 168, 169, 170, 173, 174, 175, 176, 177, 178, 182, 206.

Diorite

38, 104, 105, 152, 160, 161, 162, 163, 168, 169, 170, 173, 174, 210.

Dunite

208.

Epidosite

168, 173, 174.

Essexite

38, 52, 53, 211, 212.

Fourchite

121.

Gabbro

38, 161, 163, 169, 174.

Granite

1, 3, 8, 9, 10, 11, 25, 31, 32, 35, 37, 38, 52, 56, 57, 63, 72, 73, 74, 80, 82, 84, 86, 88, 91, 92, 97, 98, 100, 101, 104, 110, 111, 112, 122, 127, 128, 130, 134, 135, 138, 139, 140, 142, 144, 145, 146, 148, 150, 152, 153, 154, 158, 160, 161, 162, 164, 165, 166, 167, 168, 169, 170, 172, 173, 174, 175, 176, 177, 178, 182, 192, 194, 195, 203, 212.

Lamprophyre

38.

Limburgite

103, 160.

Monchiquite

27, 121, 141, 189, 211.

Monzonite

31, 32, 110, 111, 148, 174.

Norite

8.

Nordmarkite

38, 53, 63, 212.

METAMORPHIC

SEDIMENTARY

Breccia

8, 26, 33, 38, 53, 100, 121, 123, 137, 147.

Clay

3, 4, 5, 9, 62, 63, 81, 84, 95, 130, 139, 140, 150, 161, 162, 195, 213.

Conglomerate

23, 24, 26, 28, 32, 35, 36, 39, 41, 49, 50, 51, 58, 59, 60, 61, 62, 63, 66, 68, 69, 73, 74, 76, 77, 78, 88, 99, 100, 101, 105, 108, 115, 116, 117, 127, 141, 142, 145, 152, 154, 157, 161, 164, 165, 166, 167, 168, 170, 171, 172, 173, 175, 176, 177, 178, 185, 186, 188, 193, 205, 206, 207, 209, 210.

Dolomite

9, 11, 17, 20, 21, 30, 39, 60, 61, 62, 63, 66, 67, 68, 69, 70, 86, 105, 115, 116, 117, 133, 187.

Graywacke

8, 9, 37, 66, 115, 194.

Grit

24, 27, 28, 37, 78, 108, 109.

Limestone

1, 3, 4, 5, 8, 11, 13, 14, 15, 16, 18, 19, 20, 23, 25, 26, 27, 28, 29, 30, 32, 33, 34, 35, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 49, 50, 51, 53, 55, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 71, 72, 73, 74, 79, 80, 81, 82, 84, 85, 86, 88, 91, 92, 95, 97, 98, 100, 101, 110, 111, 112, 113, 114, 115, 116, 117, 120, 124, 125, 129, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 149, 151, 152, 153, 154, 157, 158, 159, 160, 161, 162, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 183, 184, 185, 186, 187, 188, 192, 194, 195, 196, 197, 198, 199, 201, 202, 205, 206, 207, 209, 210.

Sandstone

1, 3, 4, 11, 12, 13, 14, 15, 16, 18, 19, 27, 37, 41, 44, 49, 51, 55, 58, 60, 61, 63, 66, 68, 71, 77, 82, 84, 85, 86, 97, 100, 101, 105, 115, 116, 123, 124, 133, 137, 141, 142, 143, 145, 147, 152, 155, 156, 157, 158, 163, 180, 184, 185, 186, 194, 195, 197, 198, 202, 203.

Shale

1, 4, 7, 9, 15, 18, 26, 27, 29, 30, 37, 41, 44, 49, 50, 51, 58, 61, 62, 63, 64, 66, 68, 80, 84, 105, 124, 133, 136, 141, 142, 143, 145, 147, 149, 151, 152, 180, 181, 186, 188, 195, 197, 202, 203.

ACKNOWLEDGMENTS

To Mr. Howard A. Meyerhoff of Smith College is expressed my most sincere appreciation of and gratitude for his encouragement and valuable criticism and assistance. I am indebted to Miss Isabel F. Smith of Scripps College for the suggestion that this bibliography be prepared. I wish to thank Miss Pauline S. Lehman for her help in preparing the manuscript.

THE GEOLOGY OF THE VERMONT OCHER DEPOSITS

FREDERICK A. BURT

CONTENTS

INTRODUCTION

Ocher, or ochery earth, is a natural mineral pigment composed largely of clay permeated with hydrated iron (ferric oxide).[1] At present ocher has two important uses: As a pigment, and as a filler in linoleum and oil cloth.

Ocher ranges in color from light yellow to reddish brown. The color depends largely on the amount and chemical combination of the iron, but may be influenced by the presence of manganese or other substances.

Ocher is known to have originated both as a residual and as a transported deposit. The deposits of the transported type are not common and are of small commercial value as compared to those of the residual type. Probably the most valuable and extensive deposit known to be of the transported type extends for about 3 miles along the base of Catoctin Mountain, Virginia. This deposit has been described by Keith[2] as a yellow or orange-colored ocher reaching a maximum thickness of 30 feet, and overlaid by gravels. Another transported deposit, which is of peculiar type, has been described by Davis[3] as occurring near Lucky Lake, Saskatchewan. This is a yellow, red, and black ochery clay of glacial origin. The red has been used commercially.

Because ocher is essentially an intimate physical mixture of clay with much heavier iron oxides the largest and purest deposits are generally of the residual type. Residual ochers are known to have been formed in the following ways: (1) By decomposition of argillaceous and feldspathic rocks rich in iron. (2) By decomposition of argillaceous and feldspathic rocks and the later impregnation of the resulting clays with iron in solution or colloidal suspension. (3) By decomposition and molecular replacement in argillaceous rocks. (4) By decomposition of calcareous rocks bearing iron and clay impurities. (5) By decomposition of iron ores. (6) Possibly, partly through pneumatolytic action.[4] (7) By combinations of the above methods.

MINERALOGIC AND PETROGRAPHIC CHARACTERS OF OCHER

Quantitatively the principal constituents of all ochers are the aluminous clay minerals. In addition to the hydrous silicates diaspore and gibbsite may be present. Both crystalline and colloidal silica are common mineral constituents. Calcium carbonate

[1] U. S. Tariff Commission, Tariff Information Survey, Par. 55, Act of 1913, A-15.
[2] Keith, Arthur, U. S. G. S. Geol. Altas 10, Harpers Ferry, 1894.
[3] Davis, N. B., Report on the Clay Resources of Southern Saskatchewan, Can. Dept. Min., Mines Branch 468, 1918.
[4] Wilson, Hewitt, Ochers and Mineral Pigments of the Pacific Northwest, U. S. Bur. Min. Bul., 304, 1929, p. 41.

is frequently present in small amounts, but in commercial ochers it always makes up less than 5 percent of the whole, and often is considerably less than this in amount.

Qualitatively the most important constituents are the iron and manganese minerals. The iron minerals are chiefly ferric oxide (hematite) and the various degrees of hydrated oxides (turgite, goethite, limonite, and limnite). Ferrous hydroxide and finely pulverulent hydrated ferrous silicates are occasionally present. Ferrous sulphate (copperas or melanterite) may also occur in solution. Manganese may be present as an oxide, a carbonate, or a silicate mineral. Finely disseminated rutile imparts a straw-yellow color, if abundant, and reduces the intensity of red.

VARIETIES

The important varieties of ocher may be listed as follows:

Yellow Ocher.—This is the commonest and most widely distributed variety. The color is due to the presence of hydrated ferric oxide, either goethite or limonite. In commercial ochers the iron content ranges from 17 to 30 percent. Lead chromate is sometimes present in small amounts, but is detrimental to the value of the ocher. Yellow ochers have been used since prehistoric times.

Red Ocher.—In this variety the iron is either anhydrous (hematite), or contains less than 5.3 percent water (turgite). The total iron content may vary from a few percent to a maximum of nearly 90 percent in Spanish red. Talckene is the trade name for a variety of red ocher containing sufficient fine-grained mica to give it a talcose feeling. It has been mined near Greenwald, Pennsylvania.[1]

Green Ocher.—This is an uncommon ocher in which the iron is mainly ferrous hydroxide, impure hydrous ferrous oxide, or ferrous silicate. American deposits are not recorded, but considerable green ocher is mined in Bohemia. The Italian greens are also well known, and have been formed by the decomposition of basaltic tuffs.

Sienna.—Sienna is a yellowish brown variety which is very high in iron, often containing from 60 to 80 percent Fe_2O_3.[2] Manganese is generally present, but its content is low. Sienna grades into ordinary yellow or red ocher by reduction of the iron content, and into umber by increase of the manganese content. The American supply has come mainly from near Reading, Pennsylvania and West End, New Jersey.

Umber.—Umber is darker brown than sienna and contains normally from 7 to 14 percent manganese dioxide. Appreciable

[1] Ladoo, R. B., Non-metallic Minerals: Occurrence—Preparation— Utilization, 1925.
[2] Ladoo, R. B., *ibid.*, p. 372.

amounts of organic matter are also present. The hydrous iron oxide is less in amount than in sienna. Umber has been produced near Bethel, Bethlehem, and Doylestown, Pennsylvania, and at Bennington and Brandon, Vermont.

DISTRIBUTION OF THE VERMONT OCHER BEDS

In America ocher mining has been confined to Alabama, California, Georgia, Iowa, Pennsylvania, Vermont, and Virginia. Imports are mostly from France.

The Vermont ocher belt extends along the western side of the state through Bennington, Rutland, Addison, and into Chittenden counties. (Figure 2.) In these counties deposits are known to exist at many places along the western base of the Green Mountain range. Commercial development of these deposits, however, seems to have been limited to areas in Bennington and Shaftsbury in Bennington County, and Brandon in Rutland County. The iron and manganese ores with which the ocher is associated have been worked in several other towns of the state, notably Wallingford, Pittsford, and Chittenden in Rutland County, Monkton, in Addison County and Colchester in Chittenden County.

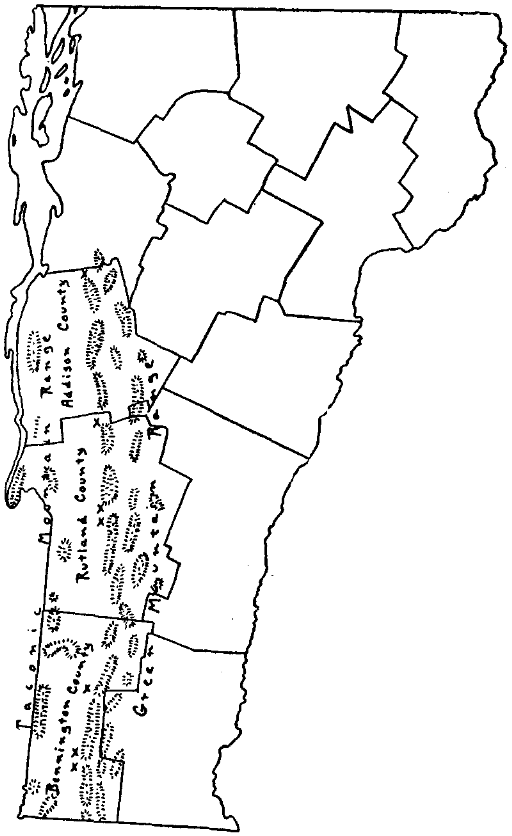

Fig. 2. Sketch map of Vermont showing the three counties containing deposits of ocher and allied substances, with their relation to the Taconic and Green Mountain Ranges. Crosses indicate the positions of the principal ocher deposits.

THE VERMONT OCHER INDUSTRY

Ocher mining is one of the oldest mineral industries of the state, having begun as early as 1820. Table I shows the values of ocher produced during the years mining was most active. From 1889 to 1913 the state ranked third in the amount of ocher produced in the country, being surpassed only by Georgia and Pennsylvania. In 1913 production began to fall off considerably and the state was passed by Virginia and California. Since 1916 no ocher of reported value has been mined.

Table I

Value of Ochers Produced in Vermont*

1889	$ 7,800	1904	$ 5,200
1891	11,095	1907	6,638
1897	7,739	1908	2,050
1898	6,650	1909	4,726
1899	6,200	1910	5,935
		1912	6,346

*Data from U. S. Mineral Resources.

THE OCHER DEPOSITS OF STATES OTHER THAN VERMONT

GEORGIA

The Georgia ochers show an almost exact parallelism to those of Vermont. The most important Georgia deposits are located in Bartow County in the northwestern part of the state. The geologic column of the area is as follows:

Ordovician	Knox dolomite
Cambrian	Conasauga and Rome shales Beaver limestone Weisner quartzite
Pre-Cambrian	Ocoee[1] conglomerate, slate, and schist Granite, gneiss, and schist

The pre-Cambrian rocks form a hilly country to the east which is separated by a steeply dipping overthrust from the lower section of folded Paleozoics on the west.

In the producing area the Weisner quartzite is exposed on the western side against the fault plane. The quartzite is very variable, but is mainly a heavy, fine-grained, vitreous rock. Interbedded with the quartzite are many beds of fine conglomerate. Intercalated beds of siliceous shales also occur. An average of many analyses of the quartzite shows: silica 90.36 percent, alumina 1.52 percent, ferric oxide 0.57 percent, iron sulphide 1.50 percent, and barium sulphate 4.46 percent.

[1] The stratigraphic position of the Ocoee, above or below the pre-Cambrian-Cambrian boundary, is a matter of some controversy.

According to Watson[1] the Georgia ocher occurs in beds and branching veins within the Weisner quartzite close to its fault contacts with the Beaver limestone and the Knox dolomite. Manganese ore is associated with the Georgia as with the Vermont ocher. The manganese ore also occurs as veins and pockets in both the quartzite and the Beaver limestone. The presence of manganese minerals, the relations to the fault lines, and the age and character of the bed rock formations, except for the additional occurrence of shales in the Georgia area, are the same in the two states. The ocher is believed by Watson to be the result of replacement within the quartzite followed by weathering.

ALABAMA

Good red and yellow ochers occur in this state in the Chilton, Red Mountain, and Tuscaloosa formations.[2] Yellow ochers of good quality occur in the St. Stephens (Tertiary) and Grand Gulf formations also.

PENNSYLVANIA

Ocher, of very similar occurrence to that of Vermont, occurs in Berks and Lehigh counties. The similarity of the ochers, and their geologic relations, in the two states was first pointed out by Hopkins.[3]. The Pennsylvania ocher, according to Stoddard and Callen,[4] lies on the Shenandoah (Cambro-Ordovician) limestone close to its contacts with the Chickies (lower Cambrian) quartzite and pre-Cambrian gneisses. The ocher carries quartzite pebbles and limonite nodules, and is younger than the Permian. There is thus a close parallelism between the Vermont and Pennsylvanian ochers so far as their age, kinds of associated bed rock, relationship to formation contacts, and principal included matter is concerned. Stoddard and Callen believe the ocher to be a weathered product residual from the limestone. Miller[5] considers it to be a replacement of the limestone, the iron having been furnished by weathering from all the formations of the area.

VIRGINIA

In Virginia[6] ocher occurs in the Coastal Plain, Piedmont Plateau, and the Valley regions. It has been extensively mined

[1] Watson, Thomas L., The Ocher Deposits of Georgia, Geol. Surv. Ga. Bul. 13, 1906.
[2] Smith, Eugene A. and McCalley, Henry, The Mineral Resources of Alabama, Geol. Surv. Ala., Pub. 30, 1904, p. 62.
[3] Hopkins, T. C., Cambro-Silurian Limonite Ores of Pennsylvania, Bul. Geol. Soc. Am., Vol. XI, 1900, pp. 475-502.
[4] Stoddard, J. C. and Callen, A. C., Ocher Deposits of Eastern Pennsylvania, U. S. G. S. Bul. 430, 1909, pp. 424-439.
[5] Miller, B. L., The Mineral Pigments of Pennsylvania, Rept. Top. and Geol. Surv. Comm. Pa. No. 4, 1911, pp. 11-43.
[6] Watson, Thomas L., Mineral Resources of Virginia, Virginia-Jamestown Exposition Commission, 1907, pp. 225-232.

in Chesterfield County. The ocher is yellow and is associated with Tertiary sands and clays.

In Augusta County the ochers are in many ways similar, geologically, to those of Vermont. They are associated with clays, wad, graphite, and decomposed argillaceous layers of bed rock. Unlike the Vermont ochers they occur in a limestone formation, the Cambro-Ordovician Shenandoah. Ocher occurs in Page County in the Cambrian iron-bearing shale, and in Rockingham County in the Potsdam iron ores.

The ocher of the Harpers Ferry area has been refered to in the introduction to this paper. Keith[1] describes it as a transported deposit. Much sand, ferric oxide, and magnetite is separated by washing.

MISSOURI

As described by Crane[2] ochers occur in the deposits of secondary iron ores which are widely distributed throughout the Ozark Plateau. The deposits are associated chiefly with the Gasconade and Jefferson City limestones and the Roubidoux sandstone, all of Cambrian age. A few deposits are associated with Mississippian formations.

The iron ores vary much in size of deposit and consist of pockets, ledges, stringers, mechanically-filled veins, and surface boulder deposits. The ore is composed chiefly of limonite with some hematite, but no goethite. The principal impurities are chert, quartz, clay, pyrite, and marcasite. Manganese minerals are not present in visible amounts, although chemical analysis of the ore shows some manganese to be present. The ore is of three types: (1) boulder and tabular ore, (2) stalactitic ore, and (3) ocherous ore.

The ocherous material forms an important part of the deposits. It is usually associated with the boulder, rather than the stalactitic ores, forming the matrix in which the boulders occur. Powdery, light brown to yellow ocher grades into the dark brown, granular varieties.

The ocher is interpreted as the derivative by oxidation and hydration from marcasite and pyrite originally deposited in the overlying limestone and sandstone. Secondary concentration is considered to have followed the weathering phenomena.

IOWA

A sandy red ocher of greasy feel occurs in Fairview township, Jasper County. It is associated with the much disintegrated

[1] Keith, Arthur, U. S. G. S. Geol. Atlas U. S. No. 10, Harpers Ferry, 1894.
[2] Crane, G. W., The Iron Ores of Missouri, Mo. Bur. Geol. & Mines, 2nd ser., Vol. X, 1912, Chap. V.

red rock sandstone and appears to be a product of rock decomposition.[1] The Marion County ocher is doubtless a part of the same formation as that of Jasper County.[2]

Bog ores with ochery clays and sands occur in Delaware County[3] resting on the Kansan drift and underlying the Iowan drift. No explanation of their origin is suggested.

TEXAS

Ocher is reported to be present close to the surface in several localities in the state, but as yet no commercial development has been attempted. Ocher is not mentioned in the geological literature of the state, but the writer has examined specimens which have been sent to his laboratory from two or three localities.

These ochers are of both the red and yellow varieties and carry from 30 to 50 percent of medium and fine sand which may be easily removed by washing. Several of the surface formations of the state are highly ferruginous and yield ochery soils. Undoubtedly a considerable amount of material capable of future development for pigment exists.

CALIFORNIA

Mineral pigments have been produced in California since 1890 but there is no comprehensive account of the state's deposits. The total production to date has been about 22,430 tons.

The ores include soft, fine-grained, red shales and gossans after sulphide ores in addition to yellow and brown ochers.[4] The ochers have been formed by the depositing of iron oxide and iron hydroxide in clay by calybeate spring water. Material has been shipped from Alameda, Amador, Butte, Calaveras, Colusa, Los Angeles, Napa, Nevada, Placer, Riverside, Shasta, Sonoma, Stanisaus, and Ventura counties.

WASHINGTON

Several varieties of ochers[5] are known in Washington, but as yet they have been little worked.

The most important area is near Deer Park, Stevens County. The section from the surface downward shows: glacial drift, 15 feet or less; fine-grained, gray to nearly white clay, 8 to 11 feet; yellow ocher, 3½ to 5 feet. The ocher is a transported product, its field conditions indicating that it may have been produced by

[1] Williams, Ira A., Geology of Jasper County, Ia. Geol. Surv., Vol. XV, Ann. Rept., 1904, pp. 358-359.
[2] Lees, James H., Personal letter to the writer, July 27, 1929.
[3] Calvin, Samuel, Geology of Delaware County, Ia. Geol. Surv., Vol. VIII, Ann. Rept., 1897, p. 187.
[4] Bradley, Walter W., Personal communication to the writer, December 26, 1929.
[5] Wilson, Hewitt, *op. cit.*, pp. 21-22.

the depositing in water bodies of colloidal clay particles and colloidal iron. The ocher material is the result of decomposition of a very old series of granite rocks to the north and east. The ocher is found both in distinct seams and merging into the clay. Sienna occurs as hard layers of from 2 to 6 inches thickness imbedded with the ocher.

Residual red pigments formed by the decomposition of mixed andesitic and more basic rocks occur between Clay City and the Mashell River. Probably the alteration to ocher has been accomplished in connection with pneumatolytic processes.

OREGON

"Red basaltic clays" (ocher) are found close to the surface at several places south of Salem. They are residual ochers, the result of the surface decomposition of basalt.[1]

GEOLOGIC RELATIONS OF THE VERMONT OCHER

THE STRATIGRAPHIC COLUMN OF THE AREA

The Vermont ocher is part of a series of unconsolidated deposits consisting of kaolin, ocher, quartz sand, iron and manganese ores, and lignite. This series of deposits extends through the western tier of counties from Colchester on the north to the Massachusetts line on the south. The group of sediments has been called the Brandon formation, and has been described by Clark[2] as extending southward through Pennsylvania into Georgia. Clark, following the early geologists, considered the Brandon lignite as Eocene. Lesquereux,[3] Knowlton,[4] and Perkins[5] have more recently definitely established its age as Miocene. It is unfortunate that the term *Brandon* has been used to denote both this entire formation and also its lignite member.

The rock materials included under Hitchcock's and Clark's term *Brandon formation* are: kaolin, ocher, quartz sand, nodular and concretionary iron ores, manganese ore, and lignite. With the exception of the lignite and the manganese ore these are all the residual products of rock decomposition. In some cases they are distinctly separated from, in some cases more or less associated with, and in some actually interbedded with the remnants of their parent formations. For this reason these associated materials

[1] Wilson, Hewitt, *ibid.*, p. 40.
[2] Clark, W. B., Correlation Papers, U. S. G. S., Bul. 83, 1891, pp. 90-94. The term "Brandon formation" was first proposed for the entire formation from Vermont to Georgia by Hitchcock in 1861.
[3] Lesquereux, L., Fossil Fruits from the Lignites of Brandon, Vermont, Am. Jour. Sci., ser. 2, Vol XXXII, 1861, pp. 355-363.
[4] Knowlton, F. H., Bul. Torrey Botanical Club, November, 1902, pp. 635-641.
[5] Perkins, George H., Fossils of the Lignite, Fifth Bien. Rpt., Vt. State Geol, 1905-6, pp. 202-205.

cannot properly be referred to as a *formation,* nor can they be consistently described as members of their parent formations as in some cases they are areally separated from any remaining part of the parent formation, and in some cases the residual matter has been derived from more than one formation, as *e.g.,* the Bennington kaolin which has been shown[1] to have been derived in some cases from the Stamford and Woodford gneisses and in some cases from the Vermont quartzite.

The relationship between these various materials is so close genetically, structurally, and petrographically that frequent references must be made to them as a unit. In an endeavor to find a handle to apply to the group which will not involve the error implied by calling them a *formation* the writer proposes to designate them by the compound word *residual-formation* and will hereinafter refer to them collectively as the *Brandon residual-formation.*

TABLE II

Geologic Column in the Ocher-bearing Area

Pleistocene	Surficial	0-50′	Drift, alluvium, and soil
Tertiary	Brandon	0-175′	Kaolin, ocher, sands, lignite, and ores
Ordovician	Berkshire	0-5000′	Graphitic and pyritic quartz schists
Cambrian	Stockbridge	1200′ ±	Crystalline limestones, dolomites, and marbles
	Vermont	1600′ ±	Cheshire and Monkton quartzite and quartz schists with feldspathic and argillaceous and conglomeratic beds
Pre-Cambrian	Stamford, Woodford, and White gneisses		Quartz, feldspar, biotite, and hornblende gneisses

Table II shows the geologic section of the ocher-bearing area.

The pre-Cambran gneisses are common in the southern part of the ocher-bearing area where they serve as important parent rocks of the argillaceous portions of the Brandon residual-formation.[2] North of Bennington County they are deeply buried, or outcrop to the east of the Brandon outcrops and, except possibly at Monkton, are not of vital importance in the ocher problems. In the southern part of the area the gneisses are hornblende and

[1] Burt, Frederick A., The Origin of the Bennington Kaolins, Sixteenth Bien. Rpt., Vt. State Geol., 1927-8, pp. 65-84.

[2] Burt, Frederick A., *ibid.*

biotite varieties rich in both orthoclase and plagioclase. Pegmatite dikes cut across them in numerous instances.

The gneisses of the area may be briefly mentioned under the heads of: Stamford gneiss, White gneiss, Woodford gneisses, and the lower interbedded gneisses of the Vermont formation.

The Stamford gneiss is a coarse granitoid rock, irregularly banded, consisting essentially of pinkish orthoclase, bluish quartz and greenish biotite and muscovite. Important accessory minerals are epidote, albite, magnetite, and garnet. A petrologic description of the Stamford gneiss has been given by Wolff.[1] The origin of the gneiss is doubtful, it has been highly metamorphosed, and its minerals exhibit many igneous features.

The White gneiss of Wolff[2] consists of several phases of banded gneisses consisting of orthoclase, microcline, quartz, and mica. There is an abundance of various accessory minerals including biotite, epidote, apatite, magnetite, rutile, zircon, calcite, and garnet. In some places it is seen to overlie the Stamford gneiss.

Woodford gneisses is a group term, proposed by Burt,[3] for several pre-Cambrian gneisses underlying the Vermont formation which have not yet been differentiated or worked out as to their relations. At least four of these gneisses are found in the ocher belt. (1) An irregularly banded orthoclase-quartz gneiss with considerable accessory biotite and some muscovite. (2) An even-grained, even-banded, red orthoclase and hornblende gneiss with minor quartz. (3) Quartz-plagioclase-orthoclase-hornblende gneiss with even, conspicuously-banded layers. (4) Fine-grained biotite gneiss with much striated feldspar and possessing no pronounced foliation.

The Vermont formation consists of interbedded gneiss, quartzite, quartz schist, quartz breccia, and conglomerate. The formation is in many places highly folded and metamorphosed. Arkosic and feldspathic beds are interstratified with almost pure quartz beds. Nearly all horizons carry some iron in the form of finely-disseminated hematite or crystals of pyrite. Some beds are very rich in iron, are dark red in color, and are deeply stained, almost black on weathered surfaces. Transition from one type of quartzite to another is abrupt and irregular in both the vertical and horizontal directions. The Vermont formation is structurally and genetically the most closely related to the ochers of any of the indurated formations of the area.

In its typical form the formation consists of the following members:

[1] Pumpelly, Raphael, Wolff, J. E. and Dale, T. Nelson, Geology of the Green Mountains in Massachusetts, U. S. G. S. Mon. 23, 1894, pp. 45-48.

[2] Pumpelly, Raphael, Wolff, J. E. and Dale, T. Nelson, *ibid.,* scattered references from pages 70 to 86.

[3] Burt, Frederick A., *op. cit.,* p. 69.

1. Schistose and pyritic quartzite, and quartz and sericite schists.
2. Heavy, massive quartzite, reddish in color with many layers containing much hematite.
3. White and gray, nearly pure quartz quartzite.
4. Conglomeratic quartzite containing many feldspar pebbles.
5. Feldspathic quartzite with arkose and argillaceous beds.
6. Interbedded quartzite and gneiss.

The gneiss of the lowest member is composed largely of quartz, mica, and feldspar, and is presumably the result of the metamorphism of arkosic beds. The feldspars of the formation are orthoclase and sodic plagioclases with much microcline.

In Rutland County the formation shows many modifications of its typical structure. There is more schist within it here than farther south, quartz and sericite schist being especially more common along the horizons of ocher and kaolin contact. The basal parts of the formation contain 50′ of interbedded crystalline, schistose limestone beds in which abundant feldspar pebbles occur.

The quartzite is overlain conformably by the "interbedded series" which consists of interbedded quartzite and dolomite which grades upward into the true Stockbridge limestone. The Stockbridge formation, including the Rutland dolomite, is a crystalline dolomite, limestone, marble, and breccia, generally of remarkable purity. The chief accessory minerals are quartz, muscovite, pyrite, minute specks of magnetite, and pyrolusite. Locally considerable hematite occurs. Dale[1] has discussed very fully the structural and petrological characteristics of the formation.

The Berkshire schist is the youngest of the indurated formations of the ocher belt. It is a highly crumpled, crystalline schist locally pyritic or graphitic. The Brandon residual-formation is nowhere known to be in contact with it, nor does it bear any genetic relationship to it.

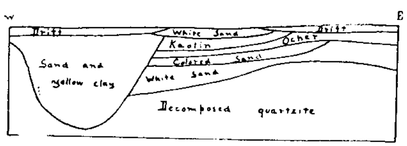

FIG. 3. Section ¼ mile south of Forestdale on east side of highway. Vertical and horizontal scales, 200 feet to the inch.

The various members of the Brandon residual-formation do not hold a constant relationship to one another. In some places, as near Brandon (Fig. 3.) the kaolin, ocher, and sand are associated in adjoining pockets while at other places they are separated by a sharp, horizontal contact. The ocher may overlie the iron-manganese ore, as in the eastern part of Bennington, or the ore

[1] Dale, T. Nelson, The Commercial Marbles of Western Vermont, U. S. G. S. Bul. 521, 1913.

may extend in veins and pockets through the ocher, as in Pittsford. In some instances, as in some drillings near Brandon (Table III) a part of the ore may be underlaid by a considerable thickness of ocher.

TABLE III

Three Well Sections South of Forestdale, Brandon, Showing Variety of Relationships Within the Formation in an Area of a Few Square Feet.*

Well A		Well B		Well C	
Yellow ocher	23′	Drift	16′	Drift	10′
Kaolin	19′	Hardpan	10′	Dark yellow ocher	20′
Decomposed rock	3′	Light yellow ocher	7′	Rock	2′
Kaolin	7′	Red and yellow ocher	2′	Yellow ocher	8′
Lignite	7′	Brown ocher	17′	Dark yellow ocher	2′
Yellow ocher	23′	Yellow ocher	2′	Iron ore	13′
Depth of well	82′	Brown ocher	6′	Dark Brown ocher	24′
		Medium yellow ocher	30′	Yellow ocher	3′
		Brown ocher	58′	Brown ocher	20′
		Depth of well	148′	Depth of well	102′

*Data furnished by I. W. Horn of Brandon.

The ore of the Brandon residual-formation consists of beds and pockets of hematite, limonite, and turgite pebbles, boulders, and concretions imbedded in clays and sands. In many parts of the residual-formation these iron minerals are mixed with smaller amounts of psilomelane, pyrolusite, and braunite. In a few cases, as at South Wallingford (Fig. 4) the manganese minerals occur in definite veins of considerable richness.

FIG. 4. Section showing position of manganiferous clay near South Wallingford. Or, manganese ore vein; Cv, Vermont quartzite; COs, Stockbridge limestone. (Redrawn after Penrose.)

One or more members of the Brandon residual-formation are usually lacking. The only place in the state where all the members are known to be present is in the old lignite mining area east of Brandon.

With a few exceptions the Brandon, so far as its base is determinable, lies on the Vermont formation. The exceptions are here noted. In the eastern part of the village of Bennington it is known to lie on the pre-Cambrian gneisses.[1] In the northern part of the township of Bennington and in Shaftsbury the ochers of the western part of the residual-formation rest on Stockbridge limestone just west of its contact with the Vermont formation along an overthrust plane. North of Shaftsbury the Brandon is

[1] Burt, Frederick A., *op. cit.*, p. 77.

not known to be in contact with the Stockbridge except at South Wallingford, in Chittenden, in Pittsford, and on the western side of the beds in Brandon.

In most cases the deposits are overlaid by glacial drift, but in a few cases they are at the surface, or covered by recent alluvial or colluvial deposits.

RELATIONS OF THE PHYSIOGRAPHIC TO THE STRUCTURAL FEATURES OF THE AREA

The Brandon residual-formation lies in the Vermont Valley between the Green Mountain range on the east and the Taconic Mountains on the west. Figure 5 shows diagrammatically the relations of these three physiographic areas and the rock formations to them. The western face of the Green Mountain range was formed by the erosion of an overthrust mass. Both the throw and heave of the overthrust decrease in amount from the south northward. The amounts at Rutland are considerably less than at Bennington. The range is composed of the pre-Cambrian gneisses and the quartzite of the Vermont formation. The western face of the range slopes down abruptly to the floor of the Vermont Valley.

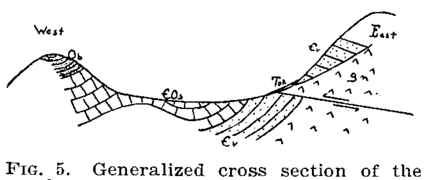

FIG. 5. Generalized cross section of the ocher area, showing the three physiographic units (Vermont Valley separating the Green Mountains on the east from the Taconics on the west) and their bedrock relations; gn, pre-Cambrian gneiss; Cv, Vermont quartzite; COs, Stockbridge limestone; Ob, Berkshire schist; Tok, Brandon residual-formation.

The Vermont Valley is underlaid by Vermont quartzite and the dolomites and marbles of the Stockbridge formation. Above these bed rocks lie deposits of glacial drift, piles of talus, lacustrine deposits, Pleistocene deltas, and alluvial fans. Through these surficial deposits rise many small hills of limestone, outliers of the Vermont formation, and inliers of the Berkshire schist. A conspicuous ridge of this outlier type is found rising as an anticlinal range nearly blocking the valley in the townships of Dorset, Danby, Wallingford, Tinmouth, and Rutland.

The Taconic range on the west is lower than the Green Mountain range and slopes down less abruptly to the valley floor. Many parts of the range are synclinal in structure, and its eastern flanks are formed by the eroded edges of the folds. The rocks of the Taconics are almost entirely the dolomites, limestones, and marbles of the Stockbridge formation, and the Berkshire schist.

DESCRIPTIONS OF THE VERMONT DEPOSITS

CHITTENDEN COUNTY

No ocher has been mined, nor is any known to exist in this county, but iron-manganese ore was mined in Colchester during the early part of the last century. The ore was mined from an ochery gravel, the geologic relations of which are such as to suggest that it belongs to the same formation as the iron-manganese ores and associated products in Addison, Rutland, and Bennington counties to the south. This relationship has long been recognized. In fact Perkins[1] states that the older Vermont geologists regarded the Colchester ores as remnants of once extensive Tertiary deposits extending throughout the state from north to south.

ADDISON COUNTY

Ocher, or its associated materials, is known to be present in Monkton, Bristol, Waltham, and Leicester townships.

In Monkton three quarries have been operated for the mining of kaolin. Two of these are in the formerly famous beds of the north and central parts of the township. The kaolin of these beds has been attributed to the decomposition of graphic granites underlying the quartzites. Lack of basal exposures of the kaolin, or the records of drillings penetrating it, prevent the proof or disproof of this theory. The third kaolin quarry lies on the west side of the north-south hill road about one mile south of the village of East Monkton. This quarry shows thin, alternating beds of white, sugary quartzite, kaolin, and sand. The beds have a northward dip of 35 degrees. To the west, and at about 100 feet higher altitude, lie the Monkton ore beds. Thin beds and streaks of ocher are present in the ore, but the quantity is too small for commercial development. Less ocher is found here than in other places where both kaolin and ore are abundant. In the northern part of the town the beds dip eastward under the quartzite. These beds lie higher up the Green Mountain slope than any other of the kaolin beds except those of the Green Mountain Kaolin Company in Bennington. It is notable that the marbles of Monkton, which rest on the Cambrian quartzite, are highly hematitic. It is possible that a part of the iron of the ores and the ocher may, at this place, have been furnished by solution from the limestone formations.

No ocher is known in Bristol, but a bed of hematite occurs in the northern part of the town. The ore, which was formerly worked, contains much manganese and clay, and the overburden contains a considerable amount of decomposed limestone.

[1] Perkins, George H., The Geology of Western Vermont, Tenth Bien. Rpt., Vt. State Geol., 1915-16, p. 209.

In Waltham the Brandon residual-formation is reported to be penetrated in wells, but neither details of it, nor specimens from the wells are available.

The Leicester deposit is found near the southwest corner of Lake Dunmore. This deposit is the northward extension of the deposit in Brandon and its description will be included with the latter.

RUTLAND COUNTY

Ocher, or its related materials, are known to occur in the following townships of the county: Brandon, Chittenden, Pittsford, Rutland, Clarendon, Wallingford, and Tinmouth.

In the township of Brandon, about two miles northeast of the village of Brandon and extending from a mile south of Forestdale northward past Fern Lake to Lake Dunmore, is the only section of the Brandon residual-formation in which all phases, including the lignite, are more or less developed (Fig. 6). The ore, ocher, kaolin, and sand form intermingled masses lying largely on the Vermont formation, but along its western edge it lies on the dolomite.

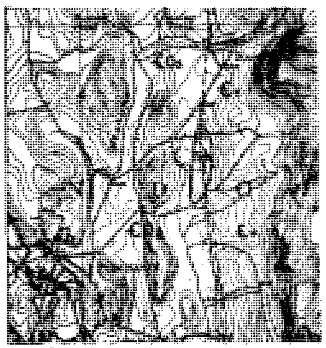

FIG. 6. Map showing the position of the main body of ocher and associated materials near Brandon, and their probable relation to the rock formations. Scale, 2 miles to the inch. Contour interval 20'. Cv, Vermont formation; COs, Stockbridge limestone; Tok, ocher, kaolin, and associated materials.

The ore is compact, fibrous, stalatitic, or in kidney-ore nodules. The relation of the ore to the ocher is very variable. In some drill holes the ore underlies the ocher while in others but a few feet distant the ore is above, or in pockets within, the ocher (Table III). The manganese minerals of the ore are abundant, in some pockets converting the mass into a rich manganese ore. They include braunite in addition to the usual psilomelane and pyrolusitic. Hollow limonite concretions from 3 to 10 inches across are common in both the ore and the ocher. These concretions are egg-shaped or irregular and are often filled with water. Locally they are known as water pots.

All gradations of ocher occur from true ocher, *i.e.,* kaolin impregnated with iron oxides, into white kaolin on the one hand to sand impregnated with iron oxides on the other. Ocher from

well "B" (Table III), 47 feet below the surface is classed as umber. Its ferric oxide content is 9.32 percent.[1]

Kaolin is abundant throughout the deposit and at the surface appears on both the east and west sides of the ocher belt. The kaolin is high-grade, white, and much of it contains very little grit. Quartz sand is associated with both the kaolin and the ocher. The sand grains are sharp, white, and unfrosted. Kaolin, ocher, and ore occur in pockets, veins, lenses, and domes within one another (Fig. 3).

The lignite occurs above, or within the kaolin. The largest body is in the form of a steeply-pitching chimney.

TABLE IV

Mechanical Analyses of Several Vermont Ochers

Material	Percent of whole raw material	Color*	Principal minerals	Accessory minerals
Brandon dark red	Sand 45.1% Ocher 54.9%	Venetian red 3i	Kaolin Quartz Hematite Turgite Feldspar	Psilomelane
Brandon dark yellow	Sand 38.3% Ocher 61.7%	Old gold 16i	Kaolin Quartz Hematite Limonite	Psilomelane Muscovite Feldspar
Brandon light yellow	Sand 39.7% Ocher 60.3%	Ivory with pinkish tinge 17²f	Kaolin Quartz Limonite Feldspar	Psilomelane
Rutland	Very variable	Yellowish orange 13°	Kaolin Quartz Muscovite	Sericite Hematite Limonite
Bennington Rockwood	Sand 24.5% Ocher 75.5%	Old gold 16i	Kaolin Quartz Limonite Feldspar	Garnet Hematite Psilomelane Turgite Tourmaline
Bennington Lyons	Sand 18.1% Ocher 81.9%	Marigold yellow 16°	Kaolin Quartz Feldspar Limonite	Hematite Garnet Pyrolusite Psilomelane Muscovite Rutile Tourmaline

*The color symbols are those of the Goldman and Merwin Color Chart for the Field Description of Sedimentary Rocks.

[1] Analysis by Hewitt Wilson, U. S. Bureau of Mines.

In Chittenden two mine shafts were sunk into the Mitchell ore bed about 1840. This bed lies in the southern part of the township near the western line. According to Adams[1] the northern shaft penetrated white clays, ocher, and iron-manganese ore. The southern shaft terminated in a bed of iron ore very rich in manganese, and resting on limestone.

An abandoned furnace in Pittsford marks the site of an extensive bed of iron ore. The ore lies in a thick bed of ocher which is associated with kaolin. It overlies limestone and underlies the glacial drift.

A mile and a half east of the southeastern corner of the city of Rutland there are excellent exposures of interbedded quartzite, schist, yellow and red clays, yellow and red sands, and sandy clay in the quarries of the Rutland Fire Clay Company. The whole is overlaid by from 2 to 6 feet of drift. In the southern quarry the interbedded materials are somewhat crumpled. In the northern quarry the folding is very pronounced.

Drilling shows considerable red ocher to lie below the quarry floor. The ocher varies from a very pure ocher with a fat sticky clay base to an ocher carrying 50 percent, or more of sand impurity. These variations are found within a dozen feet horizontally, and a fourth that distance vertically. With distances of six feet the color varies from yellowish red, to rusty brown, to dark-blood red. These variations are more abrupt than elsewhere noted within the ocher formation. The thinness of the individual beds, the small extent of the pockets, and the rapid horizontal and vertical variation in color make commercial development of the ocher impossible.

TABLE V

Analyses of Ores*

	Wallingford Ore	Pownal Ore
Silica	3.00%	22.30%
Ferric oxide	71.30%	67.17%
Manganese peroxide	12.93%	0.16%
Alumina	trace	0.00
Magnesium oxide	0.00	trace
Titanium oxide	0.00	trace
Water	12.50%	9.65%
Total	99.73%	99.28%

*Analysis of the Wallingford ore from C. B. Adams, 2nd Rpt., Vol. VI, Geol. Vt. Analysis of the Pownal ore by A. J. Patton, Chemist, Mich. State Exp. Station.

[1] Adams, C. B., First Annual Report on the Geology of Vermont, 1845.

Ocher is not known to occur in Clarendon but specimens of kaolin, some of it yellowish and ocher-like, have been seen by the writer.

The only ocher deposits known in the town of Wallingford occur in the village of South Wallingford along a brook south of the railroad station and thence northward along the foot of the mountain. Limonite nodules and pockets and veins of manganese ore run through the deposit.

The manganese ore was mined from 1820 to 1877. The ore consists of psilomelane and pyrolusite. The largest vein extends in a broken line for nearly a mile with an average trend of N. 22° E. The analysis (Table V) shows its composition.

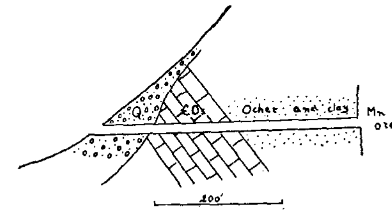

FIG. 7. Old mine drift ½ mile east of South Wallingford. The ocher and manganese ore represent older rock overthrust upon the west limb of a syncline of Stockbridge limestone. COs, Stockbridge limestone; Q, glacial drift.

Figure 7 shows the geologic relations as encountered in the old Wallingford mine shaft. The kaolin and ocher occur together and from a considerable mass lying between the Stockbridge limestone and the main manganese ore body. The whole of the Brandon residual-formation is overlaid by from 10 to 60 feet of drift.

The Wallingford ocher is of good grade and color, but is more siliceous than that farther south. Within the ocher umber is abundant, the minerals of which show remarkably little decomposition.

Ocher and kaolin are known in Tinmouth to extend along the north-south road east of Tinmouth channel in the southern part of town. No data concerning the extent, characteristics, or thickness of the deposits are obtainable.

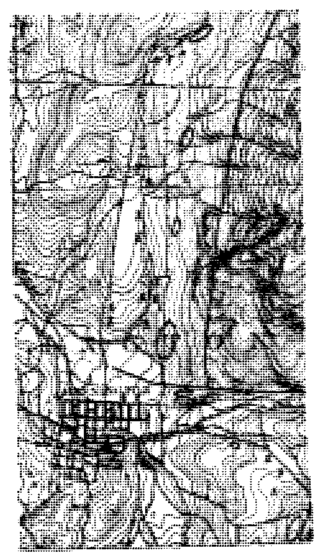

FIG. 8. Map showing position of ocher and kaolin deposits in the vicinity of Bennington, and their relation to the lines of overthrusting. Circles inclose kaolin deposits. Ocher marked by X's. Scale, 2 miles to the inch. Contour interval 20'.

BENNINGTON COUNTY

In Bennington County ocher, kaolin, and the associated ores are known to occur in Dorset, Sunderland, Manchester, Shaftsbury, Bennington, and Pownal.

The Dorset ocher has not been seen by the writer either in place or in hand specimens, but the Bennington miners report that a bed lies under the drift at the foot of the mountain east of the village of North Dorset.

The Sunderland and Manchester deposit lies on the east side of Lye Brook, between it and the base of the Green Mountain range. This ocher contains nodular iron ore and is cut by narrow manganese-bearing veins.

An almost continuous series of deposits of iron ore, ocher, and kaolin extends along Furnace Brook from the southeastern part of Shaftsbury through the eastern part of Bennington (Fig. 8). The kaolin of this deposit has been described by the writer.[1] The contact between the ocher and the kaolin is a vertical or steeply eastward pitching one. Throughout the deposit the ocher lies on the western side of the kaolin. The two are separated by a fairly sharp line, but close to the contact stringers of each are found in the other. The kaolin lies in part on the Cambrian quartzite, and in part on the pre-Cambrian gneisses. The ocher, in all determinable cases, lies on either the quartzite, limestone, or iron ore. These general relationships are shown in figure 9. The continuity of both the ocher and kaolin beds, and the relationships of them to the bed rock, are more regular here than in the deposits farther north.

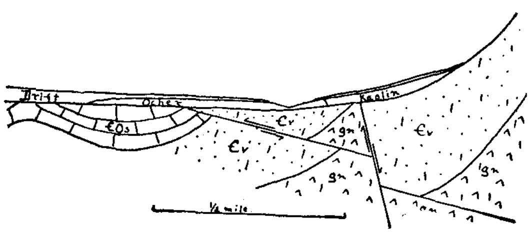

FIG. 9. Cross section of the Rockwood ocher and the Vermont Kaolin Co. deposits 1 mile northeast of Bennington; gn, pre-Cambrian gneisses; Cv, Vermont formation; COs, Stockbridge limestone.

The ocher is horizontal and contains pebbles of decomposed quartzite, feldspar, gneiss, and vein quartz in the order of abundance named. The sand mixed with the ocher consists dominately of quartz with some limonite and mica grains and occasional small hornblende, tourmaline, and garnet fragments. Much of the quartz presents fresh, clear surfaces, but some of is it frosted. Hollow limonite concretions like those of the

[1] Burt, Frederick A., *op. cit.*, pp. 75-77.

Brandon deposit are common in both the ocher and the iron ore. Psilomelane and pyrolusite concretions are common in pockets and as scattered nodules. Veins and pockets of manganese ore occur in the iron ore and the ocher, and these contain some concretionary and botryoidal braunite in addition to the oxides.

The Bennington ocher beds are more nearly continuous over large areas and the quality of color, iron content, and textural characters more even than elsewhere in the state. The ferric iron content of material 6 feet below the top of the main bed near the southern end of the Furnace Brook deposit is 7.6 percent.[1] Physical and mineralogical properties of the Rockwood and Lyons ochers were given in Table IV.

Two miles southeast of Bennington, on the Woodford line, at an elevation of between 1,300 and 1,400 feet, lies the kaolin deposit of the Green Mountain Kaolin Company. The kaolin is bounded on the west and northwest by yellow ocher. This ocher lies higher up the mountain side than any other deposits except those at Monkton.

In the extreme western part of the town iron ore was formerly taken from the Burden beds. These beds are extensive turgite deposits which, judged from their surface relations, lie on the contact of Stockbridge limestone with Vermont quartzite inliers. The surrounding beds of the quartzite inliers are highly ferruginous. Considerable ocher and umber are associated with the ore.

No ocher is known in Pownal, but both kaolin and iron ore are found. The ore is hematite and turgite and contains remarkably little clay and manganese. An analysis of the ore is given in Table V.

ORIGIN OF THE OCHER

The constant association of ocher with kaolin and iron-manganese ores, and the fact that the ocher is itself simply a sandy kaolin impregnated with highly disseminated or colloidal iron and manganese oxides makes it necessary to seek its origin along three lines of investigation. First, what was the source of the kaolin? Second, what was the source of the iron and manganese? Third, what factors have controlled the amount of iron and manganese deposited at different places, thus differentiating the various parts of the residual-formation as ore, ocher, and kaolin?

THE ORIGIN OF THE KAOLIN

The origin of the kaolin in Bennington County has been discussed by the writer[2] whose conclusions contain four essential

[1] Analysis by Hewitt Wilson, U. S. Bureau of Mines.
[2] Burt, Frederick A., *op. cit.*, pp. 80-83.

points: (1) It is a residual deposit. (2) It was developed by normal surface weathering processes. (3) Its parent rocks were the pre-Cambrian gneisses and the Cambrian quartzite. (4) It is wholly of Tertiary, and at least partly of Miocene, age.

The explanation of the Bennington kaolins appears to hold in a general way for all the kaolins of western Vermont, but there are a few places where minor modifications of the view are essential. At Monkton the kaolin is interstratified with the quartzite beds. This does not exclude the interpretation of it as a residual decomposition product from the quartzite, but it does require subterranean weathering to shallow depths along lines of easy ground water movement. The conditions at Monkton also allow the kaolin development to have occurred at any time between the Cretaceous peneplanation and the Pleistocene glaciation.

Another condition similar to that at Monkton is found at Cheshire, Massachusetts, about 30 miles south of the Vermont state line. This has been mentioned briefly by Dana[1] and Burt.[2]

An occurrence of uncertain type has been described by Penrose[3] as having been found by him at South Wallingford about 40 years ago when the mining shafts into the manganese ore were open to observation. According to Penrose (Fig. 4) the clay bearing the manganese ore occurs as a vertical bed between the limestone and the quartzite. Although there are now exposures in South Wallingford where the surface of the ocher can be reached and studied the old mine shafts are abandoned and the manganese bed described can no longer be seen, and it is not clear from Penrose's description whether the ore is a bedded deposit or a mechanically filled vein.

THE SOURCE OF THE IRON AND THE MANGANESE

The iron and manganese ores associated with the ocher are generally unconsolidated masses of hematite, turgite, and limonite boulders, nodules, and concretionary matter in beds or pockets, together with beds, pockets, veins, and concretionary masses of pyrolusite, psilomelane, and braunite. To the eastward in the Green Mountains are the so-called "mountain ores" which consist of magnetite, specular ore, red hematite, and manganese minerals in gneiss and quartzite. These "mountain ores" are reported from Warren, Rochester, Bethel, Stockbridge, Plymouth, Stamford, and other mountain townships. Thin sections of these gneisses show an abundance of hornblende and biotite with smaller

[1] Dana, James D., Manual of Geology, 4th Ed., 1894, p. 134.
[2] Burt, Frederick A., *op., cit.*, p. 81.
[3] Penrose, R. A. F., The Manganese Deposits of Vermont, Ann. Rpt. Geol. Surv. Arkansas for 1890, Vol. I, pp. 391-399.

amounts of epidote and magnetite, and some garnet, tourmaline, and ferruginous rutile. Of these iron-bearing minerals magnetite, garnet, tourmaline, and rutile occur in the kaolin and ocher as conspicuous accessories. Epidote also is found in the ochers but its quantity seems smaller than might be expected were it all preserved in the decomposition of the gneisses. Biotite and hornblende are very rare as ocher and kaolin minerals and must have been katamorphosed in enormous quantities in the decomposition of the gneisses. These facts indicate an available source of iron in the pre-Cambrian gneisses which presumably deeply underlie the ocher area, and which are known to outcrop east of the fault zone along which the ocher lies.

The Vermont formation carries an abundance of iron distributed throughout it as disseminated hematite. This hematite, together with manganese in small amounts, is responsible for colors ranging from light-pink tinges through reddish brown to purplish brown. Pyrite is also abundant in some horizons. Both the hematite and pyrite appear more abundant in the lower horizons. Iron-free, white, sugary quartzite also occurs in some abundance. Particularly along the lower horizons the quartzite is deeply stained with iron weathered from it and redeposited on the surface. Pyrite and hematite veins are rare but occasionally found. All spring and river water from the quartzite area carries iron.

Another possible source of iron is the Stockbridge limestone which is in some places ferruginous. Dale[1] states that limonite to the south in Berkshire County, Massachusetts is partly between the Stockbridge and the Berkshire formations. In this position the iron may have been derived from either of these formations, or it may have been carried upward along the contacts from the older formations of the area. Iron and manganese are much less evident in the limestone than in the quartzite.

Nearly all the iron which occurs in the limestone has been secondarily infiltered and was probably carried into the limestone either contemporaneously with the development of the ore or during Pleistocene interglacial and post-glacial weathering. This is evident both from the localized character of the ferruginous portion in the vicinity of the ores and the ocher and along contacts giving freedom of ground water circulation, and also because of its occurrence within the limestone as veins, grain coatings, and pore fillings rather than as clastic, included, or concretionary material. A very small portion of the iron is present as included matter within the dolomite crystals.

[1] Dale, T. Nelson, Note on the Geological Relations of the Brandon Lignite Deposit, 4th Rpt., Vt. State Geol., 1903-04, p. 163.

DIFFERENTIATION OF THE BRANDON INTO FERRUGINOUS AND NON-FERRUGINOUS PHASES

Two working hypotheses may be formulated to account for the differentiation of the kaolin and the ocher. The first of these supposes the ocher to have been formed by solution of iron from the iron ore, or older formations, and deposition of the dissolved iron in a part of the kaolin. According to this view the ocher is younger than the kaolin and the view may be designated as the epigenetic hypothesis. The second hypothesis regards the ocher, kaolin, sand, and ore as having originated independently but simultaneously by decomposition of different phases of the quartzite and the gneisses. This may be called the syngenetic hypothesis.

The epigenetic hypothesis is suggested by conditions in the southern part of the state where the ocher and ore lie either below the kaolin and sands or to the west of them. In both of the cases the kaolin lies on the quartzite-gneiss side of the Green Mountain overthrust while the ocher lies either on the iron ore, on the Stockbridge formation, or on an undeterminable base which from the surface relations would reasonably be inferred to be the limestone or dolomite. Throughout the ocher belt there is no essential difference, other than the presence or absence of iron and manganese, between the chemical, mineralogical, and textural characteristics of the ocher and the kaolin. In Bennington County there are no important topographic or physiographic distinctions between the occurrence of the two except that the ocher always lies farther down the slope of the mountains and farther west than the kaolin. Because of these conditions the genetic distinction between the iron-bearing and the non-iron-bearing phases of the residual-formation was sought in the structural and petrographic relations of the two to the bed rock. The bed rock relations as outlined seemed to furnish sufficient basis for explaining the distinction between the ocherized kaolin and the non-ocherized kaolin as due to precipitation by ground water of iron in that part of the deposit in contact with the interbedded series of the Stockbridge formation. Such percipitation would have been due to reactions between the deep iron-bearing waters rising along joints and fault planes and the water of the limestone.

The syngenetic hypothesis was substituted for the epigenetic as a necessity in explaining field conditions encountered in some parts of Rutland County. At Brandon and east of Rutland ocher is found on the quartzite, and at Brandon some of the westernmost deposits of kaolin are farther from the mountain range than the ocher and probably rest on the interbedded series or the limestone formation. In parts of Brandon and at South Wallingford ocher is separated from the limestone by kaolin, the reverse of the condition at Bennington. With the accumulation of evidence in the northern parts of the ocher area it becomes increasingly evident that the bed rock relations so clearly marked in southern and central Bennington County, where the overthrust from the east is large and the quartzite highly tilted, but for the most part not intricately folded, do not hold from Dorset northward where the thrust of the fault is of less amount and complex folding of the quartzite is more common. The question is therefore raised: Is the essential factor in the differentiation of kaolin and ocher areas to be found in their relation to the amount of overthrust and the intensity of the folding of the formations of the Green Mountain range rather than in their relations to the bed rock on which they rest? From Dorset northward the shortening produced by the early Paleozoic compressional forces has been more largely accomplished by crumpling of the Green Mountain beds and less by the overriding of a thrust than farther south. Much of the rock from Dorest northward is brecciated and schistose and offers ample means for ground water circulation. Certain beds and parts of horizons of the quartzite are very rich in iron and parts are nearly iron free. Quartz veins are in many places extensively developed in both the quartzite and the gneiss, and arkose, schist, and gneiss form an important part of the pre-Cambrian and Cambrian formations.

The solution of iron is at present the most conspicuous phase of surface weathering in the vicinity of the kaolin and ocher deposits. This has probably been the case throughout the short, cool post-glacial epoch and the interglacial stages of the Pleistocene. The present day extensive leeching of iron is attested by the chemical analyses of the waters of the area, by the almost universal presence of collodial iron scums on the more stagnant surface waters, and by the leeched character and staining of the exposed quartzite beds. The type of weathering most conducive to the production of kaolins and ochers from the sort of rocks exposed in this area is desilication. This was probably the type of weathering most effective in the mild Oligocene and Miocene climates of New England. The effect of this desilication would have been a Tertiary lateritization of the gneisses and quartzites to kaolin, quartz sand, ocher, and low-grade ore. The particular end-product produced at any one place would have been determined by the type of rock decomposing at that place. This in turn would have been the result of the conditions of the earlier deformation.

The epigenetic hypothesis could be applied to account for the differentiation of the iron-bearing and non-iron-bearing portions of the Brandon in southern Vermont, but it will not account for the differentiation found in the central and northern parts of the state. The syngenetic hypothesis, however, is workable in both the southern and northern parts of the state.

According to the writer's theory the ocher and the ore are the result of desilication and lateritization of the highly tilted and folded ferruginous phases of the bed rocks, while the kaolin was produced from the feldspathic and arkosic phases and the sands from the siliceous phases and the quartz complexes. This is the only theory which fits the field requirements of non-stratified masses of these four decomposition products promiscuously intermingled in domes, irregular pockets, lenses, branching veins, and steeply-pitching chutes. The more complex and intricate the original folding was the more pockety would be the deposits of the residual decomposition products. The ores, ochers, kaolins, and sands never lie on the Stockbridge formation except to the west of marked overthrusts or overturned folds. They have thus evidently been developed above the limestone only where the overthrusting forces have carried the parent rocks onto the Stockbridge (Fig. 9).

METHOD OF PRESERVATION FROM GLACIAL EROSION

A few words are necessary in regard to the preservation of these unconsolidated deposits from glacial erosion. All of these decomposition products are overlaid by glacial drift or by talus. The drift is generally thin, varying from 10 to 30 feet in thickness. Attention is again called to the fact that the deposits lie in the Vermont Valley between the Green Mountain range on the east and the Taconic Mountains on the west. The valley is narrow and deep throughout. The breadth of its bottom near Lake Dunmore, north of Brandon, is about 8 miles, and its depth is 200 feet on the west and 900 feet on the east side. The upper parts of the valley wall on the east are very precipitous. The breadth of the floor just south of Rutland is about 1½ miles, and the top 3½ miles. The depth here is about 1,000 feet on the west and 1,500 feet on the east side. From Wallingford southward to Shaftsbury the valley becomes even more canyon-like. At the southern end of the state, in the town of Pownal, the valley comes to a canoe-end terminus by the convergence of the Green Mountain and Taconic ranges. There is thus formed a deep, narrow trough, extending for a distance of about 65 miles from Vergennes and Bristol on the north to Pownal on the south. This trough trends at angles varying from 20 to 45 degrees to the direction of movement of the ice sheet. Moreover the exit end of the valley is fairly effectively blocked by the convergence of the two mountain systems. In such a valley ice work must have been sluggish and erosional work minimized. This is attested to by the piles of talus material along the valley sides, scarcity of glacial striae on the rocks of the valley bottom, and numerous exposures of weak, brecciated, but ungouged bed rock. The tops of both mountain ranges, in contrast to this, exhibit an abundance of evidences of glacial denudation.

North of Addison County the Green Mountain range is composed of rocks as suited to the production of sands, kaolins, ochers and iron ores as farther south, but the Taconic mountains on the west give way to open plains extending across the Champlain Valley to the Adirondacks of New York. These plains are broken only by the low, scattered red rock hills which must have afforded but little protection against the ice. In this region the ocher and its allied deposits are almost entirely lacking, their only certainly-known occurrence is in the Colchester iron ore. It would seem, therefore, that these Tertiary decomposition products are present only where preserved against glacial erosion by the presence of the Taconic Mountains as a bulwark.

ECONOMIC CONSIDERATIONS

The possibilities of future development of ocher in western Vermont are limited by two factors, one economic and one geologic. The first of these is the linear arrangement of the deposits, necessitating the scattering of any ocher industry over a wide area rather than centralizing it. The second is the occurrence of the ocher in pockets, the extent and character of which cannot be determined, even in a general way, except by subsurface exploration.

From the economic standpoint the most favorable sections of the ocher area for development are those around Bennington, South Wallingford, and Brandon. In these sections the quantity of ocher is large, the quality is good, water for treatment plants is at hand, and the deposits are adjacent to good highways leading to shipping centers.

In the Bennington area the ocher is in large deposits fairly well differentiated from the kaolin and ores. The deposits are more nearly continuous than elsewhere in the state. The quantity of sand associated with the ocher is not excessive, and along the Furnace Brook area abundant water is present for washing. Red and yellow ochers and umber are all present and the color quality of each averages well.

The quantity of ocher at South Wallingford, so far as exposures indicate, is large and the quality high. Based on observations made by Penrose[1] and Jones[2] at earlier dates when the manganese mines were operating the deposits are probably more

[1] Penrose, R. A. F., *op. cit.*
[2] Jones, Robert W., The Manganese Deposits of South Wallingford, Vermont, Eng. and Min. Jour., Vol. CV, 1918, p. 779.

nearly continuous and less pockety than at Brandon. Kaolin is also abundant and mining of kaolin and ocher in combination might prove to be profitable.

In the Brandon area the quantity is large, but the individual deposits are small and very pockety. Determination of the presence and extent of individual pockets is impossible except by subsurface exploration. It is the opinion of the writer that an attempt to work the Brandon area for ocher alone would not be profitable, but that the area might be worked profitably by a company prepared to market both the ocher and the kaolin. If such a company were equipped to separate and screen glass-, abrasive-, and moulding-sands and market them it is possible that a considerable mining industry might be developed.

The close association of the Brandon residual-formation with the main physiographic and structural features of the area makes easy the work of prospecting for its presence. Such prospecting should be confined to the western base and lower slopes of the Green Mountain range where it is closely paralleled by the Taconic range. Furthermore the productive area is limited to the vicinities of outcroppings of pre-Cambrian gneisses and Vermont quartzite. Where the Green Mountain overthrust is large the materials may be expected to have considerable areal extent and thickness, unless there is evidence of much glacial or river erosion. In areas of small overthrust the areal extent of the deposits will most certainly be small.

The degree of folding and crumpling of the pre-Cambrian and lower Cambrian rocks will, to a considerable extent, determine whether the various members of the residual-formation will be well separated or occur together as a series of pockets, lenses, and chutes within one another. These conditions are dependent to some extent on the degree of homogeneity of the parts of the formations which have been weathered away, but as these formations vary much in detail from place to place the condition of their remaining portions cannot be depended upon to furnish a reliable key to the condition of the portions which have been removed by weathering.

In places seepages of ground water covered with colloidal iron scums are frequent above the ocher beds. This condition is constant along the whole ocher belt. The scums have a very oily appearance, are highly irridescent, and so far as the writer has observed, are limited to areas underlaid by ocher or iron ore.

A high percentage of the glacial drift of the Vermont Valley is porous and allows free, natural subsurface drainage. Where ocher and kaolin beds are extensive, and near the surface, swampy conditions exist. In consequence of this fact swamps,

especially if close to the base of the Green Mountains, usually indicate kaolin or ocher below.

Next to Bennington and Brandon the townships of Monkton, Bristol, Wallingford, Manchester and Sunderland probably afford the best prospecting ground for all types of the materials of the Brandon residual-formation. Shaftsbury too should afford worthwhile prospecting but was omitted from the above list of townships as the Shaftsbury deposits are the northward continuation of those of Bennington, and are connected with them and similar to them in all essential respects.

SUMMARY

In summarizing the data recorded and the conclusions deduced the following points stand out as fairly established facts:

An elongated, narrow belt of mixed kaolins, ochers, sands, and low-grade nodular iron ore extends along the western base and lower slopes of the Green Mountains from near Bristol southward to the Vermont-Massachusetts line. The length of this belt is about 90 miles. In width it varies from zero, at places where erosion has completely pinched it out, to about 2 miles.

These materials are the results of rock decay during the Tertiary period. The parent rocks were the pre-Cambrian gneisses of the Green Mountain range and the Vermont quartzite.

The products of decay are residual. The former westward extent of the Green Mountain gneisses and Vermont quartzites across the area now occupied by their residual deposits is very evident from their present structural relations.

The residual products are cut by veins of iron and manganese ores. At Brandon lignites are found in pockets within these products of decomposition.

The area underlaid by mixed ochers, kaolin, sands, and ores can be determined with a fair degree of accuracy by a study of physiographic and structural features.The exact location, extent, thickness, and depth of individual deposits of each of these products can be determined only by drilling at closely-spaced intervals.

In many essential respects the ocher deposits of Vermont, Pennsylvania, and Georgia are similar, and a knowledge of the geologic relations of the ochers of any one of these states will be valuable in the study of those of any other.

In several parts of the ocher area kaolin can be mined profitably by itself. The other materials under consideration probably cannot be developed profitably, unless possibly the ocher near Bennington, except in conjunction with one another.

BIBLIOGRAPHY

Very little has been written concerning Vermont ochers, in fact the whole subject of the geology of ocher seems to be one with a relatively scant literature. Many of the most important works dealing with the geology of ocher have been referred to from time to time in the footnotes to the text of this paper. Those discussing ocher in general, or which contain material bearing directly on the Vermont ocher problem, are here listed separately for the convenience of those interested in the subject.

1. First Annual Report of the Vermont State Geologist, C. B. Adams, 1845. Numerous references to the ocher and its association with clays and ores.

2. The Manganese Deposits of Vermont, R. A. F. Penrose. Annual Report of the Geological Survey of Arkansas for 1890, Vol. I, pp. 391 to 399. References to the relations of manganese ore to the ocher, iron ore, and bed rock.

3. Cambro-Silurian Limonite Ores of Pennsylvania, T. C. Hopkins. Bulletin of the Geological Society of America, Vol. XI, 1900, pp. 475 to 502. Discussion of some Pennsylvania ochers and paint ores which are similar in their occurrence to those of Vermont.

4. The Ocher Deposits of Georgia, Thomas L. Watson. Geological Survey of Georgia, Bul. 13, 1906. A discussion of some Georgia ochers which are similar in their geologic relations to those of Vermont.

5. Ocher Deposits of Eastern Pennsylvania, J. C. Stoddard and A. C. Callen. United States Geological Survey Bulletin 430, 1909, pp. 424 to 439. A discussion of the subject indicated.

6. The Mineral Pigments of Pennsylvania, B. L. Miller. Report of the Topographical and Geological Survey Commission of Pennsylvania, No. 4, 1911, pp. 11 to 43. A discussion of the subject indicated.

7. The Manganese Deposits of South Wallingford, Vermont, Robert W. Jones. Engineering and Mining Journal, Vol. 105, 1918, p. 779. A brief description of the South Wallingford manganese mine with a short reference to the kaolin and ocher.

8. The Origin of the Bennington Kaolins, Frederick A. Burt, 16th Report of the Vermont State Geologist, 1927-28, pp. 65 to 84. References to the ocher in its relations to the kaolin.

9. Ocher and Ochery Earths, R. M. Santmyers. United States Bureau of Mines Circular 6132, 1929. An outline of the ocher problem from the production viewpoint, with a brief description of some ocher deposits.

10. Ochers and Mineral Pigments of the Pacific Northwest, Hewitt Wilson, U. S. Bureau of Mines, Bul. 304, 1929. Contains a discussion of the methods of milling and testing ochers.

11. A report on the ochers of the United States is now in process of preparation by the U. S. Bureau of Mines. The work is under the direction of Hewitt Wilson and will contain a discussion of ochers in general and of some particular areas throughout the country. A short section on Vermont ochers by Doctor Wilson and the writer of this paper will be included.

MOUNT MONADNOCK, VERMONT—A SYENITE HILL[1]

JOHN E. WOLFF

ABSTRACT

Mount Monadnock, Vermont (circa 3,200 feet), is the northernmost stock of alkali-syenite known in New England and, therefore, the first in southerly continuation of eight similar "Monteregian Hills" of Canada—in all nineteen such hills or mountains are marked on Figure 11, extending from Montreal to Mount Agamenticus in Maine, 215 miles. Monadnock is a stock of quartz-nordmarkite, with an interior, older mass of essexite and with associated bostonite and camptonite dikes intrusive into schists and quartzites of the upper Connecticut Valley, probably of Lower Paleozoic age—the igneous rock much later, possibly Carboniferous. Description of the minerals and rocks follow, including analyses of the hornblende syenite and essexite; an original topographic and geologic map and views of the mountain. Attention is called to the consanguinity shown by the minerals and their combinations in the rocks, with those of the other hills.

FIG. 10. Mount Monadnock, Vt., from hill 1500, 5 miles east. Colebrook, N. H., in foreground; Connecticut River at east base; amphitheater and gorge of Mountain Brook right center; gorge of Willard Stream extreme right; Essexite bench on the line, two-thirds down south slope of mountain (left).

[1] This article on the geology of one of the less known mountains of Vermont is republished in this volume with the courteous permission of the author and of Mr. J. G. Laing, editor of the *Journal of Geology*, in which it was first published (January-February, 1929).

INTRODUCTION

There occur in New England and the Province of Quebec a number of isolated hills or mountains formed by massive intrusions of alkaline igneous rocks and associated dikes. In 1903 F. D. Adams applied the name "Monteregian Hills" to the eight

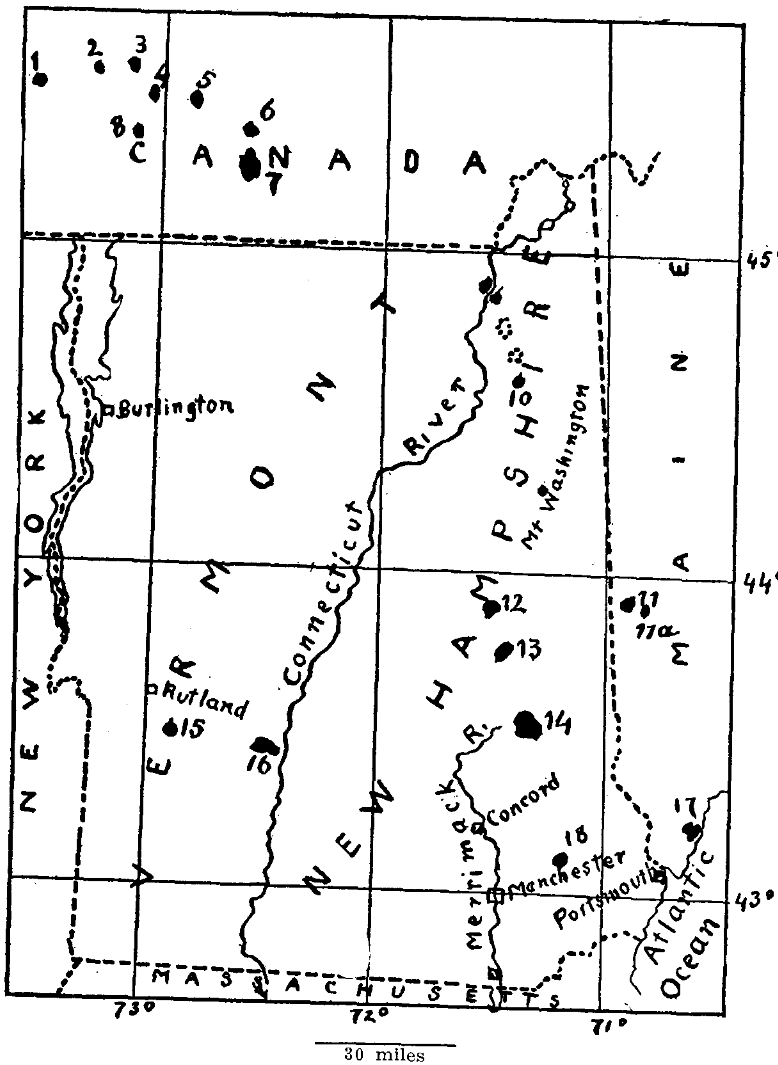

FIG. 11. Syenite Hills of Canada and New England.

occurring in Canada (Mount Royal, above Montreal, the beginning of the chain), while in 1906 Pirsson and Washington suggested "Novanglian Petrographic Province" for those in New England.

The New England list includes, from north to south (see Figure 11):

9. Mount Monadnock.
10. Devils Slide, Stark, N. H.
11 and 11*a*. Burnt Meadow and Pleasant Mountains, south of Fryeburg, Maine (studied by E. S. C. Smith, but not yet described).
12. Tripyramid Mountain, New Hampshire (4).
13. Red Hill, New Hampshire (5).
14. Belknap Mountains, New Hampshire (2).
15. Granite Mountain, Cuttingsville, Vermont (6).
16. Mount Ascutney, Windsor, Vermont (7).
17. Mount Agamenticus, Maine (8).
18. Pawtuckaway Mountains, New Hampshire (9).

The eroded mass of alkaline rocks in Essex County, Massachusetts, in Quincy, Massachusetts, and in other areas in New England and beyond belong in the province but are beyond the narrow limits of this paper. Others may be found in unexplored areas of New England—in fact, J. H. Huntington (3) mentions several syenite mountains in New Hampshire on a line running S. 20° E. from Monadnock and contained in the ranges of mountains bounding the Connecticut Valley on the east: Sugar Loaf, 11 miles distant; Percy Peaks, 17 miles; and Devil's Slide and Mill Mountain, 21 miles. The rock from Devil's Slide is similar to the Monadnock syenite. Also nephelite and alkali syenites are found in a small area in Vermont on the east side of the Green Mountains and 78 miles southwest of Monadnock (10).

The largest in ground area is Brome Mountain (see Figure 11, No. 7), 30 square miles; next, the Belknap Mountains (No. 14); the smallest, Mount Johnson (No. 8). The distance from Mount Royal (No. 1) to Agamenticus (No. 17) is about 215 miles. In Canada, six of the eight hills can be connected by a curved line (Mount Royal to Shefford [No. 6]); while the other two would lie on a parallel line, suggesting possible lines of weakness or breaks in the earth's crust (Adams). For the New England Hills, several possible linear arrangements might be imagined, but only one seems definitely suggestive (Nos. 12-18), which lie on a straight line 58 miles long. The form of the intrusions varies from stocks of varying regularity, laccoliths, and one neck (Mount Johnson, No. 8). There are two dominant rocks for the whole chain; alkali-syenite of various types; and essexite, with satellitic dikes and sills. In several of the Canadian hills, nephelite, solalite, aegirite, and alkalite hornblendes are found; but in New England the highly sodic minerals are found only at Red Hill and Cuttingsville (Nos. 13 and 15). The syenite has often several facies in one stock; but in general, in any one area the number of distinct types is small, Ascutney having the greatest number.

MOUNT MONADNOCK, VERMONT

The mountain was named by early settlers after its better-known namesake, Mount Monadnock, of physiographic fame, in New Hampshire. It lies on the west bank of the Connecticut River 30 miles below the river's head at the Fourth Connecticut Lake at the Quebec boundary, but only 7 miles from the boundary on the Vermont side of the river; mainly in the township of Lemington, Vermont, and opposite Colebrook, New Hampshire, on the eastern bank. The river washes the steep east slope of the mountain and has probably cut its valley through the syenite, but covered the bed rock with alluvial filling, thus isolations, on the surface, the small area in Colebrook and Columbia in New Hampshire from the main mass in Vermont. The river at the base is 1,000 feet above the tide and the summit about 3,200 feet. Three tributaries here join the river from the west: Willard Stream on the north has cut a deep gorge through the syenite, a smaller stream, Mountain Brook, heads in a great hollow in the center of the syenite; and a larger stream, Mill Brook, flows past the south end. On the New Hampshire side, Sims Stream cuts a wide gorge through the syenite before entering the Connecticut.

The mountain (Figure 10) has the typical form of these solid syenite masses, namely, a broad truncated cone with oval base, many subordinate spurs and, in this case, steep or precipitous slopes facing the river. A prominent rock bench, essexite, occurs on the southeastern spur 800 feet above the base, see figure and map. The ground plan is oval 3.6 miles north-south and 3 miles east-west, area 11 square miles, of which igneous rocks occupy 4.9 miles plus 0.5 mile in New Hampshire totalling 5.4 square miles. A rough estimate of the volume of igneous rock now exposed is 0.88 cubic miles, original volume 2.0 miles eroded 57 percent. There is no topographic map known to the writer, so the map (Figure 12) was hastily prepared by plane table and sketching, the bridges over the river and some other well-marked points on the New Hampshire map being used as starting points; hence the author makes no claim to great accuracy. The geology also has not been noticed, except that Huntington mentions the area in connection with the syenite of Colebrook and Columbia (3) and that the whole area is accurately marked on the accompanying atlas of New Hampshire.

The country rock is mica schist, passing in places, especially near the north and west contacts, into a micaceous quartzite. The

strike of the foliation and stratification is nearly north, and the dip east, 45-15; but at the extreme north end the quartzite is nearly horizontal, suggesting an anticlinal fold, and the apophyses of the syenite penetrate the country rock in irregular sills parallel to the stratification.

At the only actual contact found, on the west face of the mountain, the line conforms roughly to the steep east dipping

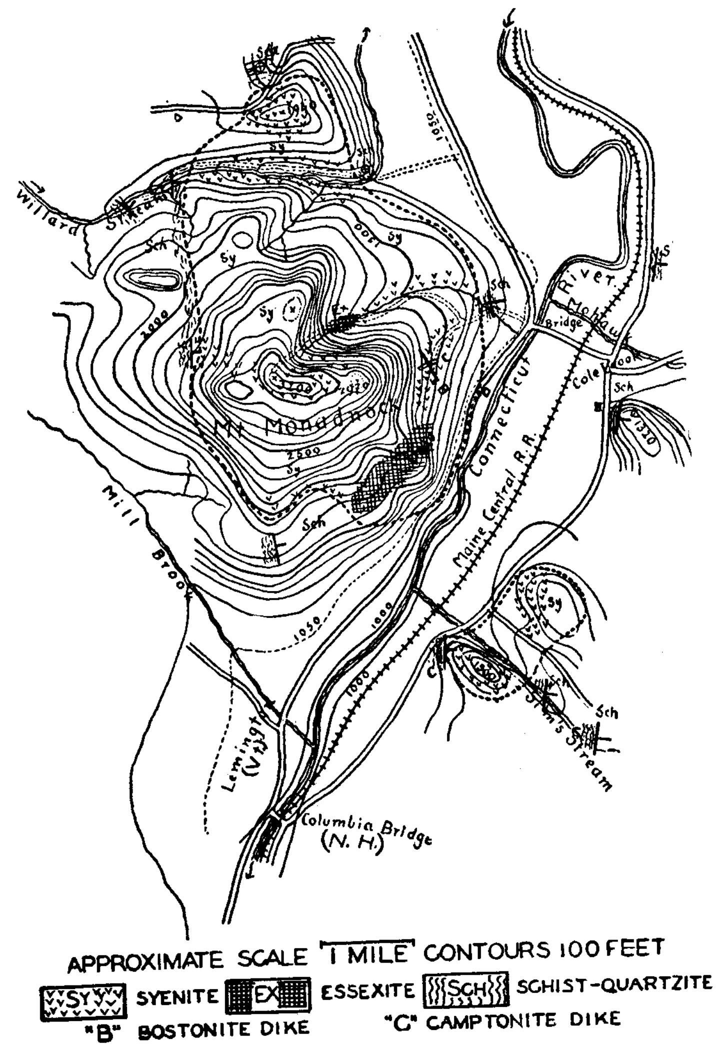

Fig. 12. Mount Monadnock, Vt.

stratification of the country rock, and in the gorges of Willard Stream and Mountain Brook, on both east and west sides the same attitude is indicated, although contacts are covered. In general there is no marked disturbance of the enclosing schists near the intrusion, the longer axis of which trends slightly west of the regional strike; so apparently, the strike crosscuts the strike on the south, nearly uniform to dip on east and west sides, and against crosscuts at the north. Xenoliths of the schists are common in the syenite (stoping). The small area in Colebrook and Columbia, New Hampshire, shows no actual contact with the schist-quartzite, but the latter dips east on both sides of the syenite, suggesting the same combination of crosscutting and parallelism.

Distribution of the Igneous Rocks.—The main rock is an alkali-syenite between quartz-nordmarkite and granite (69 percent SiO_2, 10 percent alkalies)—a massive medium-grained gray rock without pronounced jointing, composed of microperthite, albite, quartz, biotite, hornblende, and accessories, with frequent variations in the proportions of the last three, which the field work could not relate to position in stock or contacts. Exactly in the center of the syenite and 1,400 feet below its highest point at the summit, an area of essexite is exposed in the bed of Mountain Brook for a hundred yards or so cut by tongues of syenite and camptonite dikes, but the exact extension laterally and vertically is concealed. A much larger exposed area of essexite occurs along the southwest side of the mountain, forming a prominent bench, which continues northeast for a mile, then cut off by syenite; the essexite forms cliffs extending down several hundred feet until covered by talus, the highest point on the bench 800 feet above the river, topped by syenite; this is the same topographic level as the smaller exposed area in the brook bed, the connecting line about parallel with the longer axis of the igneous area, so that they are probably parts of one interior mass of essexite surrounded and topped by syenite. This interior position of an older essexite mass is common in these syenite hills. The rock itself is dark, coarse grained, composed of large prismoids of hornblende and augite, biotite, labradorite and accessories.

The few dike rocks are described below.

PETROGRAPHY

THE MINERALS

Hornblende.—In the typical fresh syenite from the Norton mine, prisms of a lustrous black hornblende, 3 mm. long at most, are common and were selected for chemical and optical analysis.

The Leitz universal stage was used for the measurements of $_2V$, extinctions, birefrigence and pleochroism, using the methods

and precautions prescribed by Berek (11), supplemented by Berek compensator, Wright eyepiece, and eyepiece dichroscope, etc. Indices by immersion.

Indices:
$\gamma = 1.713$ $\gamma - \alpha = 0.020$.
$\beta = 1.711$
$\alpha = 1.693$ $\acute{c}:\gamma = 20°\text{-}21°$
$_2V$ measured and reduced $43\frac{1}{2}°$ (—). Computed from indices $44\frac{1}{2}$

Pleochroism:
γ = deep grass green.
β = deep olive green
α = light yellow

Analyses of similar amphiboles and tabulation of their optical properties are added for comparison—Tables I and II, the former including some from outside regions; the latter, with one exception (Idaho), from the alkaline rocks of the Monteregian and New England provinces. It is seen that the complete optical properties are rarely given (at least in publications at hand), and apparently in no case was the Universal stage used for accurate orientation of the side pinacoid ($\gamma:\acute{c}$); but even then the chemical and optical similarity is evident, and illustrates the peculiar position of amphibole as a test for consanguinity.

In other parts of the Monadnock syenite and New Hampshire extension, the optical properties are in general similar ($\gamma:\acute{c} = 19°\text{-}22°$), pleochroism tending to more greenish-brown tints, only that from the Devil's Slide has the same deep green yellow, but here $\gamma:\acute{c}$ is 12° and $_2V = 70°$, and in general $_2V$ is larger than in the type specimen (58°-70°), indicating a change in the composition and, therefore, in the indices; but how much of this may be due to conditions in the magma or to paramorphism due to weathering is uncertain. The essexite amphibole has $\gamma:\acute{c} = 12°$; $_2V = 70°$ (—); $\gamma - \alpha = 0.023$; γ and β = deep chestnut brown, α = lighter, yellowish brown.

The Cuttingsville, Vermont, hill, 120 miles southwest, well described by J. W. Eggleston (6) has nordmarkite and essexite facies similar to Monadnock and corresponding amphibole (see Table I). From material kindly furnished by Doctor Eggleston, the optical constants have been amplified by the newer methods. The complex character of the amphiboles is shown in Table I.

NOTE.—In the original article in the *Journal of Geology*, Doctor Wolff presents a table showing optical characteristics of the amphiboles, but this table is omitted here. Those wishing to examine the table are referred to the *Journal of Geology*, January-February, 1929.

In the syenite, the crystals have a deep green exterior, transitional to a brown-yellow interior; in the former $_2V$ is 42°, in the latter 61°, with indices close to those of the green crystals of Monadnock. In the essexite the indices are lower, and $_2V = 72$,

TABLE I

Analyses of Amphiboles*

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
SiO_2	38.72	38.50	38.04	35.65	45.4	34.18	38.63	38.41	35.42	37.49	36.86	37.40
TiO_2	5.03	tr	1.06	7.09	4.0	1.52	5.03	1.26	1.34	0.86	1.04	3.20
Al_2O_3	10.94	10.88	13.50	11.94	...	11.52	11.97	16.39	8.89	10.81	12.10	12.34
Fe_2O_3	4.33	6.70	6.21	5.92	16.8	12.62	3.90	3.75	9.73	7.52	7.41	4.16
FeO	26.03	27.28	15.85	12.04	22.0	21.98	11.52	21.75	24.48	25.14	23.35	25.84
MnO	0.88	tr	1.21	0.10	...	....	0.73	0.15	1.17	0.95	0.77	1.24
CaO	8.55	11.30	12.42	11.21	4.2	9.87	12.81	10.52	6.93	9.77	10.59	9.72
MgO	2.19	1.40	7.26	11.01	0.6	1.35	10.20	2.54	0.17	1.34	1.90	2.20
K_2O	1.25	1.66	1.68	0.99	...	....	1.49	1.95	3.23	1.91	1.20	1.36
Na_2O	1.39	1.22	3.21	2.33	6.7	3.29	3.14	2.95	5.13	2.06	3.20	1.80
H_2O+	1.22	1.27	0.48	....	...	....	0.33	0.24	3.15	2.01	0.60	0.00
H_2O-	....	....	....	NiO 0.04 SrO 0.01	...	Rest 3.26	....	....	....	....	0.70	0.69
	100.53	100.16	100.92	99.59	99.7	99.59	99.76	99.96	99.64	99.86	99.72	99.86
Sp. Gr.	3.422	....	3.518	....	...	....	....	....	....	....	....	3.375

*I, Monadnock, Vt.; II, iron amphibole from Idaho, E. V. Shannon (13); III, from syenite, Cuttingsville, Vt., C. D. Test (6); IV, from essexite of Mount Royal, J. B. Robertson (14); V, riebeckite in paisanite, Red Hill, N. H., Pirrson and Washington (5); VI, hastingsite, Harrington (15); VII, Mount Johnson, Quebec, N. Evans (1); VIII, barkevitic hornblende, sodalite-syenite, Square Butte, L. V. Pirrson (16); IX, alkali iron amphibole from umptekite, F. E. Wright (17); X, hastingsite (umptekite), Almunge, Sweden (18); XI, hudsonite, Cornwall, N. Y., Nelson and Daniells (19); XII, ferrohastingsite from nordmarkite, Jackson, N. H., W. H. Herdsman (12).

with pure brown-yellow pleochroism. Since these rocks are fresh, it is evident that, with both rocks, in the earlier stages the crystals represented the pure brown variety; but in the more acid syenite, the composition gradually changed to form the green.

Augite.—Rare in the syenite but abundant in the essexite. In the Devil's Slide syenite, a deep emerald green diopsidic augite is associated with the amphibole ($_2V = 65\frac{1}{2}° + \gamma{:}\acute{c} = 45°$). In the essexite, the larger augites have a faint pinkish color titanium?), $_2V$ from 52° to 63° $+ \gamma{:}\acute{c}$ — 40° — 45°, the Cuttingsville essexite has the same.

Biotite.—The biotite of the rocks has a deep brown-yellow pleochroism, reddish in the syenite, 3° extinction to cleavage, and a large axial angle, $_2E$ from 28° to 18° in different specimens, average 24° (+ or — 3°) Cuttingsville is similar.

Titanite.—In the essexite, gives $_2E = 58°$ (white light).

Feldspars.—These are described with the rocks.

THE ROCKS

Syenite.—The freshest quarried syenite was selected from the Norton mine for detailed study. It lies 500 feet above the east base of the mountain, and well in from the contact. It is a medium-grained light greenish gray rock with small black prisms or hornblende prominent. *Section:* Aside from the hornblende and scant biotite plates, the bulk of the rock is composed of quartz and feldspar. The latter is a coarse microperthite. The potash element usually a sodium-orthoclase, but sometime microcline, both giving 6°-7° on M; the albite is an albite-oligoclase (14½° perpendicular to M, An 14) the proportions of the two elements being variable. A subporphyritic texture is caused by larger crystals in a ground mass of microperthite crystals, separate albite grains and quartz. Allanite in large, rounded crystals is common; zircon, abundant, sometime associated with areas of fluorite; a little magnetite and apatite. Occasional clumps of altered allanite, inclosing secondary actinolite prisms, and surrounded by a rim of apatite, magnetite, zircon, biotite, hornblende, and augite represent segregations of the earlier formed minerals. The analysis, norm, and mode (Rosival) are given in Table II, with analyses of nordmarkites from Cuttingsville and Ascutney (further analyses from the province are given by Eggleston (6); they show a close relationship, but this rock has the highest silica and might be termed a quartz-nordmarkite, transitional to granite.

The syenite from other parts of the stock and in New Hampshire shows variations in the proportions of the minerals and have occasional augite and titanite. Biotite may be the sole mafic mineral, and hornblende and biotite may be equal or both may disappear; but no reason was found for these changes.

Essexite.—This is older than the syenite, as seen in a contact in the Mountain Brook, where it is cut by tongues of the former, with an intervening mixed zone, indicating near contemporaneity of the two rocks. It is a dark, medium-coarse, granular rock, with equal amounts of feldspar, biotite, hornblende, and augite, and visible titanite. The labradorite lathes produce an ophitic texture. *Section:* Large prisms of deep brown to yellowish hornblende, often green by paramorphism, pale-green augite with reddish core, biotite plates, and stout lathes of labradorite ($Ab^1 An^1$), with accessory titanite, apatite, titaniferous magnetite and a rare grain of quartz. Its analysis (Table II) norm and mode (Rosival) are similar to many of this type (cf. No. 4, Cuttingsville, and other tabulated by Eggleston (6).

Dikes.—A few were found in both areas, doubtless more are concealed by the forest cover.

Quartz-Bostonite.—A dense, yellowish-gray rock cuts the syenite at the Norton mine as a dike 11 feet wide. Composed of thin plates of a blotchy albite-orthoclase-mixed feldspar and a little interstitial quartz, with abundant areas of calcite, pyrite, muscovite, etc., as decomposition products, the whole rock being too decomposed for accurate study.

Aplites.—These vary in width from 11 feet down to small irregular stringers, and cut syenite, essexite, and schists. They are fine-grained white rocks, with slight content of dark minerals at most, granular or porphyritic, and represent an acid phase of the syenite with orthoclase-microperthite, and quartz as essentials, and zircon titanite, allanite, apatite, and pyrite as accessories; in one case abundant diopside with some hornblende and biotite.

Camptonite Dikes.—These are the latest igneous rocks, cutting essexite, syenite, bostonite, varying from 10 to 3 feet in width. The black, fine-grained rocks contain small phenocrysts of the dark minerals. In some the phenocrysts are biotite, and barkevitic-hornblende ($\gamma:\acute{c} = 16°$, $_2V — 70°$); in others a diopsic augite ($\gamma:\acute{c} = 44°$, $_2V = 57°$). The groundmass has a plagioclase varying from labradorite (An 50) to basic andesine or oligocene; the hornblende in acicular prisms may be associated with augite or biotite. A little quartz filling is common; also titanite, magnetite, apatite. In general the rocks are similar to the typical camptonites of Livermore Falls, New Hampshire, but like them, lack the large lustrous phenocrysts found in many camptonites.

Table II gives the chemical analysis of the rocks found in this locality.

TABLE II

Analyses of Rocks*

	1	2	3	4	5	1a		1b		2a		2b	
SiO_2	60.43	46.09	67.30	46.47	65.43	Q	16.68	Qu.	16.4	Or	11.12	Lab	35.8
Al_2O_3	15.67	17.29	17.44	16.86	16.11	C	0.20	Microp	62.0	ab	20.44	Oligo	1.4
Fe_2O_3	0.36	1.63	1.56	3.21	1.15	Z	0.10	Alb	15.6	an	25.02	Ortho	0.2
FeO	2.50	7.26	1.76	7.72	2.85	or	29.47	Ho	4.2	ne	5.96	Qu	0.2
MgO	0.12	8.04	0.14	5.16	0.40	ab	42.97	Bi	0.1	di	10.92	Bi	16.2
CaO	1.13	7.89	1.00	9.45	1.49	an	4.73	Zir	0.2	ol	13.22	Ho	16.9
Na_2O	5.11	3.68	7.08	4.20	5.00	hy	4.39	Allen	0.5	mt	2.32	Aug	16.2
K_2O	4.97	1.92	4.78	1.35	5.97	mt	0.70	Magn	0.3	il	8.51	Mag	9.3
H_2O+	0.42	0.77	0.05	0.45	0.39	il	0.50	Dec.	0.4	ap	2.02	Tit	0.2
H_2O-	0.01	0.12	0.05	0.04	0.19	ap	0.30			pr	0.24	Apat	2.7
TiO_2	0.18	4.49	0.17	2.86	0.50	pr	0.10	Allan	99.7			Pyr	0.09
ZrO_2	0.06	n.d.	0.08	....	0.11						99.77		
P_2O_5	0.06	0.90	0.04	1.15	0.13		100.04						100.9
S	0.07	0.10	....	....	0.036								
MnO	0.06	0.16	0.16	0.23	0.23								
BaO	abs	0.09	....	tr	0.03								
SrO	n.d.	tr	....	0.04	tr								
	100.11	100.43	101.61	....	....								
FeS_2	....	....	....	0.21	0.07								
Fe_7S_8	....	....	....	0.08	....								
Cr_2O_3	....	....	....	abs	....								
Li_2O	....	....	....	abs	tr								
F	....	....	....	0.10	0.08								
SO_3	....	....	....	abs	abs								
Cl	....	....	....	0.06	0.05								
CO_2	....	....	....	tr	....								
				99.64	100.18								
Sp. Gr.	....	....	....	2.919	2.659								

*1, Quartz-nordmarkite, Mount Monadnock, J. E. Wolff, 1*a*, Norm of same; Toscanose to Lassenose: I 4, (1)2, 3(4) 1*b*, Mode (Rosival).
2, Essexite, Mount Monadnock, J. E. Wolff, 2*a*, Norm; Camptonose; (II) III, 5. 3. 4. 2*b*. Mode (Rosival).
3, Nordmarkite, Cuttingsville, Vt., C. D. Test (Eggleston [6]).
4, Essexite, Cuttingsville, H. E. Merwin (Eggleston [6]).
5, Nordmarkite, Ascutney, Vt., W. F. Hillebrand (Daly [7]).

SEDIMENTS

The country rock adjacent to the syenite is a quartz-rich mica schist or micaceous quartzite, in which quartz grains predominate, with some feldspar, both orthoclase and oligoclase. Parallel plates of biotite are abundant, muscovite scant or wanting; and accessory pyrite, magnetite, apatite and titanite present. Larger, rounded grains of zircon and of feldspar, enclosed in an aggregate quartz cement, are considered clastic; otherwise a typical schist.

Contacts.—At or near the contact with the syenite, an intimate mixing of the two rocks is evident, with mineralogical changes or accessions on the schist side, especially an abundance of biotite and some grains of microperthite. The syenite has finer grain and porphyritic texture and enrichment in biotite similar optically to that in the schist. Exceptionally peculiar mineral combinations are found in the schist which may be attributed mainly to the igneous rock, although earlier regional metamorphism may contribute. In one case the banded quartzite has little biotite or muscovite, but large crystals or aggregates of a pale greenish brown amphibole (γ:ć — 17°-20°) intergrown with droplets of quartz and with a granular labradorite, also occurring in bands all forming a cement for the larger quartz grains of the rock, with other bands of garnet and the clastic zircons and other accessories of the normal schist. Again the contact rock, finely banded, is composed of oval quartz grains with anhedral grains of diopside, basic oligoclase, and titanite as a cement. At another place the banded quartzite rock is quartz free, and composed of prismoids of hornblende (identical with that of the syenite). biotite plates, anhedral crystals of orthoclase and oligoclase, titanite and magnetite.

CONCLUSION

Mount Monadnock adds one more to the series of these peculiar hills, nineteen of which are located, but not all described. Aside from the geological features as here outlined, and the chemical relations of its two principal rocks to those of the others, the further evidence of consanguinity given by a detailed study of the amphibole common in all the hills has seemed worth the space devoted to it.

The larger problems of the consanguineous rocks here and in the great area extending from Maine (Litchfield), Massachusetts, the Connecticut Triassic (Monchiquite), New Jersey (Beemerville, Brookville (Triassic), central New York and intervening territory (camptonites, bostonites, etc., here and there) and in Canada; the age of the intrusions; factors affecting their distribution, depth of their original cover, physiographic study of these "monadnocks," etc., are not discussed here, the writer believing that this should await further discovery and study.

NOTE.—As this article was ready for the press, an interesting and valuable paper on the Hastingsite group by M. P. Billings was received in which new optical and chemical data are given and subdivisions of the group based on the ratios of FeO and MgO are proposed. Figures bearing directly on this paper have been added to the tables. The amphibole of the Monadnock nordmarkite would belong to the subdivision named "ferrohastingsite."

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MINERALS OF VERMONT

G. H. PERKINS

In the Vermont Geological Report of 1927-1928 the Geologist has discussed the rocks of this State and it is his desire to consider the minerals of Vermont in much the same manner. As in the former article so in this the author has endeavored to write for the boys and girls in the high school, the farmer in the field, the business man in his store rather than for the mineralogist in his laboratory. Those of us who are especially interested in geology or mineralogy have been very glad to know that in many of the schools throughout the country nature study has become an increasingly important subject and in many cases what is called a "Project" means some phase of nature study. Many letters from pupils in schools not only in Vermont but from distant states, ask for information as to the rocks or minerals of this State. It has been especially this class of enquirers that the writer has had in mind. But such inquiries are not by any means limited to students. If the letters received are an indication, a large portion of our people are interested, as never in past times in discovering what is all about them. I wish that it were possible to state some of the many facts which the Vermont minerals present in a simpler fashion, but in many cases only more or less technical terms can be used for the very sufficient reason that no others are available. At any rate by using some of the smaller manuals of mineralogy such as are mentioned later, it is believed that most terms used can be correctly interpreted.

As has been noticed above, the rocks and the minerals have been treated in separate articles. Some may wonder why two articles instead of one. If the enquirer will read the two, that in the preceding Report and this, he will have little difficulty in understanding why. It does not require very much technical knowledge to know that all stones are not technically rocks nor are all technically minerals. What then is the difference? All are stones. As stated in the former Report, a rock, in briefest terms, is a stone made up of minerals, a mineral is a stone formed by the chemical union of several, sometimes few, sometimes many, chemical elements. This is not a perfect definition, but as a general statement to which there are exceptions, it is useful. Technically then a rock should be a more complex body than a mineral and usually it is, but not always. There are some stones which may be classed as either rock or mineral, as for example, quartz, and a few other stones. Hence it is obviously impossible to so word any definition of one group that it excludes all of the other. Some minerals, as gold, copper etc., are themselves simple elements, though most of these also occur as "ores" that is they are in combination with other elements. Iron ore is a very common mineral, but iron pure and simple is very rarely found anywhere in the world. Gold is on the other hand usually found as gold and ores of this metal are rare. In Vermont rocks are, as no one needs to be told, as a farmer's boy would probably think, unnecessarily abundant. Ledges, hills and mountains are masses of rock not of minerals, these latter are usually found not in masses, but in veins, pockets, beds of no great size. Our quarries are all in rock. In the great rock masses of the mountains, etc., are usually smaller beds of minerals. This is what makes Vermont a quarrying not a mining region. And it can never be otherwise.

Again the writer would remind the reader that this article does not consider minerals found elsewhere, but is entirely limited to such as now are, or in past years have been, found in this State. In other localities conditions vary and with this variation variety may easily occur in the minerals discovered. In many cases there is little or no difference in the minerals found, elsewhere or there may be great differences seen when compared with those from other localities. The reader is then asked continually to remember that the different species mentioned on the following pages are Vermont species and are described as they occur in Vermont.

A few species have been included in the following lists which are reported in some of the older geological reports but which have not been found of late and may have been wholly removed, or, though rarely, the original specimens may have been wrongly identified. In any case there are but very few of such species. A few species have also also been included which have never been found except after diligent search in localities where they are to be found only in very small quantity. The chemical symbols giving the composition of the species considered, while of no use to those who do not read them, are introduced because chemistry is so generally taught in our higher schools that they will be of use to many who can understand them.

If one is so fortunate as to have a teacher or friend who has studied minerals this is of course a very great assistance in identifying those specimens he studies and some are so difficult that only careful and thorough analysis serves to distinguish them from other and different forms which in many respects they closely resemble. A not inconsiderable number of our Vermont species can be made out by the exercise of care, patience and study.

Get as much help as you can but do not be discouraged if at first the study seems confusing. Inevitably as one continues the

study it becomes less perplexing and more interesting. Teachers are, or may be, good, manuals of mineralogy are good and as indicated above, should by all means be referred to as far as possible, but with these, it is the study of actual specimens that counts most. And the best way is to begin as near home as possible. After long and careful study of Vermont minerals then if one wants to continue the study, as he probably will, it is well to look abroad for newer forms. But there are mineral varieties enough in Vermont to keep a diligent student busy for some years.

As would naturally be expected, of the many species of known minerals only a part are found in the small area of Vermont. However, there is a very creditable number and while none of our localities are famous for the beauty or peculiarity of the specimens they have afforded it may be said that not a few interesting varieties have been found. Of course only those minerals which can be obtained in what is known as the crust of the earth can be obtained and therefore, studied. As compared with the whole body of the earth, we know with certainty of only a very little. From volcanoes, earthquake activities, etc., many inferences may be and have been drawn, but they must be received as having the authority only of inferences, theories, not as facts. Some of these inferences are very probably true, others as probably not true, none can tell. To discuss the construction and character of the earth's interior, by which we must mean by far the greater part of its mass would take us much too far afield, but as all the known materials with which we are acquainted found on or in the surface must have originated from materials in the main body, it cannot be out of place to devote a brief space to that portion of the earth which is below the little of which we have any sure knowledge It is not possible to even mention here the pros and cons, the reasons for believing this or that respecting the interior of the earth. Much may be and has been written in support of each of the theories given below and much has also been written to show that one or another theory cannot be correct but geologists are far from unanimous in accepting any of the views now current, some holding to one view, others to another, none really knowing what is true. For a time many geologists adopted, and for apparently very good reasons, the theory that all things considered the interior of our planet consisted mostly or at least very largely of iron. Professor Schuchert in "Textbook of Geology" states three theories.

First, that as just stated, the main body of the earth consists of iron. "First it has been thought probable that the core of the earth for some six thousand miles in diameter is of metalic iron. This in turn is surrounded by a rock envelope which in its deeper parts is thought to be very basic, that is high in basic elements represented by iron or other metals low in the acidic element, silicon. Such rocks are the dark and heavy basalts and gabbros. Toward the surface it is thought according to this view, that the lighter and more siliceous rocks prevail, marked by the presence of quartz. The typical example of such rocks is granite.

Second, "Interior more nearly like basalt." The granites are a later differentiation product, separating like cream from milk and rising by virtue of lesser density to the higher parts of the reservoirs. This brings us to the second view of the earth's interior—that the average composition probably approaches that of basalt rather than that of metallic iron on the one hand or granite on the other. (Basalt is a cooled lava, hard, heavy, dark color as the Palisades of the Hudson or like some of the dikes that are seen cutting ledges.)

Third, "Interior more like granite." Textbook of Geology, Part II, page 534. Which is most probable? No one knows. We do know that the interior of the earth is more dense, more heavy, more rigid than the outside. Perhaps more may in days to come be discovered, perhaps not.

At any rate, out of this great mass of material which forms the interior of the earth must have come by the action of the various forces and processes which for long have been in action, all the many forms of minerals now found on or near the surface; geologists differ somewhat in their estimates of what materials have contributed in larger amount to the crust. It is obvious that a much greater amount of some minerals have made up the mass of that which we now find on the outside than others. As most know some minerals are very rare, because only a small quantity exists, while others are very common because of their abundance. However, I think that most would agree that the following species are most important in the structure of the outer layers of the earth. More as to these will be found on following pages.

The important minerals then are, if arranged alphabetically: calcite, chlorite, feldspar, hematite, hornblende, magnetite, mica, pyroxene, quartz, serpentine, talc. All the above are found in greater or lesser amount in Vermont. In addition to those species named some would give clay, dolomite, gypsum, limonite, rock salt, siderite. Some of these names will mean little to some who read this, but as indicated all are mentioned more fully later. As will be shown some of these are far more abundant than others in that part of the earth which is accessible to us.

The need of such guide to the study of minerals as is afforded by standard works on the subject has already been mentioned. These should be accessible in every school or town

library, better if the student can own his own copy. Other excellent works are to be had, but here two are especially recommended, Ford's revision of "Danas Manual of Mineralogy," 14th edition and "Phillips Mineralogy."

It may be well to add that in the study of minerals certain features should be particularly noticed. These are color, hardness, if crystallized, form of crystals, luster, streak (mark made by scratching the specimen with a hard steel knife). Unless one has access to a laboratory these are about all that the student can use and many minerals can be identified by the aid of these.

The various formulae giving the chemical composition of the mineral which is described are in most cases shown. To those unfamiliar with chemistry these will of course be of no value, but in most of the high schools more or less chemistry is now taken by the students and to these the composition of a mineral is of interest.

Again the writer asks the reader of this article to remember that it is strictly a Vermont list and the different mineral species are treated from Vermont specimens so that in reading about any of them in a general work on the subject there will now and then be characters mentioned not found in our specimens. In all cases a mineral is spoken of as it has been collected in this State. It should also be noticed that in a few cases a mineral mentioned may no longer be found in a given locality or anywhere in the State, because the variety has been entirely removed. It is also probable that in some cases the mineral was never found in Vermont, but the reported find was a mistake in identification. It is also probable that with the use of modern methods of determination by microscopic study of thin sections a few species not hitherto reported from Vermont will be discovered.

On the whole the writer has thought that, although quite unscientific, an alphabetical arrangement of the names in the following list, would be most convenient in use by those not very familiar with mineral arrangement. For the same reason the metallic minerals are separated from non-metallic and given as a separate list.

In the lists here presented the writer has in most cases included only those he has seen and verified but in some cases this has not been possible. As has been repeatedly stated in former Reports, Vermont is not a mining State and, while a number of mines have been worked in the State during the last hundred years or more, none have been more than temporarily remunerative. With few exceptions those metals or ores of metals which have been found have been in too small quantity or too difficult to smelt, to pay for working. Those mined at one time or another are: chalcopyrite for its copper, bornite for copper, iron (limonite, hematite), manganese (psilomelane, pyrolusite), gold, pyrite and pyrrhotite (for copperas). Other metals are in too small masses to be mined. Chalcopyrite has been far more extensively mined than any other metal. No mines are now worked and it seems safe to add that none will be. Additional facts respecting the above may be found on following pages.

METALLIC MINERALS FOUND IN VERMONT

Arranged Alphabetically

Arsenopyrite	Gold	Molybdenite	Rutile
Bornite	Hematite	Nickel	Siderite
Chalcopyrite	Ilmenite	Platinum	Silver
Chromite	Limonite	Psilomelane	Sphalerite
Chrysocolla	Magnetite	Pyrite	Titanite
Copper	Manganite	Pyrolusite	
Galena	Melanterite	Pyrrhotite	

ARSENOPYRITE

This mineral is commonly called mispickel. It is essentially one of the pyrites with the addition of arsenic. That is to say it is a compound of iron, sulphur and arsenic ($FeAsS$). It is a moderately hard mineral, of gray color and plainly indicates its metallic nature. Its only economic value seems to be as an ore of arsenic. It is not common in Vermont but it is found in considerable quantity in Braintree. See Report Vermont State Geologist, Vol. 12, p. 78.

BORNITE

Bornite is a compound of copper and sulphur (Cu_5FeS_4). It is dark-reddish copper color, sometimes brown. Pieces that have weathered may be iridescent. Bornite has been found in this State only in the town of Berkshire, where a number of years ago some mining was carried on. Quite an amount of work and money was put into this mine, but it proved to be unprofitable and was abandoned. The copper content of the ore obtained was too little. Chalcopyrite was also found in this mine.

CHALCOPYRITE

Bornite is sometimes called "purple copper ore" and chalcopyrite "yellow copper ore." It is a compound of copper and sulphur ($CuFeS_2$). As the name indicates, this ore of copper is brass yellow, though it often changes to bronze and is more or less iridescent. "Distinguished from pyrite by its being softer than steel and from gold by its being brittle," Ford.

Chalcopyrite is the most common ore of copper in Vermont. It has been mined extensively at Fairlee, Corinth, South Strafford and in a smaller way at several other localities, but all the mines have finally proved unprofitable and none has been worked for several years.

CHROMITE

Many years ago chromite was regarded as the most important ore of iron in Vermont. It has not been mined mainly as a source of iron, but as "a constituent of certain green, yellow, orange and red pigments and of similarly colored dyes," Ford. It is also used mixed with other metals to give hardness to steel, and in making fire brick. Chromite (or chromic iron) is of medium hardness, in color, black, steel gray, and occasionally yellowish. It is most likely to be found near serpentine. There are nowhere large deposits. It is found at Troy, Jay, Lowell, Westfield and in small amount in a few other towns. Chemically chromite is iron chromate ($Fe_2Cr_2O_4$).

CHRYSOCOLLA

Chrysocolla is one of the copper minerals, though it is not considered an ore of that metal. Chemically, it is copper silicate ($CuSiO_2 2HO_2$). Colored by the copper it is usually green or blue, but may be darker. It is not often in quantity sufficient to be of economic use. "Chrysocolla is a mineral deposited from the percolating waters which carry copper and silica," Phillips. In the southwest it is not infrequently used as an ornamental stone and as it closely resembles turquoise, it is sold as that mineral. It has been found only in the town of Ira in Vermont.

NATIVE COPPER

It is not necessary to say much as to this metal here for, as far as the writer is able to discover it has never been found in this State. Copper has several times been reported as found in Vermont, and small pieces have been picked up here and there, but it appears to be quite certain that these were all "finds" that is they did not originally occur here. Many tons of "copper" have in past years been sold from Vermont, but in all cases it was copper ore like the chalcopyrite of the Ely mine, not pure copper which was so sold. True native copper is the pure metal, or nearly pure. Many years ago, that is in 1859 and 1860, Vermont is reported to have produced more copper than any other state, but this was all chalcopyrite which contained only a comparatively small percent of pure copper and, as has been stated, all the mines formerly worked have long since been abandoned as unprofitable.

GALENA

In most localities everywhere in which lead is mined the ore is galena. This is a lead sulphide (PbS). Only a very few metals are ever found pure. All are familiar with the appearance of lead and galena has the color and luster of lead and its softness, a little harder. Galena does not occur in other than small quantities in this State. When freshly broken galena is very bright, but soon tarnishes to dull lead color. It has been found at Brandon, Corinth, Thetford and several other towns. When found galena very often contains a little silver, but only a little. Like the silver is in the form of sulphide.

GOLD

Most of the gold mined is found as native, that is simple, uncombined gold, though in some localities it occurs in paying quantities in pyrite and other minerals. It is often mixed with silver. Most commonly gold occurs in veins or quartz. A large amount is sometimes found, as nuggets or as gold dust, in the gravel of streams, which have originally come from quartz veins and have been washed out and carried on by flowing water. Although rarely found in large masses, gold is very widely distributed over the world. Usually the nuggets are small, they really are little pebbles mixed in gravel with other pebbles and like them rounded by the wear of the stream. Once in a great while, nuggets of considerable size have been found. The largest known was found in Australia. This weighed 190 pounds, but none other of this size has ever been reported. Though more commonly found in quartz, gold has the property of retaining its color under all circumstances, but it is by no means every metal which is yellow that is gold. Nor even every nonmetallic minerals. Some of these, in which there is never any trace of gold, in some circumstances and to a casual observer, more or less closely resemble gold. In former Reports several allusions have been made to a very common rock in Vermont—a sort of granite—which contains little scales of mica with the ordinary quartz and feldspar. Some of this decomposes readily into a sort of gravel and finally into sand. The mica, at first black, or very dark, because of iron it contains, changes by the oxidation of the iron, to a bronze and often a golden yellow color. As has been said before, more people have been deceived by this than by any other rock, except some forms of pyrite. Nevertheless, it is very easy to distinguish this worthless material from gold. Gold is very soft, softer than lead, and heavier than lead, it never is possible to split gold in thin, elastic scales as in mica. Indeed this mineral differs in every respect from gold except in appearance. Another quality of gold is that it is not affected in any way by the application of an acid.

In writing the above I do not forget that a great deal of gold ore is not by any means nearly or quite pure and it is only of this more or less pure ore that what has been written is true. When, as is not infrequently the case, the gold ore is mostly pyrite or some other mineral, then it may be very hard, less heavy and less malleable. I have often met people who thought that in a vein of white quartz which occurred on their land there must be gold. As most people know, much of the gold mined is found in quartz, or quartz rock, but the presence of quartz is no sure indication of the presence of the precious metal. I suppose that most of the quartz found so commonly in all parts of the world, is wholly barren. Besides in quartz, gold is found in other igneous rocks and in some limestone. When in what proves on examination to be gold ore of some value, the large mixture of other substances entirely conceals the gold and only careful chemical analysis can discover any of the desired metal, identification is difficult. It may be well to notice that such ores have never been found in Vermont. So many of our people, especially those owning land, spend time and money searching for gold on their premises that there seems to be need of "line upon line" in every geological publication issued. For this reason some advice published in former Reports is repeated. During more than a century more or less money and labor have been wasted in trying to get rich quick by exploiting as a gold mine some worthless ledge. In this way the State has up to the present time, been pretty thoroughly investigated. It is true that gold has been and very occasionally still is, found in a ledge or stream in Vermont, but it has so far as all records inform us, been unprofitable, usually from the first, in all cases before the end. Again let me say that in my opinion, it is entirely useless to throw away money, time and labor seeking gold in Vermont.

HEMATITE

In most parts of the world hematite is the most abundant ore of iron. Chemically it is a red oxide of iron (Fe_2O_3). It is found in Vermont in small masses in a considerable number of towns and has been mined in years long passed at several places. It varies in color from red brown to gray or almost black. The streak, however, is always red. The great beds in the Lake Superior region are hematite. Some varieties appear on casual inspection much like some of the other iron ores, but it is usually and easily distinguished by the streak. Hematite is the most frequently seen ore in this State, although as is noticed later, magnetite is also found. The Brandon ore is magnetite as also Plymouth, Weathersfield, Colchester, Berkshire and other towns.

ILMENITE

Ilmenite, or as it is sometimes called, titanic iron, is only found in the rocks of Vermont in small masses, not often larger than one's fist or less, though rarely pieces larger than this have been found. Ilmenite is mainly a compound of iron and titanium ($FeTiO_3$). It often is seen in bright plates dark brown or almost black, much harder than other ores of iron. It is of little commercial value. Ilmenite is found here and there in many of our rocks as at Newfane, Bethel, Troy, etc.

LIMONITE

Limonite is often called "brown hematite" and often "bog iron." It is an oxide of iron like hematite but instead of the reddish color, when scratched, it is a yellowish brown. Authors give somewhat different chemical formulas, but probably as correct as any is (Fe_4O_3, $(OH)_6$). This ore of iron is found in many of the Vermont towns, but nowhere in large amount. The common color of limonite is dark brown or black. At several localities in this State it was formerly mined, but not very successfully. Probably this mining was carried on longest at Forestdale. This was in 1810 and the following years. Considerable money was invested here, but the mines were finally abandoned, though worked for forty years. Limonite was also mined for several years at Wallingford, Bennington, Plymouth.

MAGNETITE

Magnetite is another oxide of iron (Fe_3O_4). It is harder than limonite, black as to color, the surface of any piece often glossy and in many specimens it is a natural magnet. It is not found in Vermont except in small masses. Most of the mines formerly worked in the Adirondack region and still worked in a few places are of this ore. Magnetite is much more readily attracted by a magnet than other iron ores and, as above, is not infrequently itself a magnet. Magnetite is found in several of our towns, as Plymouth, Corinth, South Troy, Cavendish, Wolcott, Pomfret, etc.

MANGANITE

Manganite is an oxide of manganese ($MnO(OH)$). Though found in some places in Vermont it is nowhere of much importance, except for a few specimens in a collection of Vermont

minerals. It is in color dark gray to black. When scratched or powdered it is dark brown. It is rather hard and has a metallic appearance. The best locality in Vermont is Forestdale.

MELANTERITE

Perhaps melanterite should not be included in a list of Vermont minerals, since it is only found in very small quantity as an incrustation on bits of iron sulphide. Many years ago it was manufactured in considerable quantity. It is more commonly known as copperas or green vitriol. Chemically it is ($FeSO$). Copperas was formerly manufactured at South Strafford, made from the pyrite abundant there, but it is many years since "The Vermont Copperas Company" ceased to exist. It is mentioned here rather as historically interesting than otherwise. Notwithstanding its name this substance contains no copper.

MOLYBDENITE

Molybdenite is molybdenum sulphide (MoS_2). It is not found in any deposit, only as scales in rock. It is lead color, very soft, splits in scales, which are not at all elastic and have a feel as if greased. This mineral has in many respects the appearance of graphite and like it marks paper. It is found in Cuttingsville, "Granite Hill" in syenite. The exact location is shown on the map of Plate XVL, Eleventh Report, page 181. It is also found in Brighton. The metal is easily recognized by the characters given above.

NICKEL

"Emerald nickel" is reported as occurring at South Troy, in the Geology of Vermont, Vol. I, p. 526, 1861. I have not seen this mineral from Vermont and include it in this list only because its identification rests on good authority. I doubt if it can now be found.

PLATINUM

It is with some hesitation that platinum is included among Vermont minerals. The reasons for including it are as follows: For quite a number of years there have been reports published in several papers which mentioned finding platinum in this State, also a notice occurs in the Fourth Report of this series that the metal had been found in rocks with gold in Plymouth and I have had a report of similar sort from Bennington, but I have never seen any of the so-called platinum. Mr. M. L. Hinchman, on whose land in Plymouth the stone "a laminated blue-gray sandstone" and also in "black sand" has had several hundred pounds in all analyzed by several New York assayers and chemists with reports that in all the samples submitted a small amount of platinum was found. Waller and Renaud. . . . "0.15 oz. per ton of 2,000 lbs." Another sample examined by the same firm gave . . . . "0.22 oz. platinum per ton." Torrey and Eaton report, "We have found only $1 per ton of platinum in the sample sent by you." Apparently a small amount of platinum was found in the Vermont samples sent, but too small to be of economic value.

PSILOMELANE

Psilomelane is a manganese ore. It is an oxide of manganese (MnO_2) and in Vermont is found usually in the same locality as other ore of this metal. It like other ores in this State, is to be obtained only in small amount, although in past years, considerable quantity has been mined at Forestdale, more than in any other of our towns, but also at Wallingford, Bennington, Bristol, Plymouth, Colchester and other localities. In color psilomelane is black, or dark brown, is harder than the other manganese ores found here.

PYRITE

Pyrite, pyrites, iron pyrites, fool's gold is common in all parts of the State. The attractive appearance and yellow color make it very noticeable in all sorts of rock. To a trained mineralogist it does not so closely resemble gold as to those unfamiliar with the usual characters of the precious metal and it is the experience of all students of minerals that specimens of pyrites are more frequently brought to him for identification than those of any other mineral. It has been in many localities more perplexing because pyrite does often contain usually a small percent of gold. Apparently, in Vermont there is never any gold associated with pyritiferous ore and I think the same is true of all New England, but on the Pacific Coast, some of the paying mines have supplied only an ore containing a much larger percent of pyrite than of gold. Chemically, pyrite is an iron sulphide (FeS_2) as is usually proved if a little is powdered and heated, when a strong odor of sulphur is noticed. Pyrite is very bright yellow, very hard, when, as often, it is in crystals these are usually cubical, it is brittle, when powdered, is soluble in nitric acid. Gold is soft, duller yellow, less brilliant, not at all brittle. Pyrite is not as heavy as gold. It may be distinguished from chalcopyrite by its greater hardness (it is not easily scratched by a knife), and usually by its lighter color.

PYROLUSITE

Pyrolusite is an ore of manganese (MnO_2) and is often found with other ores of that metal. It is black in color, very soft. Like other manganese ores it nowhere in the State is

found in large quantity. Elsewhere pyrolusite is an important ore. In Vermont is has been found in Brandon, Chittenden, Irasburg, Bennington, Monkton and a few other towns.

PYRRHOTITE

Pyrrhotite, or magnetic iron pyrites, is another iron sulphide ($Fe_{11}S_{12}$). It is much softer than pyrite and brownish yellow or bronze, the streak is black. Like pyrite it is sometimes mistaken for gold. It is far less common than pyrite and is less vividly yellow and only about half as hard. It does not occur anywhere in Vermont in large quantity. Where found it is usually associated with other iron or copper sulphides.

RUTILE

Rutile is chemically a titanium dioxide (TiO_2). It is rather hard, metallic luster, red to black color, found most often in granitic, metamorphic or schistose rocks and quartz. Very beautiful specimens were found in the town of Waterbury many years ago, but the locality has been long exhausted. These specimens were crystalline quartz penetrating which long very slender or hair-like crystals of rutile ran in all directions. This mineral is also found in less beautiful form at Newfane, Corinth, South Strafford and other localities and microscopic crystals occur in some of the granites. It nowhere in Vermont has been found in large masses, as it has in some other places, where it is mined.

SIDERITE

Siderite is an ore of iron. It is also called spathic iron. Chemically it is a carbonate ($FeCO_2$). In appearance it is quite unlike any other ore of iron. It is only slightly metallic, or rather resinous, as it is seen in a lump. The color varies from light to dark brown. Our Vermont specimens are usually light. For some years this ore was mined and worked at Tyson Furnace in the southeastern part of Plymouth, but has long since been given up. This is the only locality where the ore has been found in quantity, though it occurs in several places in small amount.

SILVER

Silver ore as such does not occur in Vermont, but in combination with other minerals a little silver is found and has been reported. Were it not that so many "silver mines" have been reported it would scarcely be profitable to include silver in this list, but for many years every now and then some such report is current in some of our towns and there are always those who are ready to believe anything which they hear about a mine. Let me repeat the truth that no silver mine has ever been discovered in Vermont and that it is entirely useless to look for one. Seventy years ago, in one of the old Vermont Reports we find: "Notwithstanding the many reports of silver mines we have never been able to learn the precise locality of one." Much the same might truthfully be written today. However, the present writer may say that he had once or twice been directed to definite localities, but examination showed the falsity of the story. The confusion has been greatly increased by notices of silver in this State which have been printed in the U. S. Report once or twice. A cursory reading of these notices might lead one to think that silver did occur in Vermont, but a more careful reading shows that the metal had not been found except as a by-product obtained in small quantity in the reduction of copper ore. Also a very small amount of galena, as has been noticed, is found in several places in the State and this ore of lead generally carries a little silver. In no single instance has enough silver been obtained to pay for mining the ore for silver, but as a by-product a small amount has been secured.

SPHALERITE

Sphalerite is a zinc sulphide (ZnS). It is also well known as zinc hende and black jack. Like the silver sphalerite is only found in Vermont associated with other metals, usually copper, pyrites. Even then it is in only small quantity and of no commercial value here. It has also been rarely found, as in Thetford and Bridgewater in small lumps.

TITANITE

Titanite is a rare mineral in Vermont and is only of value as in mineral specimens. It has been found at Marlboro in hornblende schist and in very small inclusions in granite. Dr. G. I. Finlay has found it in some of the Barre stone. Titanite may be black, brown, yellow or gray. Though not common in Vermont titanite has been found in other localities in larger masses.

LIST OF NONMETALLIC MINERALS FOUND IN VERMONT

Arranged Alphabetically

Actinolite	Calcite	Lepidolite	Sillimanite
Adamsite	Cyanite	Mica	Spodumene
Albite	Dolomite	Microcline	Staurolite
Alamandite	Epidote	Muscovite	Steatite
Alunite	Feldspar	Natrolite	Stilbite
Andalusite	Fluorite	Ocher	Sulphur
Anthophyllite	Fuchsite	Oligoclase	Talc
Apatite	Garnet	Olivine	Tourmaline
Aragonite	Graphite	Orthoclase	Tremolite
Asbestos	Gypsum	Prehnite	Wavellite
Augite	Hornblende	Pyroxene	Wernerite
Barite	Iolite	Quartz	Zaratite
Biotite	Kaolinite	Rhodonite	Zircon
Brucite	Labradorite	Serpentine	Zoisite

ACTINOLITE

In one form or another, actinolite is a very common mineral in Vermont. This is not intended to say that good cabinet specimens are common for they are not. The slender green glassy crystals are found in talc, and other minerals in many localities. Bethel, Cavendish, Roxbury, Windham, etc. By many mineralogists actinolite, tremolite, hornblende are grouped in one as amphibole as they are similar chemically, not identical. All are silicates, all are hard, and abundant in the metamorphic rocks. Chemically actinolite is $Ca(Mg, Fe)_3(SiO_3)$. Actinolite is a hard glassy mineral, usually green and as noted, crystallizes in long slender prisms. In some localities actinolite is found in a massive form and then closely resembles jade so that it is called jadeite and a good deal of the jade of commerce is jadeite. In some varieties of Vermont marble there are more or less numerous green veins of actinolite. Actinolite is one of the varieties of amphibole, hornblende and tremolite being two other varieties.

ADAMSITE

Adamsite, named after a former State geologist, is found only in Vermont. The mineral obviously belongs to the mica group. By some mineralogists it is recognized as a good species, by others not. It is a foliated mineral, but unlike any other mica the scales are not elastic. This species is not recognized in either the last edition of "Dana's Manual of Mineralogy," or "Phillips Mineralogy," but it is given in other authorities and therefore is included here. It is fully described in the 1861 Report on the Geology of Vermont and Derby is given as its locality. On page 484, Vol. I, of Geology of Vermont the mineral is named and described. It is "clove brown" in color, has also been found in "Glover and Newfane." Even if adamsite is a good species, which seems very doubtful, it is yet more doubtful if any such mineral can now be found.

ALBITE

Albite is one of the feldspar group. It is a silicate of soda and alumina ($Na\ AlSi_3O_8$). Albite is less abundant in Vermont than some of the other feldspars, as orthoclase. As the name indicates, it is usually white though sometimes gray, the luster is glassy. It is quite hard. Though it is not the common feldspar of our granites, syenites, etc., it does sometimes occur in them. In larger masses albite has been found at Castleton, Cabot and some other localities.

ALMANDITE

Almandite is one of the varieties of garnet.

ALUNITE

Alunite is found only as an encrustation on rocks. Often it is scarcely noticeable, but when found it is easily recognized by its alum taste. It has been noticed in a number of our towns.

ANDALUSITE

Andalusite is not a common mineral in Vermont and is reported only from Bloomfield, Saxtons River and Vernon. Like other silicates it is very hard. Chemically it is an aluminum silicate (Al_2SiO_2). Its color varies in various localities. It may be brown, or reddish brown, gray, blue or green.

ANTHOPHYLLITE

Anthophyllite is a member of the amphibole group of silicates, an iron mangnesium metasilicate ($(Mg\ Fe)SiO_3$. It is not common in Vermont, but has been collected in Plymouth, Grafton, and perhaps a few other towns. Like all silicates it is hard, gray, green or brown in color, fibrous or in plates, sometimes in slender crystals.

APATITE

Apatite is a lime phosphate ($Ca_4(Ca\ F)(Po_4)_3$. Like the preceding, apatite is not common in Vermont. It may occur in massive form or perhaps more often in hexagonal crystals, which in some localities are quite large. It is most often of a greenish or reddish color, but rarely brown or even white. It is hard. In small crystals apatite may be found in many of our granites. In some parts of Quebec and other localities apatite is found in beds of considerable size, and here it can be obtained in sufficient quantity to be used, when properly prepared, as fertilizer. Nowhere in Vermont is the quantity large enough to make such use possible.

ARAGONITE

Aragonite in composition and appearance is much like calcite, which is the common carbonate of lime. Chemically, it is ($Ca\ Co_2$).

ASBESTOS

There are two distinct species of mineral known as asbestos, chrysotile asbestos and tremolite asbestos. The kind chiefly used in manufacture is the chrysotile and this is by far most common in Vermont and is that considered here. Tremolite asbestos is considered later on under tremolite. In small quantities asbestos is found in many of our towns, but is abundant enough to mine in only a few. Chrysotile asbestos is a variety of serpentine. It is composed mainly of silica and magnesia ($H_4Mg_3SiO_2$). Chrysotile asbestos is readily recognized, as, except the tremolite variety it is unlike any other mineral in its silky, flexible fibers and satin luster. It may also be easily distinguished from the other form by its elasticity, as tremolite has no elasticity, but readily breaks if bent. It is very unfortunate that in all our Vermont localities the fibers are too short. It is seen in veins in cross fiber in serpentine. It is found in greatest abundance at Belvidere Mountain, though as stated above it occurs at many other localities in the State. On both sides of Belvidere Mountain during the last twenty years or longer much money and labor has been expended in developing a paying asbestos mine, but so far the returns have not been very satisfactory.

BARITE

Barite or heavy spar is not common in Vermont, but has been found in Richford. It is a barium sulphate ($Ba\ SO_4$). It is easily recognized by its white color when not crystallized, transparent when, as is usual, it is in crystals. More rarely barite may be brown, blue, yellow or green. It is not vary hard.

BIOTITE

This is the most common form of mica found in Vermont. The black, or dark specks in much of our granite schist, etc., is this mineral. Chemically it is a complex mineral $(HK)(MgFe)_2 Al_2(SiO_4)_2$. It is more rarely found crystallized in flat tabular shape of varying thickness. In Vermont, however, crystals are very rare. Biotite is not a hard mineral, is easily scratched by a knife and may usually be readily recognized by its dark color, due to iron, glassy luster, and by the thin lamina or plates into which it may be split and which are always very elastic. While most commonly black or very dark, biotite is sometimes green or yellow. When long exposed to decomposition of the rock of which it forms part, biotite becomes brown or like bronze, or yellow like gold, for which, as noticed when discussing that metal, it is often mistaken (see under gold). Biotite is found almost everywhere in this State usually in very small scales.

BRUCITE

Brucite is reported to have been found in Roxbury, but I have not seen any specimen from that or any other of our towns and very probably it should not be included among our minerals.

CALCITE

Aside from the pure forms calcite forms a large part of the limestone, a smaller part of many shales and to a greater or lesser degree in many minerals. Besides forming a part of limestones and other rocks, calcite is often found in crystalline masses especially in limestone. Here in Vermont the usual form of the crystals is "hexagonal-rhombohedral," clear, transparent or white opaque, easily scratched by a knife and usually easily detected by its ready effervescence when acid hydrochloric or other is dropped on the surface. While the above is the common form of crystals in most localities, calcite is well nigh protean in its many forms. Phillips says, "some 330 forms have been described with about 100 additional forms which are doubtful." So too in color calcite varies much. By far the most usual color is white, when not transparent, but it may contain almost any substance from which it takes any color that the added material produces. The white veins often seen in our ledges are generally due to calcite or quartz, and the great difference in hardness easily distinguishes the two. All the true marbles of Vermont, not all sold under the trade-name marble, are largely calcite. Chalk is chemically the same. Calcite is so widely distributed in this State that no list of localities is here given.

CYANITE

The blue, blade-like crystals of cyanite are found in several localities in Vermont though not abundantly. In other localities this mineral is white, red or green, but all the Vermont specimens that I have seen are blue. It occurs imbedded in various schists. It is an aluminum silicate (Al_2SiO_5) and has the hardness of all

silicates. Its hardness is very peculiar. When tested by drawing a knife longitudinally this is represented as 5 of the scale, but when the knife is drawn across the crystal it is 7. The luster is glass-like. The name is often written kyanite. It is found in Thetford, Grafton, Chester and some other towns.

DOLOMITE

Dolomite is like calcite but it contains magnesium. In some of our limestone and marble there is more or less dolomite. Dorset marble, the common red sand rock which forms cliffs and mountains, like Snake Mountain, etc., are dolomitic. Such stone may be of almost any color, red, white, gray, brown, etc. It is often difficult to distinguish calcite rock from that which is dolomitic without chemical analysis, the only difference being that the latter always contains magnesium while the former is only lime carbonate.

EPIDOTE

Epidote is a complex mineral, a silicate of iron, aluminum and calcium, $Ca_2(AlOH)\ (AlFe)_2(SiO)_3$. It is usually green of lighter or darker shade. The crystalls are glassy. They are long slender prisms. When not crystalline it is granular. Like other silicates it is very hard. It occurs in metamorphic rocks like gneiss and schist, and some of the granites.

FELDSPAR

Feldspar is a general name for a group of more or less similar minerals, several of which are found in Vermont and several have not been found here. As each of the species which have been collected in this State is in this list considered under its appropriate name, only a brief mention is necessary here. All feldspars are hard rocks with a glassy luster. They are, besides silica, composed of aluminum, potassium, sodium, or calcium and sometimes other elements. Not all of these are found in any one specie or variety, some contain soda but not potash. Some of the feldspars which contain potash are ground and used as a fertilizer, but it is a mistake to suppose, as some have done, that any feldspar when prepared is useful as a fertilizer. Some kinds are of little more use than any chance rock. The feldspars which contain potash are orthoclase, and microcline, those that contain soda are albite, while oligoclase, labradorite and andesine, anorthite contains calcium. As may be seen from the special description, the varieties vary more or less in appearance, as would be expected from the difference in composition. In Vermont the following varieties have been found: Oligoclase, albite, labradorite, microline, orthoclase, plagioclase. Some of these are common, others not. As indicated above, for a fuller account of each Vermont variety see under each name. Authors give some minor varieties but the above are best defined. Of these all are found in Vermont.

FLUORITE

Fluorite is a calcium compound (CaF_2). It is reported in this State only from Putney and Bellows Falls. Here it is green, of a clear glass-like appearance. In many other localities it is blue, purple, white or brown, and it may be other colors and shades of color. It is usually more or less transparent and is one of the most beautiful minerals in any collection. These finer specimens are usually European.

FUCHSITE

Fuchsite is a variety of mica. It is not common anywhere and only a single locality is known in Vermont. This is in the town of Shrewsbury not far from Rutland. It is a very pretty chrome green. I have no knowledge of any other American locality. Professor Phillips places fuchsite as only a variety of the common muscovite mica.

GARNET

Garnet of some sort is very common in the mica schists and other metamorphic rocks of Vermont. The mineral is found in a number of varieties all of which are not found in this State. None of those found here are of the clear bright variety used in jewelry. Nor are our garnets large, usually very small. Chemically garnet is a silicate of rather complex composition which differs in different varieties. With some rare exceptions, the color is some shade of red, usually dark. It is usually crystallized, but in some localities is massive. Our specimens are most often dodecahedron (twelve sided). Garnet is very hard and for this reason where it can be obtained in sufficient quantity is ground and used in what is known as "crocus paper" which is harder than ordinary sandpaper. While the usual color of garnet is as stated above a dark red, it is sometimes white, yellow or brown.

GRAPHITE

Graphite, "black lead" is found in many parts of Vermont in small quantity and usually mixed with a greater or lesser amount of impurity. Chemically graphite is one of the forms in which carbon occurs. Though so different in almost every character from diamond it is yet essentially the same. It is one of the

softest of minerals, is usually foliated, laminae not elastic, much like lead in color, metallic luster, unless very impure it marks paper. Has a feel as if greased, when rubbed. Though found in many places in the State it nowhere forms thick beds, and is not mined in any of our towns as in many localities. In lead pencils, the lead is graphite mixed with more or less clay, as the pencil is hard or soft. Most of that used in the United States is imported from Ceylon or Mexico.

GYPSUM

Gypsum is a lime sulphate ($CaSO_4 2H_2O$). Though very abundant in many parts of the world, gypsum is not common in Vermont and nowhere forms large beds. It is a very soft mineral when pure. In color it may be white, gray or like glass or when containing impurities may be colored by them. When burned it is ground and forms plaster-of-Paris. Some gypsum is like marble and is called alabaster.

HORNBLENDE

Hornblende is now regarded as one of the varieties of amphibole rather than a distinct species. Hornblende, either as a distinct mineral or as an important part of some other rock, is very common in the Green Mountain region. Hornblende is, like other silicates, a very hard mineral, occurring in slender prismatic crystals, often very conspicuous in the containing rock, usually of a dark black or green color and glassy appearance. Hornblende is found in some granites and other igneous rocks and in metamorphic rocks, gneiss, schist, etc. Chemically hornblende has the formula $CaMg_3(SiO_3)_4$.

IOLITE

Iolite is a complex silicate of some shade of blue. It has been reported in Vermont only from Chittenden and Rockingham, and sparingly. It is found in granite and gneiss and perhaps it may be found in these rocks in other localities. It forms one of the constituents of these rocks and also of various schists. "Often altered into some form of mica," Ford.

KAOLINITE

Kaolinite, or as more commonly called kaolin is found in several localities in Vermont. Kaolinite is a clay, pure white, unless colored by impurities. It is usually regarded as a residual from the decomposition of feldspar. However, Prof. F. A. Burt in the Report immediately preceeding this says, of the Bennington kaolin, "The kaolin has been developed by normal weathering processes. The parent rocks are primarily the pre-Cambrian gneisses of the area and to a less extent to the feldspathic and argillaceous phases of the quartzite." [1]

LABRADORITE

Among the many varieties of feldspar labradorite is perhaps least common in Vermont. It is abundant across the lake south of Port Kent. Here it is reported only in Weybridge, but it is also found in some of the boulders of Canadian rocks. Unlike most feldspar labradorite is usually dark in color to almost black, though in some foreign localities it is lighter, even white. The surface of a specimen is usually more or less irridescent and in some pieces exhibits a very pretty play of color. It is a hard stone, though not quite as hard as quartz. Like other feldspars, the chemical composition is very complex.

LEPIDOLITE

This mineral is one of the forms of mica. It is generally a pretty shade of purple, in which it is unlike other species of mica, and thereby it is easily distinguished from them. Like other micas, lepidolite is found in thin elastic scales in other rock. Lepidolite is very complex in composition. Its purple color is due to the presence of lithia. It is rare in Vermont but has been reported from one or two localities.

MICA

There are various species of the mica group which are to be found under the separate captions. As has already been noticed, any of the micas can be easily recognized by the shining appearance, thin plates into which it is easily split, by using a knife blade and, this is important, by the flexibility and elasticity of the plates. Some other minerals can be split in thin plates but none are elastic as mica. The principal varieties of mica are as follows: Lepidolite, biotite, muscovite, these are found in Vermont and in addition phlogopite and lepidomelane, not reported from this State. All are silicates of iron, aluminum, potassium, etc., with divers other elements. Look under the name of each variety for details.

MICROCLINE

This mineral is found only in microscopic examination of some of the Barre granites. Very likely it may be found in some

[1] Sixteenth Report, Vermont Geologist, p. 65.

of the other granites in the State. Microcline is one of the less common varieties of feldspar.

MUSCOVITE

Muscovite is the ordinary white mica found in all parts of Vermont. As has been said in writing of biotite, the black or dark mica of our granite is that species of mica, but the mica of the white granites is this kind. It is called "white mica" but it is usually light gray or light brown. Like the other micas it is not found here in large sheets, as in many places, but only in scales or at most, and this seldom, in somewhat larger plates. Professor Phillips says, "If a blunt-pointed instrument is placed on a cleavage piece of muscovite and struck a sharp blow, a six-pointed star will be produced at the point of contact (mineralogy, p. 489). The mica which has been used so much in stove doors, etc., is of this sort.

NATROLITE

Natrolite has been reported from Newfane, but it is to be regarded as a doubtful species in Vermont.

OCHER

Where it occurs ocher is generally regarded as clay or earth and very little noticed. It is scarcely to be enumerated among minerals, but it may not be out of place if a few words are written about it. See page 107 of this volume for study of ocher.

OLIGOCLASE

Oligoclase is one of the varieties of feldspar, as mentioned under the general name of the feldspar group. Oligoclase is not, as far as I have noticed found in large veins, but as a component part of some of our syenites and granites. It is a soda feldspar, as are many of the feldspars in Vermont granites. As to name a few among many, the stone quarried at Kirby, Ryegate, Dummerston, Derby, etc., as stated by Richardson in the Vermont Geological Report for 1923-24, page 94. Like that of orthoclase the chemical composition of oligoclase is very complex.

OLIVINE

Olivine, also called chrysolite, is another silicate $(Mg_2Fe)_2(SiO_4)$. It is not a common mineral in this State, but it has been found in small quantity in Thetford, Corinth, and very likely it may be discovered in some other towns. It is generally seen in more or less scattered granules in some other rock. It has a glassy luster, is some shade of olive, green or brown. A yellow form is often called chrysolite and when clear is used as gem. Apparently the specimens found in Thetford originated in Corinth, as they occur only in boulders that evidently came from the north.

ORTHOCLASE

This mineral is the common feldspar, found in many granites, as those of Barre, Woodbury, Calais, etc. They are potash granites, while as noted under oligoclase, the other granites named above, are soda granites. In some places as in Chester, orthoclase appears in large veins in other rock. I do not need to repeat, perhaps, that all true granite is a mixture of quartz, mica, feldspar, and that the latter may contain potash or soda. Chemically, orthoclase is composed of silica, alumina, potash ($KAlSi_3O_3$).

PREHNITE

Prehnite is a silicate of lime, aluminum, calcium ($H_2Ca_2Al_2$), $(Si_3O_4)_{12}$. It usually is found in rounded bunches of crystals of a green shade, sometimes very light, with a glassy surface. It has been found at Bellows Falls and Vernon.

QUARTZ

Quartz, better known as seen in the variety flint, is one of the most widely and, in one or another of its varieties, most commonly noticed minerals. There is scarcely a shade of color which is not seen in some of its forms. Simply to enumerate the varieties of quartz would occupy more space than is here available. It enters largely into the composition of many of our harder rocks, most sand is largely, if not entirely, made up of grains of quartz, here in Vermont veins of light or pure white quartz are common in our ledge. In many of these veins it closely resembles calcite, especially when seen at a short distance. Its hardness, scratched only by a knife of very hard steel, its more glassy luster and its unresponsiveness to acids, all distinguish quartz from calcite. The prismatic six-sided crystals which scratch glass are often very transparent, and when properly cut are very brilliant, and very attractive. Almost without exception sandstone is largely or wholly made up of quartz. As to some of the varieties of quartz, Doctor Barrell writes (Lithology of Connecticut, page 38): "In part cement quartz may be derived from the solution of ordinary quartz in the presence of hot or alkaline waters. The aggregate may be massive as in jasper, carnelian or flint, or from an encrustation of differently-colored layers, as in agate or onyx. When the encrustation shows a fibrous structure at right angles to the surface it is called chalcedony and if finally crystallized with a surface of velvety luster it is called drusy quartz. Silica also occurs combined with water as opal, forming incrustations of waxy, greasy opalescent luster somewhat softer than quartz. Where this cement quartz fills up the spaces of rocks the cementing material is added to the quartz grains extending their limits and dovetailing them together. In this way porous sandstones are turned into quartzites, characterized by their lack of porosity and a rather smooth but slightly flaky and faintly granular fracture." Chemically quartz is oxide of silicon (SiO_2). As has been stated above, quartz varies greatly in color. The ordinary crystals are transparent, but they may be opaque and white. In some localities, as the Lake Superior region they are purple and often called "amethyst." Rose quartz is pink, carnelian is red chalcedony, prase is green, cairngorm is smoky, or brown, jasper red or yellow, etc.

RHODONITE

Rhodonite is a manganese silicate ($MnSiO_3$). It may usually be distinguished by its light red or pink color. Rhodonite has been collected at Coventry, Irasburg and Topsham. It is not common anywhere. Once known, this color is determinative as no other mineral is exactly of the same.

SERPENTINE

Serpentine is a magnesium silicate ($H_7Mg_3Si_3O_9$). It is always "an alteration product." The most common color is green, of various shades, but it is often abundantly veined or clouded, white, yellow, black. It is sold under the trade-name of "Verde Antique Marble," and is often a very elegant stone especially when polished. It has been quarried for many years by the Vermont Marble Company and long before that by others, but only in a small way. The oldest quarry of which I have found mention was at Cavendish and worked more than a century ago, but it may very probably been quarried to some extent before this. Chrysotile is a variety of serpentine, and as has been noticed under asbestos, is the common asbestos of commerce. Good specimens of serpentine may be found in Vermont at Roxbury, Rochester, Cavendish, Marlboro, Jay, Norwich, Ludlow, Grafton and several other towns.

SILLIMANITE

This silicate is one of our less common minerals. It usually occurs in needle-shaped crystals, or bundles of fibers. From this character it is sometimes called fibrolite. The color may be green, gray or brown. Saxtons River is the only locality as far as I know where it has been found.

SPODUMENE

Another rare mineral in Vermont is spodumene, found at Brattleboro. As it is elsewhere found in pegmatite—a very coarse granite often found in our quarries, it is very likely that other localities will be discovered for spodumene. This mineral has usually a dull glassy luster of a dirty white, or it may be, yellowish, gray, or pink. Its chemical formula is $(LiAl, SiO_3)_2$.

STAUROLITE

In good specimens staurolite is easily recognized by its form black-crossed crystals, like the letter X. The present name has been substituted for the older name staurotide. It is nowhere abundant, but is widely distributed in this State. The prismatic crystals are often not in pairs making the X but single. They are not usually large, one or two inches long. "Staurolite is a product of contact metamorphism occurring in argillaceous shales and schists." Among very numerous localities may be given Cabot, Chester, Victory, Bellows Falls, etc. The chemical formula is $HAl_3FeSi_2O_{12}$.

STEATITE

Steatite, commonly known as soapstone, or the older name, freestone, is common in many parts of Vermont in larger or smaller quantities. Steatite is really a compact, massive variety of talc and therefore will be more fully considered when that mineral is taken up.

STILBITE

Stilbite may be white, red brown, or yellow. It is composed of an unusual number of elements. It has been reported only from Rockingham.

SULPHUR

There are in different parts of the State various springs the water of which is redolent of sulphur. Most of these "sulphur springs are ordinary springs more or less charged with sulphuretted hydrogen. Such water deposits a thin layer of clear sulphur about their borders. Formerly some of these springs were regarded as medicinal and the water was much used, but latterly few, if any, have been very highly valued. In no other form is sulphur found in Vermont.

TALC

Ordinary talc is magnesium silicate $(H_2Mg_3(SiO_2))_4$. It is usually a very soft stone to be recognized by its greasy feel. It is common in many parts of Vermont and in several towns, as stated below, it is mined and sold. In color good talc is very light green, white or gray. It has a pearly luster, if not too much mixed with other minerals. In good specimens talc easily splits in more or less thin foliation, the plates being brittle. When, as is often the case, it is compact and harder it becomes soapstone or steatite, and is of darker color. It is mined in considerable quantity at Moretown, Johnson, East Granville, Rochester, Chester.

TOURMALINE

This is another of the many silicates. Its composition is complex and in different specimens varies more or less. It is most often seen in black shining prismatic crystals, often in white quartz or similar rock and very conspicuous. In this State we rarely find other than black tourmaline, or very dark, but in Maine and elsewhere many other and often beautiful colors are sometimes found. This mineral is widely distributed over the State, not in large masses, but in scattered groups of crystals in some other mineral or rock. Small crystals, large enough to be easily seen, are found at South Strafford on the wall rock in the old mine where they are brown. Black tourmaline is found in Brattleboro, Bellows Falls, Cavendish, Newfane, Grafton, etc. Chemically tourmaline is very complex.

TREMOLITE

Tremolite is a calcium magnesium silicate $(CaMg_5(SiO_2))_4$. With actinolite and hornblende tremolite for the amphibole group. They are all crystalline hard, with glassy luster. The color varies from pure white to black, in hornblende. Tremolite when in fine more or less silky fibers is often called asbestos, and sometimes used as such, but it cannot properly supply the place of chrysotile, the variety of serpentine mentioned above. The fibers are not elastic.

WAVELLITE

Wavellite is very rare in this State and is, or has been, collected at Bellows Falls. Generally it is found in small concretionary masses of light color, white, green or gray. At the above locality it occurs in the gneiss rock. It has a glassy luster.

WERNERITE

In the older mineralogies this is called scapolite. It is a very complex mineral, containing soda, aluminum, silica, chlorine and perhaps other elements. It has been found in Brattleboro, Marlboro, and Guilford.

ZARATITE

Zaratite has been reported only from South Troy. Only in very small quantity has this rare mineral been found. Chemically it is a complex compound of nickel. It is green from the nickel in its composition.

ZIRCON

Zircon is a very hard mineral, a little harder than quartz. It occurs in igneous rock such as granite, diorite, etc., in small amount. It is usually dark in color, but may be other colors.

ZOISITE

Another hard compact stone found in several Vermont towns is zoisite. It is another of the great family of silicates. It is not quite as hard as zircon, but is yet one of the harder minerals. Its color may be white, green, pink, yellow or red. Zoisite is found ported from Bethel, Roxbury, Newfane, Woodstock and several other localities.

THREE GEOLOGICAL SERIES IN NORTH-WESTERN VERMONT[1]

HAROLD W. MCGERRIGLE

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CHAPTER I

INTRODUCTION

During the summers of 1928 and 1929 an area in southern Quebec known as the Lacolle Quadrangle was mapped for the Geological Survey of Canada by the writer. An area, about one-tenth of the total, in the southeastern part of the Quadrangle proved to be much more difficult and complex, geologically, than all of the remaining territory. This portion of the Quadrangle contains three distinct series of formations, or parts of them, which continue across the international boundary into that part of Vermont considered in this paper, and are represented there in greater or lesser force than in Quebec. In order to have more information regarding these series three weeks of outcrop mapping were spent by the writer in Vermont; this work being made possible by the joint support of the Geological Surveys of Canada and Vermont.

The three sets of formations are, first, the Highgate Springs Series; second, the Philipsburg Series; and third, the Central Sequence or Series of the "Cambrian Succession of Northwestern Vermont"; these are named in the order of their west to east succession and, generally speaking, from youngest to oldest. Thrusting from the east piled these series, and further folding, thrusting, and faulting within them added to the complexity of the region. The Highgate Springs Series is well shown south of the international boundary, but is barely to be recognized in Quebec; the Philipsburg Series has a much greater development

[1] Permission to publish granted by Director, Geological Survey of Canada.

in Quebec than in Vermont; while the Central Sequence, reaching from Monkton or still farther south in Vermont to the boundary line, a distance of about 60 miles, only extends 4 miles north of the boundary into Quebec and there it is minus many of its formations.

ACKNOWLEDGMENTS

The writer is grateful to Professors B. F. Howell and T. H. Clark for their guidance and help in the field, for their aid in the identification of formations and interpretation of structures. Most of the determinations given in this paper in respect to the Lower Cambrian formations of the Central Sequence resulted from the experience which Professor Howell has had with the strata of that sequence.

LOCATION AND EXTENT OF THE AREA

The area here considered lies beween the Quebec-Vermont boundary on the north and the Missisquoi River on the south, and between the shore (roughly) of Lake Champlain on the west and the seventy-third degree of longitude.

PREVIOUS WORK

Probably the most productive earlier work in this area was done by Sir William Logan.[1] He recognized the three distinct sets of formations mentioned above, and also that they were separated from one another by northerly-trending thrust faults. The Highgate Springs Series was described[1a] by him, 1863, in more detail than ever since and his sections are still standard. Also, his section of, and conclusions regarding, the Philipsburg Series[1b] are essentially correct. In regard to those Lower Cambrian strata, now included in the Central Sequence ("Red Sandrock," "Potsdam"), sections were given which seem to be fairly complete, but it is difficult at times to locate and recognize from his descriptions the various formations to which Logan refers[1c]; these beds are now included in the "Central Sequence."

In 1922, Prof. C. E. Gordon[2] published a generalized account of the geology of western Vermont in which additional information regarding the three series was given.

And, in 1923, Dr. Arthur Keith[3] described the "Cambrian Succession of Northwestern Vermont"; in this work the "Red Sandrock" series was separated into formational units and made

[1] Logan, Sir William, Geology of Canada, 1863. [1a] pp. 273-275; pp. 855-859. [1b] pp. 275-280; pp. 844-854. [1c] pp. 281-286.

[2] Gordon, C. E., Studies in the Geology of Western Vermont (Second Paper), Rpt. Vt. State Geol., 1921-22, pp. 143-285.

[3] Keith, Arthur, Cambrian Succession of Northwestern Vermont, Amer. Jour. of Sci., 5th series, Vol. V, 1923, pp. 97-139; also in Rpt. Vt. State Geol., 1923-24, pp. 105-136.

a part of the "Central Sequence" which includes Cambro-Ordovician as well as Cambrian formations.

Other work has been done on the geology of this particular region and results published, but little will be found in the relating literature elsewhere that is not contained in the reports of the geologists mentioned above.

Chapter II

GENERAL DISCUSSION OF THE THREE SERIES OF FORMATIONS IN THE AREA AND THEIR RELATIONS TO ONE ANOTHER

1. HIGHGATE SPRINGS SERIES

The formations composing the Highgate Springs Series are Chazy, Lowville, Black River, and Trenton in age. Logan and others believed that the Utica formation was present also, but only one fossil, "*Orthis testudinaria,*" mentioned by Logan,[1] has been found in the supposed Utica, and this form may be any one of a number of species with varying ranges although holding generally to the Middle and Upper Ordovician.[2] It is probable that these "Utica" beds are a shaly upper part of the Trenton.[3]

The most complete exposure of the series is at Highgate Springs, where all the formations mentioned above are shown. Between that village and Swanton, 4 miles to the south, no outcrops were seen by the writer. In the half-mile or so between Swanton and the Missisquoi River is a large outcrop of marbly-appearing, white or greyish limestone in massive beds. Similar rock outcrops about a mile to the northeast, on the Swanton-Highgate Center road. A third outcrop of this rock (south of the map limits) is a quarter of a mile east of the Central Vermont Railway and a half mile south of the river, and a fourth may be seen at Fonda Quarry 4 miles south of Swanton. The writer's observations did not continue southward from Fonda Quarry, but Logan[4] mentions outcrops of the "dove grey limestone" at 1, "Rich's lime works"; 2, about a mile south of Stevens Brook; and 3, at St. Albans Bay.

The chief problem in connection with these limestones is that of age, and there are two possibilities. The first is that they are Chazyan and a part of the Highgate Springs, as Logan[5] believed. But the resemblance between these limestones and the limestones of subdivision A 2 (see below) of the Philipsburg Series makes

[1] Geology of Canada, 1863, p. 275.

[2] Bassler, R. S., Index of Ord. and Sil. Fossils, U. S. Nat. Mus., Bul. 92, 1915.

[3] *Vide,* Ruedemann, R., Report on Fossils from the So-called Trenton and Utica Beds of Grand Isle, Vt., Rpt. Vt. State Geol., 1919-20, pp. 90-100.

[4] 1863, p. 857.

[5] 1863, p. 857.

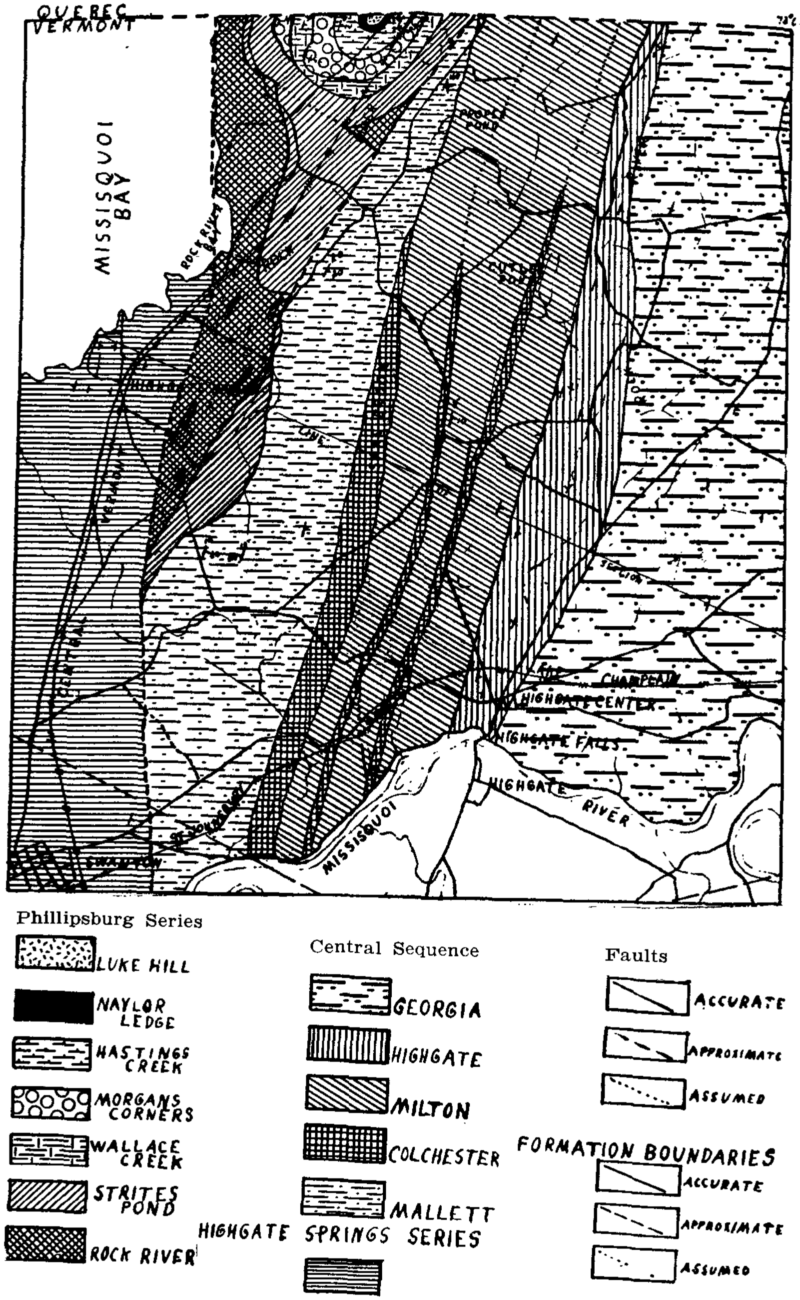

FIG. 13

it necessary to consider the second possibility, that the limestones mentioned above and those of A 2 may be the same.

If the limestones at Swanton and southward belong to the Highgate Springs Series then the Philipsburg Series is cut out by a thrust fault about 3 miles north of Swanton (see map, Figure 13). But if the limestones are actually subdivision A 2 then the Philipsburg Series must be continued southward as a relatively narrow strip to Swanton and thence southward through the Fonda Quarry to St. Albans Bay.

The main objections to calling the limestones in question the same as subdivision A 2 of the Philipsburg Series are: First, the absence at Swanton and southward to St. Albans Bay of the more resistant strata (dolomites and impure limestones) that are associated with A 2 at Philipsburg; and second, the mechanical difficulty of securing the long, narrow thrust block required if these limestones are A 2. If they are A 2 they are considerably older than the Black River strata associated with and to the west of them, at Fonda Quarry, for example, and have been thrust westward over the Black River; and, they are in turn overthrust by the still older strata (Cambrian) to the east of them.

From these considerations and from the discussion of the strata in question in the Geology of Canada[1] it is concluded that the light-colored limestones from Swanton southward to St. Albans Bay belong to the Highgate Springs Series (Chazy?) and have no relation to subdivision A 2 of the Philipsburg Series.

North of Highgate Springs to the boundary line and northward to Philipsburg, Quebec, along the eastern shore of Missisquoi Bay, are shaly beds which probably belong to the Highgate Springs Series but which do not seem to be represented at Highgate Springs. Judging from the structure these shaly beds would come in above the highest beds of the Trenton there exposed. Resting upon these shales by thrust from the east are the older beds of the Philipsburg Series.

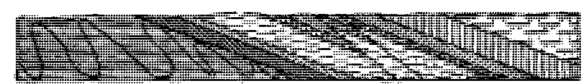

FIG. 14. Section east of Highgate Springs. Scale as in Fig. 10.

Although lying to the west of the St. Lawrence and Champlain fault and, therefore, in the region popularly considered to be made up of flat-lying strata, the Highgate Springs Series has suffered sharp folding and occasional faulting and thrusting within itself[2] (Figure 14). At Highgate Springs the folds plunge to the north under Missisquoi Bay, the bay itself being lined along

[1] 1863, pp. 273-275, 855-859.
[2] *Vide*, sections 444, 445, and 446, pp. 855-856, Geology of Canada, 1863.

its eastern and western shores with shaly strata of Trenton age. Formations definitely resembling the Highgate Springs Series do not again appear until about 50 miles north of the international boundary.[1]

2. PHILIPSBURG SERIES

The term "Philipsburg Series" is meant to include a group of thirteeen formations ranging in age from Ozarkian to Chazy and extending from about the latitude of Highgate Springs, Vermont, northward across the Quebec-Vermont boundary for about 20 miles. The name is taken from the village of Philipsburg, Quebec, where the lower formations of the series are well exposed.

Logan[2] has given the most complete account of the Philipsburg Series, and his table of formations[3] has been the standard of reference for other workers in this field. An outline of this table is given below; the formations are in descending order:

D 3.	Gray and black striped slates	1,500′
D 2.	Black and greenish, argillaceous slates	1,000′
D 1.	Limestone conglomerates, at least two bands, separated by slates	300′
C 2.	Black slates, or, thin-bedded black limestones	170′
C 1.	Black, massive, pure limestones	150′
B 5.	Black limestones, magnesian beds at the base	350′
B 4.	Black, slaty, thin-bedded limestones	300′
B 3.	Dark, bluish-gray, thin-bedded limestones	150′
B 2.	Dark limestones, some magnesian beds	120′
B 1.	White and dove-gray, pure limestones, some magnesian beds	120′
A 3.	Reddish-gray and black dolomites, some thin-bedded black limestones	200′
A 2.	White, and dove-gray, pure, compact limestones	100′
A 1.	Dark-gray and yellowish-white dolomites	400′
		4,860′

In this report the only formations that will be considered are those from A 1 to B 3 inclusive. Owing to the structure of the series, that of northward plunging anticlines and synclines, these older formations are the only ones which cross the boundary line into Vermont. Along the boundary the formations are arranged in a syncline with the axis about a half mile west of Rock River Valley.

During the writer's work on the Philipsburg Series north of the boundary it was found advisable to make some changes[4] over

[1] *Vide*, Logan, 1863, p. 273.
[2] Geology of Canada, 1863, pp. 275-280; pp. 844-855.
[3] 1863, pp. 844-846.
[4] The reasons for these changes are given in detail in a paper now being prepared by the present writer for publication by the Geological Survey of Canada.

Logan's section in that part of the series from subdivision A 1 to B 3; these are outlined below:

Logan's section		Revised section	
B 3	150′	Luke Hill	160′
B 2 (summit bed of)	120′	Naylor Ledge	30′
B 2 (except summit bed) and B 1	120′	Hastings Creek	260′
A 3	200′	Morgan Corners	150′
		Wallace Creek	200′-250′
A 2	100′	Strites Pond	400′
A 1	400′	Rock River	500′

In other words, Logan's subdivision B 3 remains practically unchanged; the summit bed of B 2 has been separated as a distinct formation, while the remainder of B 2 and all of B 1 have been placed in one formation; A 3 has been divided into two formations; one, the Morgans Corners, being a dolomite, while the other, the Wallace Creek, is an interstratified series of thin-bedded shaly limestones with thicker-bedded limestones; the thickness of A 2 has been increased from 100′ to 400′; and the thickness of A 1 has been increased by 100′.

The above-mentioned formations are shown on the map (Figure 11); it will be seen that the only beds having any considerable extent south of the boundary line are the two oldest members, the Rock River (A 1) and the Strites Pond (A 2). These members run almost due south from the line for about four miles. North of the line and for one mile south of it the Rock River and the Strites Pond preserve their identity fairly well, one below the other; but to the south, in the neighborhood of Highgate Springs, dolomites like the Rock River and marbly limestones like the Strites Pond become somewhat complexly interrelated. These relationships are such as to indicate either faulting, or, as the writer believes, interbedding of dolomites with limestones. The contacts along the strike and across it between the limestones and the dolomites are gradational in every case, and this fact would indicate interbedding or probably selective dolomitization rather than thrusting. Also, although the strikes and dips vary somewhat, they are so uniform at critical points as to argue against faulting.

However, it seems evident that thrust faulting has affected this southern part of the Philipsburg Series in at least two places. One of these is a mile and a half northeast of the cross-roads at Highgate Springs, and the other is about the same distance east-southeast of the same crossroads. At the former locality a band of marbly limestone about 100 feet thick overlies a wide exposure of dolomite, and is in turn overlain by about 100 feet of brecciated dolomite and limestone. At the second locality, the evidence of thrusting is in the easterly strike as contrasted with the normal northerly strike. The brecciation and the abnormal strike are evidently due to the proximity of the affected beds to the sole of the overthrusting Cambrian block lying to the east; at the places mentioned the overthrusting Cambrian block and the Philipsburg Series are seen almost in contact.

The eastern and western limits of the Philipsburg Series, as well as the southern limit, are determined by thrust faults. Taking the village of St. Albans Bay, Vermont, as an arbitrary starting point the great St. Lawrence and Champlain thrust runs just east of the village between the Highgate Springs Series and the Central Sequence. From here the abruptly rising ground on the east marks the approximate position of the thrust as far north as Missisquoi River. North of the river the course of the thrust is masked by a sand plain for about a mile and a half when its approximate position is again given by isolated dolomite outcrops of Lower Cambrian age. Somewhere in this vicinity the thrust branches, one arm continuing the northerly course and marking the limit between the Highgate Springs Series and the Philipsburg Series, and following along the shore of Missisquoi Bay from the mouth of Rock River to the Quebec-Vermont boundary. The other arm turns sharply to the east to pass between the Philipsburg Series and the Central Sequence blocks, and then, within a mile, also assumes a more northerly course to reach the valley of Rock River and follows this valley to the boundary line.

3. CENTRAL SEQUENCE

The greater part of the map area is underlain by strata of the Central Sequence ranging in age from Lower Cambrian to Lower? Canadian. The formations of the sequence, considered in this report, as well as others which do not appear this far north in Vermont, were described by Dr. Arthur Keith in 1923.[1] Since that time Prof. B. F. Howell[2] recognized other formations in the sequence. Any attempt to define the formations here in terms of lithology and relationship would necessarily be in the main a repetition of the work of these authors; a brief, compiled summary of their results is given below, in the form of a table of formations in descending order:

Middle Ordovician	Georgia slate (fossils)	2,000′+
"Post 'Saratogan'"	Swanton conglomerate (fossils)	0-30′
Unconformity		——
"Saratogan"	Williston limestone (fossils)	500′?
Upper Cambrian?	Shelburne marble (no fossils)	200′+
Upper Cambrian	Highgate slate (fossils)	300′+
Upper Cambrian?	Mill River conglomerate (fossils)	—— ?
Unconformity		——
Middle Cambrian	St. Albans shale (Pxbeds) (fossils)	200′?
Unconformity		——
Lower Cambrian	Milton dolomite (no fossils)	800′
	Unconformity	——
	Colchester shale (fossils)	500′
	Mallett dolomite (fossils)	700′-800′
	Winooski marble (fossils)	400′
	Monkton quartzite (fossils)	300′+

[1] Keith, Arthur, Cambrian Succession of Northwestern Vermont, Amer. Jour. of Sci., Series 5, Vol. 5, 1923, pp. 97-139 also in Rpt. Vt. State Geol., 1923-24, pp. 105-136.

[2] Howell, B. F., The Cambrian Paradoxides Beds of Northwestern Vermont, Rpt. Vt. State Geol., 1927-28, pp. 249-273.

Referring to the above table of formations, the formational names "Mill River" conglomerate and "St. Albans" shale were introduced by Professor Howell, who showed, also, that the Milton dolomite was not Upper Cambrian as previously supposed, but was pre-St. Albans and probably disconformable to the St. Albans and, therefore, probably Lower Cambrian. Fossils have been found in all of these formations except the Shelburne and the Milton. In this connection it should be recalled that in 1924 Prof. P. E. Raymond[1] described fossils from the "Milton" at Highgate Falls; later, Doctor Keith[2] recognized that these fossils did not come from the Milton and named the beds in which they occurred the "Missisquoi" formation, but, as this term was preoccupied, the fossiliferous beds in question are now without a name.

Judging from the distribution of formations given by Doctor Keith and Professor Howell, cross sections at Burlington, St. Albans, Highgate Springs, and the international boundary would show the following sequences:

Burlington	St. Albans	Highgate Springs	International Boundary
....	Georgia	Georgia	Georgia
....	Swanton	Swanton	Swanton
Williston	....	....	....
Shelburne	....	....	....
....	Highgate	Highgate	Highgate
....	Mill River	....	....
....	St. Albans	....	....
Milton	Milton	Milton	Milton
Colchester	Colchester	Colchester	Colchester
Mallett	Mallett	Mallett	Mallett
Winooski	Winooski	Winooski	Winooski
Monkton	....	Monkton	....

The Burlington and St. Albans sequences are given for comparison with the ones which more directly concern us here, namely, the sequence east of Highgate Springs and that at the boundary.

[1] Raymond, P. E., New Upper Cambrian and Lower Ordovician Trilobites from Vermont, Proc. Boston Society Natural History, Vol. 37, No. 4, 1924, pp. 389-466; also in Rpt. Vt. State Geol., 1923-24, pp. 137-203.

[2] See footnote by Doctor Keith on page 137 of second reference given above.

It will be seen from the cross sections (Figures 11, 12 and 13) and from the map (Figure 11), that the present writer does not recognize either the Monkton or the Winooski formations north of the Missisquoi River; and, also, that the Colchester formation, twice repeated by thrusting, does not reach the international boundary, while the Mallett has been greatly reduced in thickness along the boundary section.[1]

Doctor Keith[2] stated that the Monkton quartzite was represented by a "small mass east of Highgate Springs," except for which the formation was not found north of the Lamoille River. The only beds that the writer could find which would compare with the Monkton as described by Doctor Keith or as seen by the present writer farther south in Vermont were reddish sandstones which were traceable from about the latitude of Highgate Springs northward for 2 miles, east of the first north-south road east of Rock River. These beds, carrying *Ptychoparia adamsi,* are interstratified with brown-weathering, grayish dolomites through a thickness of about 200 feet, after or above which the red beds disappear but the dolomites continue and become interbedded with heavy layers of grayish quartzite. Thus, the "red beds" seem to be interstratified with, and to be conformably overlain by dolomites of the Mallett type without the intervention of the Winooski which, to the south, lies beween the Monkton and the Mallett; nothing referable to the Winooski was observed. From these considerations the "red beds"—the only strata observed which might be the Monkton—were mapped with the Mallett.

The most northerly definitely recognized outcrop of the Winooski formation is a half mile south of the area mapped, south of the Missisquoi River and just east of the Swanton-St. Albans road. At this place the mottled dolomite of the formation is quarried. North of the river, along the strike of the formation, no rocks are exposed for two miles, and the strata which then appear are greyish, brown-weathering dolomites which are here referred to the Mallett. West of these dolomites, or, about a mile and a half south-southeast of the crossroads at Highgate Springs, is a type of rock quite different from the others in the area; these the writer originally mapped as a separate unit, but Professor Howell believed that they should be placed in the Mallett. The rocks are grayish, fine-grained, arenaceous limestones with numerous interbeds of brown-weathering, somewhat arenaceous dolomites, and occasional interbeds of dark grey, oolitic limestones carrying fossils. The recognizable forms are the trilobite *Ptychoparia adamsi* and the brachiopod *Kutorgina cingulata(?)*.

[1] For the identification of the Mallett, Colchester, and Milton formations the writer depended largely on the opinion of Professor Howell who has had many seasons' experience with the strata of the Central Sequence.
[2] 1923, p. 107.

The strata in this outcrop form a syncline with a steeper eastern limb and an apparent southern plunge.

The Mallett dolomite begins, in the map area, as a wide exposure about two miles north of the Missisquoi River and maintains its width northward for two and a half or three miles. In this distance it comes upon the thrust fault along the eastern side of Rock River Valley, and from here northward the width of exposure and the thickness of the formation decrease through progressive loss of beds from the base of the formation. This decrease in the more northern reach of the formation is due to the swing in the strike of the beds which carries them across the trend of the thrust fault; the beds swing from an average N. 10° E. strike to one which averages N. 10° W., while the trend of the thrust is N. 15°-20° E.

The Colchester shale formation, estimated to be 500 feet thick in certain places,[1] is not well exposed north of the Missisquoi River. The best exposure is about two miles N. 15° W. of Highgate Center, on the eastern side of a road; as this road is followed northward the Colchester outcrops sparsely and intermittently on the eastern side for about two miles. In this distance the Milton dolomite lies immediately above the Colchester, but the actual contact was not observed. To the north the Milton dolomite lies across the line of strike of the Colchester, apparently having attained this position through thrusting. East of the Colchester mentioned above, or a little more than half a mile N. 15° E. of Highgate Springs, a few feet of Colchester shale are seen in uncertain relationship to the overlying Milton. If a line is projected to the north and south from this exposure along the general strike of the beds it will be seen to follow low land which, in part, is occupied by a stream draining northward towards Cutler Pond. This is important in view of Doctor Keith's statement[2] that the formation "usually occupies narrow valleys or hollows." The chief importance of this second occurrence of the Colchester is that it signifies a repetition of both the Colchester and Milton by thrusting.

That these formations have been once repeated seems certain, but that they have been twice repeated, as indicated on the map (Figure 10) and in the cross sections (Figures 14, 15), is not so definite. However, the dolomite immediately to the west of the first line of Colchester outcrops mentioned above bears more resemblance to the undoubted Milton (above the Colchester) than to the Mallett. Also, between this supposed Milton dolomite and the Mallett, and corresponding to the proper position of the Colchester if the dolomites are correctly identified, is the valley of

[1] Keith, Arthur, 1923, p. 112. The statement in regard to the thickness of the Colchester is as follows: "The thickness of the formation varies from 200 to 250 feet at the south and from 20 to probably 500 feet at the north."
[2] 1923, p. 112.

Saxe Brook; and it is logical to assume that this pronounced valley had been eroded in the less resistant Colchester shales rather than in either of the dolomites.

Following next above the Milton in this region, and without the intervention of the St. Albans shale or Mill River conglomerate, is the Highgate formation. No contact between the Milton and the Highgate was seen. The formation runs northward from Highgate Center to the boundary line through fairly continuous outcrops. The width of exposure is much greater at Highgate Center and northward for about four miles than it is at the boundary line. This is due to the more severe folding which the southern strata have suffered.

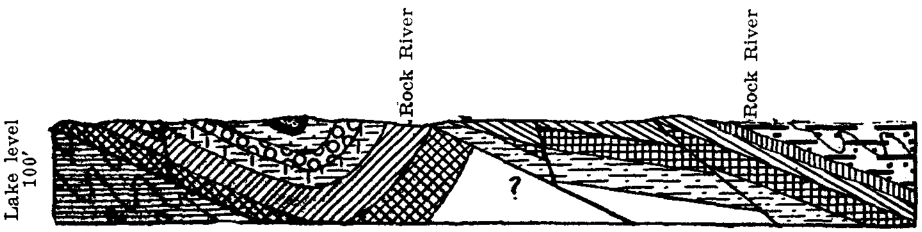

FIG. 15. Boundary line section.

Overlying the banded, calcareous shales and shaly limestones of the Highgate is the Georgia formation. The two formations are seen in contact at only one locality, and here, also, is the only exposure of the Swanton conglomerate north of the Missisquoi River. This is the locality mentioned by Doctor Keith[1] who stated that "At the Oliver Grandge farm, 4.5 miles N. 10° E. of Highgate Center and 0.5 mile from the Canada border, the (Georgia) slate was found by the author . . . , lying unconformably on the Highgate slate and separated from it by only a little lense of Swanton conglomerate. The gray, slightly sandy slate of the Georgia cuts out two feet of the Highgate slabby limestones, the two formations dipping easterly from 10 to 15 degrees."

The full extent of the Georgia across the strike is not shown (see map, Figure 11); the greatest width shown, in the southern part of the map area, is two miles, and, as the formation extends to the east of the limit of the map for probably another two miles, the total width of exposure in this region is four miles. This width gives little clue to the thickness, however, for the slate is highly folded. Although the Georgia consists preeminently of slate, some of which shows pronounced color banding, there are several interbeds (lenses?) of limestone conglomerate. The

[1] 1923, p. 125.

boulders in the conglomerate are commonly lath-shaped, fine grained, dark colored limestones; brownish-weathering dolomite boulders also occur, varying in size up to one foot in diameter, and worn very little; also, there are occasional slabs of somewhat shaly limestones which closely resemble strata in the Highgate. The matrix or cement is similar in composition to the lath-shaped pebbles.

AGE OF THE HIGHGATE AND GEORGIA

The problem of the age of the Highgate and Georgia formations is in a very unsettled state as far as the literature goes. It is hoped that the following résumé will prove helpful both to those familiar and unfamiliar with the formations in question.

In Doctor Keith's report[1] the Highgate is stated to be of Upper Cambrian age. Later, trilobites from this formation were described by Professor Raymond[2] and the following statement was made regarding them: "So far as can be judged from the trilobites as known at the present writing, the Highgate would be termed Ordovician rather than Cambrian but would be placed about on the border between the two." From a further study of the trilobites of the formation Professor Raymond has become more inclined to place it in the Ordovician, and tentatively suggests[3] that it is of Beekmantown age. Dr. E. O. Ulrich, basing his conclusions on field determinations of fossils, suggests[4] that the Highgate is Lower Ozarkian in age.

The Georgia formation: In 1923, Doctor Keith[5] stated that the fossils from certain localities, "according to the field determination by Schuchert, were at least as young as Black River and possibly as young as Trenton." In 1924, Professor Raymond described some trilobites from the lower part of the Georgia formation, and concluded[6] that the fauna indicated a Beekmantown age. And field determinations of fossils from two horizons in the formation led Doctor Ulrich to the conclusion[7] that these particular horizons are Upper Ozarkian.

[1] 1923, p. 115.
[2] Raymond, P. E., New Upper Cambrian and Lower Ordovician Trilobites from Vermont, Proc. Boston Society Natural History, Vol. 37, No. 4, 1924, p. 462.
[3] Personal communication, March, 1929.
[4] Personal communication, July, 1930.
[5] 1923, p. 125.
[6] 1924, p. 463.
[7] Personal communication, July, 1930.

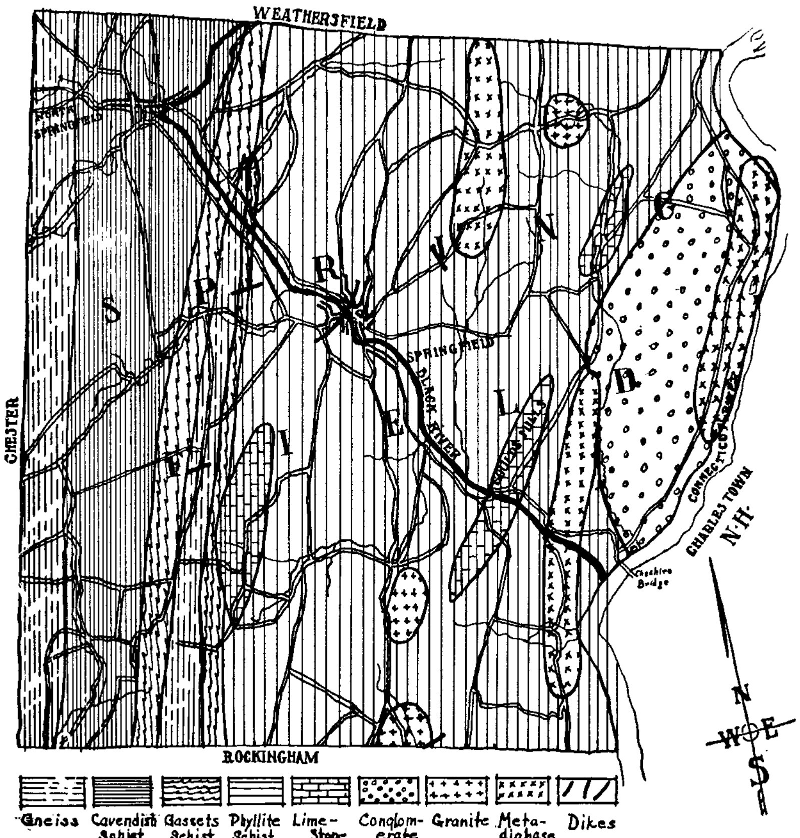

FIG. 16. Areal map of Springfield, Vt.

THE AREAL AND STRUCTURAL GEOLOGY OF SPRINGFIELD, VERMONT

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

INTRODUCTION

The report upon the Areal and Structural Geology of Springfield, Vermont, is of necessity brief. It can be considered only as one of progress in the study and interpretation of the complex geology on the eastern side of the Green Mountains.

The detailed field work upon which this report is based was done during the summer of 1930. However, some work was done in Springfield during the summers of 1928 and 1929. The reason for the selection of this area lies largely in the fact that it carries the field work east of Chester which was covered in the Report of the Vermont State Geologist for 1927-1928 eastward to the Connecticut River.

Springfield lies between north latitude 43° 21′ and 43° 14′. It also falls between meridians 72° 24′ and 72° 35′ west of Greenwich. It furthermore lies in four quadrangles. The eastern part is covered by the Claremont, New Hampshire, and the Bellows Falls, Vermont, quadrangles and the western part by the Ludlow and Townshend quadrangles which are not yet issued by the United States Geological Survey.

It is difficult to determine all of the field relations of the different terranes in Springfield for the area is hilly, glaciated and in part densely wooded. A few contacts were found that are intensely interesting.

The areal map shows the distribution of the different terranes as far as this factor could be determined in an area deeply covered by glacial drift. Outcrops were available for study on the crests of numerous hills, in stream channels and road cuts. The areal map appears in this report as Figure 16. A cross section of the terranes in Springfield is also given as Figure 17.

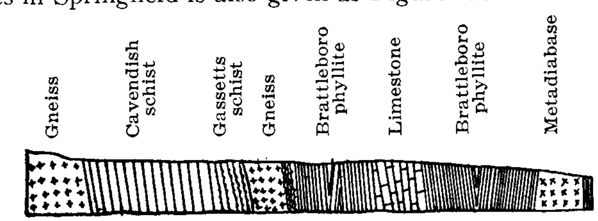

FIG. 17. Section, Springfield, Vt.
Scale: 1 inch = 2 miles, horizontal; 2,000 feet = 1 inch, vertical.

The area involved in this report has always been mapped as purely sedimentary, but both acid and basic intrusives have been discovered this summer and so far as possible their location will be shown on the areal map. It is interesting to note that some of the rocks considered by earlier geologists as highly metamorphosed sediments are now definitely proved to be granite gneisses. The presence of a large amount of microcline showing the characteristic grating structure substantiates this view.

Approximately fifty samples of rocks have been collected from Springfield alone from which microscopic slides have been made for detailed petrographic study. Without this type of study it is impossible to correctly translate the results of field investigations.

DRAINAGE

The chief drainage of the area involved in this report is effected by the Black River which rises in Plymouth, flows in a southeasterly direction through Springfield and empties into the Connecticut River a little to the south of the new Cheshire Toll Bridge. Spencer Brook is a much smaller stream that rises in the northern part of Springfield and empties into the Connecticut River a little to the north of the Toll Bridge. Black River receives several small tributaries from both the north and the south sides. Many of them have only local names and need not be mentioned.

TOPOGRAPHY

There is only one broad U-shaped valley in Springfield. This is the valley of the Black River. It crosses the township diagonally through the center. It is pre-glacial in origin. There are numerous transverse valleys that are in part pre-glacial and in part post-glacial.

In the absence of complete topograhpic maps of the area involved in this report a few of the observed altitudes may be of interest. The highest altitude observed was found on Mt. Ephraim in the southwestern part of the township. The altitude was 1,425 feet. Other altitudes observed were Pudding Hill, north, 1,300 feet, Monument Hill 1,290 feet, Rattlesnake Hill 1,060 feet, and Skitchewaug Mountain 920 feet. The altitude given as a bench mark on the steps of the Adnabrown Hotel is 415 feet. The altitude at the Cheshire bridge is 314 feet and along the Connecticut River east of Skitchewaug Mountain 300 feet.

GLACIATION

Evidences of glaciation in Springfield are very abundant. The general direction of the ice movement can be determined by

the striations on the more resistant rocks. Well-defined grooves were observed in the highly metamorphosed pre-Ordovician schists in their outcrops on the higher altitudes. The variations in the directions recorded range from due south to south 20 degrees east and south 20 degrees west.

One of the most interesting evidences of glaciation is found in the Cathedral rocks in the extreme northern part of Springfield on what is locally known as the Boss farm. Here there are two huge boulders of granite that came from Mt. Ascutney on the north. Each boulder will weigh over 500 tons.

On the farm to the northwest of the Horace Brown place there is a boulder of Cavendish schist that has been estimated to weigh over 1,000 tons. It has not traveled far.

LAKES

The only lake or pond found in Springfield that is worthy of mention is Bloodsucker Pond which is located in the northeast part of the township. It is a glacial pond and covers only about ten acres.

GEOLOGY AND PETROGRAPHY

The geology of Springfield is more intricate and complex than it is in most of the towns in eastern Vermont. The sedimentaries consist of highly folded and faulted metamorphics that are often invaded by intrusives of more than one period of introduction. The sediments range from quartzose marbles to quartzites with no trace of a lime content, and from slate or phyllite to highly chloritic and epidotic mica schists. In fact some of the rocks listed as sediments in this report are so highly metamorphosed that it is extremely difficult to prove that they were not of igneous origin. The intrusives range from acid aplites through soda granites to diorites and diabases. No peridotites or pyroxenites were found in Springfield.

In the petrographic study of the microscopic slides under polarized light the microscope tells us what the individual constituents in both the sedimentary and igneous rocks now are but does not always reveal with certainty the mineral composition of the original rock Metasomatic replacement has been so complete in some instances that we cannot say with certainty what the original rock was, or whether it was of igneous or sedimentary origin. In some instances what constituents have been subtracted and what added and under what conditions various solutions were introduced, we do not know.

The sediments vary in age from Cambrian to Ordovician. There is no positive evidence of any pre-Cambran sediments in

Springfield, nor is there any evidence of any sediment younger than Middle Ordovician. The intrusives range in age from the Cambrian to the Carboniferous and possibly the Triassic.

A large number of microscopic slides have been examined in the petrographic laboratory. The detailed study of these slides has brought out some exceedingly interesting facts. These are so nearly akin to the facts listed in the report on Grafton and Rockingham in this volume that they need not be repeated here.

CAMBRIAN

The Cambrian formations consist of a series of highly folded, faulted, metamorphosed sediments that may be listed as quartzites, feldspathic quartzites, feldspathic mica schists, sericite schists, biotite schists, hornblende schists, chlorite schists and epidotic chlorite schists. These were apparently derived from the erosion of some Algonkian land mass on the west during Cambrian times.

That these terranes listed as Cambrian are post-Algonkian in age is proved by three facts:

1. They all overlie the Algonkian gneiss that flanks them on the west.
2. They all underlie the Irasburg conglomerate which is Ordovician.
3. The lowest member of the Cambrian group is the Sherburne conglomerate.

LOWER CAMBRIAN

There is no positive evidence that any lower Cambrian terrane exists in Springfield. Lower Cambrian formations do exist in Ludlow, Andover, and Windham which lie directly to the west of Chester and Grafton.

UPPER CAMBRIAN

The terranes listed as Upper Cambrian comprise a series of highly-folded metamorphic rocks that have been invaded by both acid and basic intrusives. These schistose rocks may be listed as muscovite schists, biotite schists, hornblende schists, chlorite schists, quartzites and a conglomerate. Two or even more of these members may occur within the same formation.

CAVENDISH SCHIST

The essential mineral composition of the Cavendish schist is quartz and biotite. Hornblende is often present and sometimes the hornblende replaces nearly all of the biotite when the rock is best listed as a hornblende schist. Among the accessory minerals

epidote is very abundant. A plagioclase feldspar is invariably present. Garnet, tourmaline, chlorite, apatite, pyrite and magnetite are common. Zoisite, zircon and rutile have been found in some slides. The normal color of the Cavendish schist is a dark gray. Its texture varies from fine to medium.

In stratigraphic position this schist unquestionably underlies the Gassetts schist which belongs to the Missisquoi group. Actual contacts between these two formations can be seen in the road cut a few rods north of Gassetts Station and by this side of the Springfield Fairgrounds. Arguments are not conclusive that it either underlies or overlies the Bethel schist which is regarded as the oldest of the Upper Cambrian formations in eastern Vermont. It may represent the time equivalent of the Bethel schist. It is definitely proved to be older than the sericite schists and the Gassetts schist.

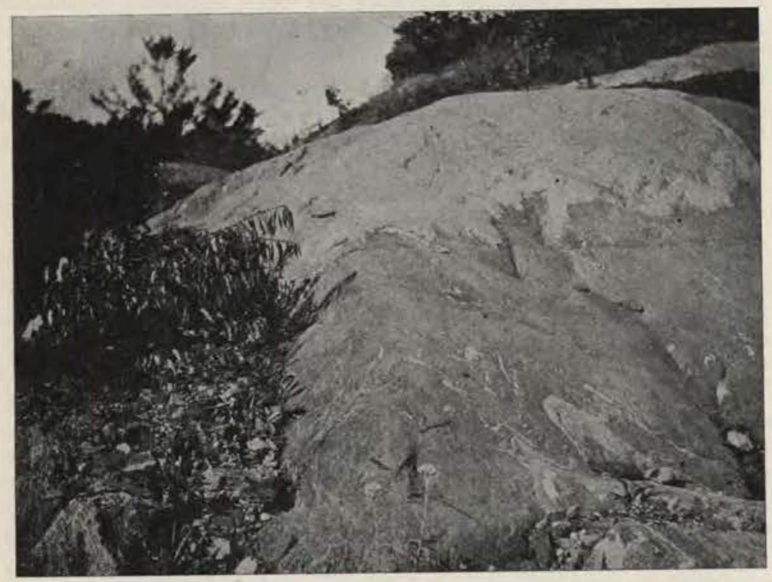

FIG. 18. Contact, Cavendish schist and Gassetts schist, Springfield, Vt. Gassetts schist, upper; Cavendish schist, lower.

The Cavendish schist occupies a large area in Springfield as will be seen by consulting the areal map, Figure 18. It stretches across the entire township in a north and south direction. Its strike varies from north and south to north 10 degrees east. Its dips are mostly from 75 to 85 degrees east. In a few instances the dip is vertical, and in some instances the dip is at a high angle to the west. It carries several more or less lenticular beds of granite gneiss which may in part be responsible for these variations in dip. As a unit it constitutes the eastern leg of an anticline. The western leg can be seen in the cut a few rods north of Gassetts Station and in the railroad cuts south of Cavendish. The two legs of the anticline are usually separated by granite gneiss. That this gneiss is not a para-gneiss is evidenced by a large amount of microcline which shows excellent grating structure in the microscopic slides.

MISSISQUOI GROUP

The Missisquoi group comprises sericite schists, sericitic quartzites and a medium to coarse textured, highly garnetiferous muscovite schist with minor beds of chlorite schist, hornblende schist and gneiss that may not be of sedimentary origin in all instances. This group of terranes has been followed southward from the international boundary on the north into Windham County, a distance of nearly one hundred and fifty miles. The typical fine-grained sericite schist of the more northern townships does not occur in mapable areas in Springfield. The typical silvery white highly garnetiferous muscovite schist does occur and is listed as the Gassetts schist.

GASSETTS SCHIST

The Gassetts schist is essentially a silvery white, highly garnetiferous mica schist. The texture is scaly, or the muscovite is arranged in parallel plates and is by far the most abundant constituent. It is not the fine-grained silvery-white sericite of the sericite schists. The quartz grains are somewhat angular. The garnets are abundant and vary in size up to an inch in diameter. One was found this summer nearly two inches in diameter but this was exceptional. In form the garnets are rhombic dodecahedrons. Well-defined tourmaline and staurolite crystals are abundant at the Gassets mine but they do not appear to be present in all of the outcrops in Springfield. The garnets also do not appear in Springfield in sufficient abundance to be an economic factor even though they are invariably present in all the outcrops.

The stratigraphic position of the Gassetts schist is unquestionably above the Cavendish schist. As already noted the actual contact between these two formations can be seen on the north side of the road from Springfield to Chester a little to the west of the Springfield Fairgrounds. Figure 18 shows this contact. The dark-colored rock is the Cavendish schist.

The general strike of the Gassetts schist is north and south but it varies up to north 20 degrees east. Its dips vary from 75 to 85 degrees to the east but in some of the highly-folded outcrops westerly dips were recorded. It lies to the east of the Cavendish schist and affords the best area for study on Stellafane Hill which is noted for its camps and telescopes for astronomical work. Here the schist is highly folded, crumpled and injected with numerous quartz veins and stringers.

CHLORITE SCHISTS

There are numerous beds of chlorite schist in the Missisquoi group that conform to the dip and strike of the Gassetts schist. This fact has also held true with reference to the sericite schist and sericitic quartzites which also belong to the Missisquoi group. Beds of chlorite schist also occur in the Cavendish schist. All such beds are regarded as of sedimentary origin for the following reasons:

1. The extreme narrowness of the beds.
2. Their conformity in dip and strike to beds of unquestioned sedimentary origin.
3. The presence of an appreciable amount of more or less rounded quartz grains.
4. The absence of any alteration by igneous intrusions in the walls of the enclosing sediments.
5. The absence of any plagioclase feldspars that could not have been derived from sediments.

If the above interpretation is correct then the age of these chlorite schists must be the same as the age of the enclosing sedimentary rocks. There are chlorite schists in Springfield that do not fall in this category. These will be described later.

HORNBLENDE SCHIST

There are lenticular beds of hornblende schist in Springfield that may represent hornblendized sediments. The arguments in favor of a sedimentary origin and also the arguments in favor of an igneous origin of such deposits are given in full in the report in Grafton and Rockingham in this Biennial Report of the State Geologist and need not be repeated here.

One of these hornblendic beds may be found about one-half mile west of Hardscrabble Corner. Some of the crystals of hornblende are three to four inches in length and from one-half to one inch in width. Some of them are parallel with the planes of schistosity while others lie directly across these planes. It is possible that the more hornblendic phase of the Cavendish schist already described should have been described here. This dark-colored schistose rock listed as the Cavendish schist covers an extensive area in Cavendish, Chester, Rockingham and Weathersfield.

SPRINGFIELD CONGLOMERATE

The term Springfield conglomerate is new in the geological literature of eastern Vermont. Its introduction is demanded by the discovery on the west side of Skitchewaug Mountain a new conglomerate. An outcrop easy of access can be seen on the hill a few rods east of the Spencer School house. Figure 19 shows this conglomerate dipping to the west.

FIG. 19. Conglomerate, dipping west, near Spencer Schoolhouse, Springfield, Vt.

The Springfield conglomerate lies on the east side of the Spencer Hollow road. The nearest approach to the road is only a few rods east of the Spencer School house.

The pebbles in the conglomerate range in size from a fraction of an inch up to six inches in diameter. The most of them are quartz. A few small pebbles of a mica schist were observed. The matrix is a mica schist. The mica is mostly muscovite. It presents a silvery white appearance in many of the outcrops. This conglomerate carries much secondary quartz in veinlets and stringers. In some outcrops the rock appears as a quartz schist while in others it appears as a coarse textured quartzite. Some of

the pebbles are well rounded while others are stretched or elongated. The metamorphism has been intense. The strike of a given bed can change 90 degrees within a foot. It is highly folded and crumpled and dips in all directions. At the locality cited above the dip is to the west. While near the top of the Skitchewaug Mountains the dip is to the east.

The exact age and true stratigraphic position cannot be stated without additional field work. The time available for field work this summer was inadequate for detailed work on Skitchewaug Mountain. This area needs to be carefully worked out when the township of Weathersfield is surveyed for this township lies immediately to the north of Springfield.

Several interesting questions can be raised concerning this mountain area for this conglomerate and its associated beds does not occur in Vermont south of Springfield nor does it occur to the north of Springfield. To the south of Springfield the terranes in the Connecticut Valley are all Ordovician save for intrusives. The same holds true for Weathersfield and Windsor to the north of Springfield. The queries raised may be listed as follows:

1. Does Skitchewaug Mountain represent a fault block that has been thrown to the west of the Connecticut River from New Hampshire?
2. Does it represent a block faulted upward from the Cambrian beds beneath the Ordovician in eastern Vermont?
3. Does it represent a conglomerate formed at the base of the Cambrian? If so it should be the time equivalent of the Sherburne conglomerate.
4. Does it represent a conglomerate formed at the close of the Cambrian and upon which the Ordovician terranes rest unconformably?
5. Does it represent a new unexpected Ordovician conglomerate? If so it should be the time equivalent of the Irasburg conglomerate.

There is no evidence of anything Ordovician either in the pebbles themselves or in the matrix. Both the pebbles and the matrix appear to be Cambrian. The formation is worthy of further study that the above questions may be answered.

ORDOVICIAN

The term Ordovician as here used embraces a series of sedimentary rocks that lie unconformably upon the east flank of the Cambrian terranes. They consist of limestones, or quartzose marbles, slate and phyllite schists.

The structure of the limestones and phyllite schists is best seen in the Black River Valley. Near the Cheshire Toll Bridge the dip is 85 degrees to the east, but the dip soon becomes vertical and then changes to a steep westerly dip of 80 to 85 degrees. There is, therefore, a sharp anticline in the eastern border of the Ordovician in Springfield. Before reaching Goulds Mills the dip is again to the east and this easterly dip continues across the remainder of the Ordovician terranes save for minor variations as observed on some of the higher altitudes. This easterly dip can be easily seen in the interbedded phyllites and limestones at the falls in the Black River in the village of Springfield.

WAITS RIVER LIMESTONE

The Waits River limestone in Springfield is of a dark-gray color and susceptible of a high polish. It does not form a continuous terrane across the township. It is usually interbedded with the phyllite. Sometimes these limestone beds are only a few inches in thickness and again they may be 8 to 10 feet in thickness.

There are three limited areas in Springfield that may be mapped as limestones. The most distinctive of these lies to the west of the Cregg Hill road and to the east of Mt. Ephraim and Monument Hill. A second and much narrower belt lies in the Black River Valley or better crosses the valley in a direction approximately N. 10 degrees east. The smallest of the three areas lies at the head of Spencer Hollow and south of Rattlesnake Hill.

The only essential minerals in any of the rocks of these areas are quartz and calcite. A few small plates of muscovite are usually present. The calcite is perfectly recrystallized. The quartz grains are usually small and well rounded but sometimes they appear elongated by the pressure to which the rock has been subjected. Strictly speaking the rock is a quartzose marble and belongs to the Washington phase of the Waits River limestone.

MEMPHREMAGOG GROUP

The Memphremagog Group consists of slates and phyllites. In the northern half of the state the slate has appeared as a continuous belt. In Springfield the belt is broken. The phyllites constitute the prevailing terranes.

SLATE

The Memphremagog slate occurs in two distinct belts in Springfield. One lies in the wooded area back of the stone house of Roland Greely at the head of Spencer Hollow and south of Rattlesnake Hill. This slate was quarried for several years but the quarry is now idle. The slate makes an excellent flagging stone.

The second slate belt is on the farm of Lillian Crary in the northeast part of the township. The quarry is in the open pasture by the side of the road leading from Spencer Hollow to the Connecticut River. It is on the east slope of the hill and extends to the river. The strike of the slate belt is N. 40 degrees east and the dip is 45 degrees to the east. Some strikes were recorded N. 50 degrees east. The slate is bluish black in color with good fissility and can be used for both roofing and flagging purposes.

BRATTLEBORO PHYLLITE

The Brattleboro phyllites constitute the prevailing terrane in the eastern half of Springfield. The area covered by this phyllite in Springfield is nearly if not quite equal to the area covered by all the other formations combined. It crosses the entire township, extends northward into Weathersfield and Windsor and southward into Massachusetts. It flanks the Connecticut River on the west save for the area covered by the Springfield conglomerate.

The Brattleboro phyllite may be the time equivalent of the Randolph phyllite which lies to the west of a broad belt of Waits River limestone. The Brattleboro phyllite here lies to the east

Fig. 20. Limestone and phyllite dipping east, Springfield, Vt.

of a broad belt of Cambrian terranes that extend in a northeasterly direction across Springfield and its adjacent townships.

The strike of these phyllites varies from north and south to north 40 or even north 45 degrees to the east. In Springfield the dip of the planes of fissility vary from 75 degrees east to 90 degrees and with correspondingly steep westerly dips. The structure of the phyllites would be that of close folded anticlines and synclines. Figure 20 shows the easterly dip of the limestone and phyllite.

ACID INTRUSIVES

The acid intrusives in Springfield consist of aplites, granites, pegmatites and granite gneisses. The gneisses are the most abundant.

APLITE

Aplite dikes are occasionally observed in Springfield but they are not abundant. The best exposure is at the Power Plant just above Goulds Mills in the Black River Valley. Acid dikes varying in width from two to three feet cut the limestones and phyllites. Sometimes they are nearly but not quite parallel with the strike of the sedimentary rocks and again they are nearly at right angles to the strike of the sedimentaries.

The aplites are of fine even texture, of light-gray color and exceedingly tough. In composition they consist of quartz, albite to albite-oligoclase and muscovite. There are a few crystals of orthoclase and plates of biotite. Minute apatites are also present.

At the further end of the dam the dikes are wider and nearly at right angles to the schistosity of the enclosing rock.

GRANITE

There are three granite outcrops in Springfield but they are not of large dimensions. They are all soda granites for the plagioclase feldspars, albite to albite-oligoclase exceeds the potash feldspars, orthoclase and microcline. They are usually biotite granites but some are muscovite granites while others carry both muscovite and biotite. The typical accessory minerals are apatite, zircon, epidote, microlites of pyrite and magnetite, with occasional scales or plates of chlorite derived through the chloritization of the biotite.

These granites are of fine to medium texture, of light gray to a medium gray color, and susceptible of a good polish. These can be used for both monumental and constructional work. The stone house built at Hardscrabble Corner about eighty years ago is an illustration of the weathering qualities of this stone. The house is in a good state of preservation. The most conspicuous

iron-stained block is one that was set with a joint plane in the face of the building.

The largest and the most important granite area in Springfield is the one just south of Hardscrabble Corner. There is an abandoned quarry of this granite on the Perry Robinson farm now occupied by Joseph Siliski.

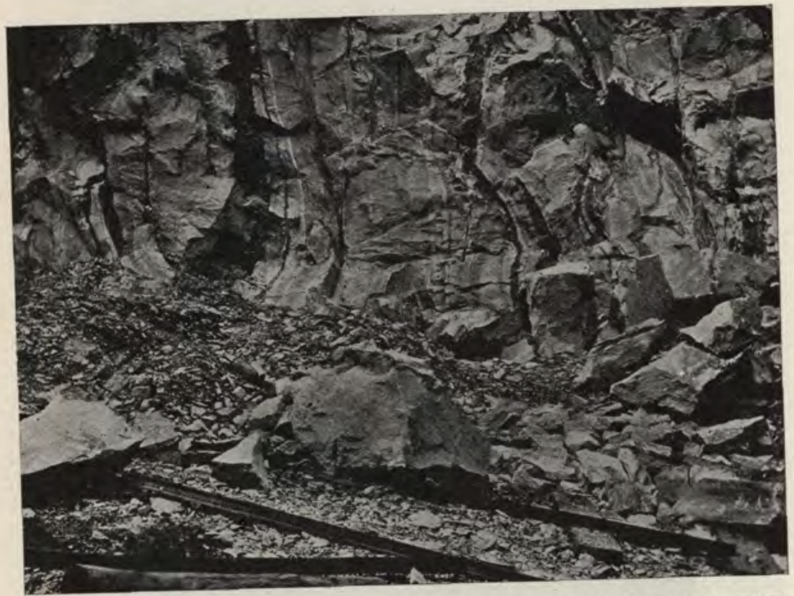

FIG. 21. Quarry of granite gneiss, showing zenolith of Cavendish schist four feet in diameter, Springfield, Vt. Also shows a long zenolith.

The second granite area in size and importance is situated in the extreme southern part of Springfield, a little to the southeast of the Parker Hill School house. The granite lies in both Springfield and Rockingham. It is of medium-gray color and could be used for both monumental and constructional work.

On the high altitude of Mt. Ararat some two miles northeast of the village of Springfield there is a small granite area. It is doubtful if this granite could be used with success either as a monumental or constructional stone.

GNEISS

Gneisses are abundant in Springfield. They represent more than one period of introduction and possibly more than one mode of origin. Their mineral composition, texture and structure are widely different. They do not belong to the Bellows Falls gneiss of Rockingham nor to the Bull Hill gneiss of Grafton. Most of them are closely related in mineral composition and texture to the Reading gneiss and therefore they are listed as Reading gneiss in this Report (Figure 22).

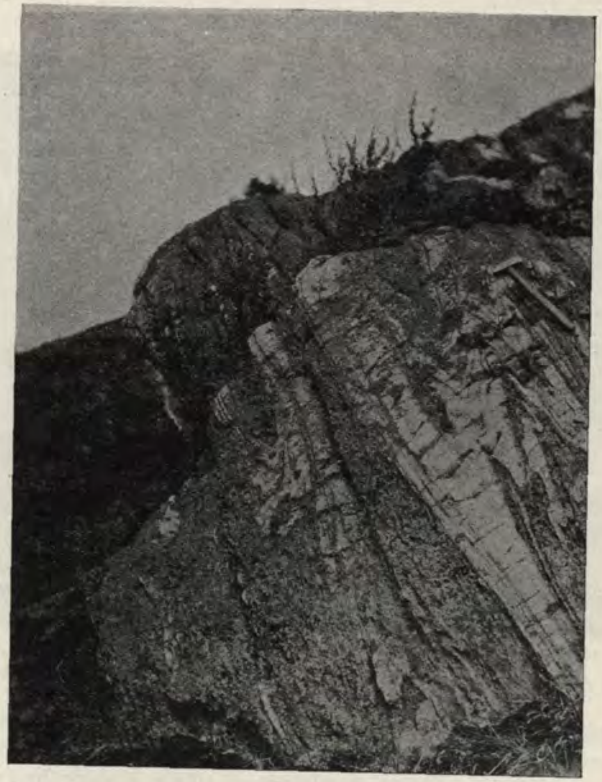

FIG. 22. Close-folded gneiss and schist, Springfield, Vt.

READING GNEISS

The Reading gneiss occupies rather an extensive area in the extreme western part of Springfield. It appears to extend across the entire township. An excellent exposure of this gneiss can be seen in the open pasture on the north side of the road from North Springfield to Gassetts. Here the dip of the gneissoid planes is at a low angle to the east. The rock is quite massive. Other good exposures are found along the west road from North Springfield to Chester Depot and on the hill north of the road from Springfield to Bartonsville but near the Chester town line.

The general structure is that of an anticline. It is flanked both upon the east and the west by the Cavendish schist. On the east side the Cavendish schist dips to the east and on the west side it dips to the west. The gneissoid planes often dip at high angles but between North Springfield and Gassetts the dips are low.

The petrographic study of a large number of microscopic slides has revealed an abundance of microcline. The feldspar in some slides is nearly all microcline which shows the characteristic grating structure. The abundance of this feldspar suggests that the rock was derived from a granite rich in microcline rather than from highly feldspathic sediments.

A second belt of the Reading gneiss occurs about a mile west of the village of Springfield. A little to the north of the main road from Springfield to Chester there is an active town quarry that gives an excellent opportunity to study the structure and general character of the gneiss. In this quarry alone three different phases of the gneiss were found.

1. A gneiss rich in biotite and of dark color.
2. A muscovite-biotite gneiss of medium-gray color.
3. A muscovite gneiss of very light gray or even white in color.

The quarry carries three zenoliths of the Cavendish schist. One of these is about four feet in diameter and completely surrounded by the gneiss. Another extends from the top of the quarry down to the quarry floor but it is here cut off by the gneiss. The third extends beneath the quarry floor for an unknown distance. The gneissoid planes dip at a steep angle to the east. The gneiss makes a very satisfactory road-building rock.

Another excellent exposure of this gneiss occurs on the Walnut Hill farm owned by the Rev. Dr. F. S. Idleman. Here there is an abandoned quarry. The stone house of Doctor Idleman was built in 1840 and is in a good state of preservation. The massive blocks show but little if any iron stain. The stone in the Methodist Church in Springfield also came from this quarry. The church was built in 1843.

Reading gneiss also occurs on Monument Hill about two miles southwest of the village of Springfield. Here the gneiss is highly folded, crumpled, and faulted.

The gneiss of Mt. Ephraim is of entirely different mineralogical composition. The ferromagnesian mineral is now hornblende. Microcline is absent and the feldspars are albite to albite-oligoclase. They are largely small granulated feldspars. Many of them show the characteristic albite twinning. They may have been more basic when first formed and albitized during the metamorphism of the rock as a whole. The hornblende is well preserved but some of it is chloritized. The paucity of quartz in the rock suggests that the original rock was a diorite rather than a hornblende granite and that the rock is now a diorite gneiss.

Some petrographers may suggest that this is a paragneiss with the original sediment hornblendized by metasomatic solution but the large abundance of granulated plagioclase feldspars is against this theory. The gneiss is highly folded, crumpled and faulted like the gneiss on Monument Hill.

PEGMATITE

The pegmatites of Springfield are far less abundant than they are in Grafton and Rockingham. They do cut the gneisses and schists of Cambrian age and are not regarded as commercial possibilities.

BASIC INTRUSIVES

Basic intrusives occur in Springfield. They are associated with both the Cambrian and Ordovician terranes. They consist of diorites, diorite gneisses, diabases and metadiabases. The pyroxenites and peridotites that were so abundant in Reading, Cavendish, Chester and Grafton do not occur in Springfield for Springfield is situated to the east of the peridotite belt that traverses Vermont in a north and south direction.

DIORITE AND DIORITE GNEISS

These granitoid igneous rocks are of limited distribution in Springfield. They occur mostly in dikes. Such a dike consisting of hornblende and plagioclase feldspar can be seen on the south side of Black River near the turn that leads to the Horace Brown place. It is also a little northwest of the Springfield Fair-grounds. Here the dike some three feet in width cuts directly across the Gassetts schist in an east and west direction. It is possible that the diorite gneiss of Mt. Ephraim should have been discussed here rather than under the caption of gneisses.

DIABASE AND METADIABASE

Dikes of typical diabase are rare in Springfield. One such dike occurs in the southern part of Springfield a little to the southeast of the Parker Hill School house. It cuts the granite in both Springfield and Rockingham. It varies from two to three feet in width and its position is nearly vertical.

A basic dike was found on Monument Hill cutting the granite gneiss. It is only about a foot in width. It is of dark-gray color and extremely tough. It has been very highly altered

and it is extremely difficult to say with certainty what the original dike was. Probably it was a diabase. The presence of a few small augite grains and crystals of labradorite substantiates this view.

METADIABASE

The term metadiabase as here used is a shortened form for a metamorphic diabase. The term was first used by Dana for certain rocks resembling diabase, but supposed to have been produced by the metamorphism of sediments. If the broader interpretation can be given the term making it include highly metamorphosed basic igneous rocks of the diabase group then the term metadiabase is applicable here. The author of this report long considered the use of the term epidotic chlorite schist but this seems too long and cumbersome.

It is true that the outcrops are all chloritic, highly epidotic and schistose. The outcrops at times are so rich in epidote that the rocks may well be called epidosites (Figure 23).

FIG. 23. Outcrop of metadiabase, Spencer Hollow, Springfield, Vt.

The metadiabases in Springfield are of green color, often compact and extremely tough, but planes of schistosity traverse all of them. These planes are far more marked in some outcrops than in others. Epidote and chlorite are the most abundant constituents. Plagioclase feldspars, magnetite, titanite, calcite and pyrite are invariably present. In some slides there is a little sporadic quartz while in others there is not a single grain of free quartz. In some slides the plagioclase feldspars are labradorite and some grains of augite were identified. The presence of these two minerals together with the fineness of texture are strikingly suggestive that the original rock was a diabase. The original labradorite has been calcitized and albitized. The augite has been hornblendized and then chloritized. The rock has been so completely changed that scarcely a single original constituent remains.

The field relations of these outcrops are very important. The outcrops at times stand out in bold relief with the surrounding sediments worn away (Figure 24).

FIG. 24. Highly altered metadiabase, Springfield, Vt. Planes of schistosity nearly vertical.

There are two distinct belts of metadiabase in Springfield. The smaller of the two lies on the first range of hills east of the Poor House. It extends northward nearly if not quite to the Weathersfield town line and southward nearly to the Crown Point road. It cuts rocks of Ordovician age. This is the first instance where the metadiabase rocks have been found cutting the Ordovician terranes in eastern Vermont.

The larger of the two areas of metadiabase in Springfield is situated in the extreme eastern part of the township. The northernmost outcrops were found to the east of the Spencer Hollow road on the west side of Skitchewaug Mountain, and the southernmost outcrops observed were about one-half mile south of the outlet of Black River. Quite a large part of Skitchewaug Mountain appears to be metadiabase.

The general structure appears to be that of an anticline but the dips are nearly vertical. In a section in the Black River Valley the dips on the east side are to the east and on the west side to the formation they are to the west. The sedimentaries which this rock cuts have the corresponding dips both to the east and the west.

PALEONTOLOGY

As yet no fossils have been found in the pre-Ordovician terranes on the eastern side of the Green Mountains. The relative age, therefore, of these formations has been determined by their stratigraphy, continuity and lithological characteristics. No new fossils were found this summer in the Ordovician terranes in Springfield. The paleontological evidence of the Cambrian and Ordovician terranes in eastern Vermont was given so fully in the Biennial Report of the Vermont State Geologist, 1927-1928, that it need not be repeated here.

ECONOMICS

There are no known commercial metallic or non-metallic minerals in Springfield. True it is that some of the quartz veins have been opened and selected samples sent away for assay which are reported to show gold values. The narrowness of the veins and spotted character of the values are against these deposits being commercial possibilities. The talc and steatite deposits which are so abundant in Chester and Grafton do not occur in Springfield.

The granites in Springfield are susceptible of a good polish and can be used locally for monumental and constructional work. The stone house which was erected at Hardscrabble Corner many years ago for a hotel is an evidence of the weathering qualities of this stone.

The granite gneiss of the Town Quarry and the Walnut Hill farm of Dr. F. S. Idleman is an excellent road-building stone and it can also be used in constructional work. The Methodist Church in Springfield erected in 1843 shows the value of the Walnut Hill stone in constructional work.

The slate on the Roland Greely farm is a good flagging stone and that on the Lillian Crary farm is good for both flagging and roofing purposes. The quartzose marbles of the Black River valley and the Dutton district are susceptible of a high polish and can be utilized for monumental work. The metadiabase of the Skitchewaug Mountain area is an excellent road-building stone.

THE GEOLOGY AND PETROGRAPHY OF GRAFTON AND ROCKINGHAM, VERMONT

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

INTRODUCTION

The report upon the Geology and Petrography of Grafton and Rockingham, Vermont, is of necessity brief. The time available for detailed field work and the petrographic study in the laboratory at Syracuse University has been altogether too limited to bring out all that might be desired as to structure and the mineralogical composition of the terranes involved. However, some important discoveries that bear upon the mineralogical composition and probable age have been interesting. It is hoped that the results will be presented clearly of this new study of field relations and petrographic evidence in a field hitherto undescribed, yet closely folded, faulted, and invaded by both acid and basic intrusives. The mode of origin cannot be ascertained with certainty in some instances even with a most careful petrographic study. While in others the petrographic evidence is practically irrefutable. The high percentage of microcline showing the characteristic grating structure in rocks that are coarsely laminated is a strong argument in favor of an igneous origin. Yet these terranes have always been mapped in as sedimentaries. In other instances metasomatic replacements have been so pronounced that it is impossible to say with certainty what the original minerals were and what the original rock was. It is difficult to determine the actual age of some of the terranes because no fossils have yet been found in the pre-Ordovician formations of eastern Vermont. The absence of topographic maps have impeded progress in mapping the areal distribution of the different terranes. The heavy burden of glacial drift that covers the area renders the correct interpretation of structure exceedingly difficult in Grafton, but in Rockingham in the valley of Williams River the structure could be determined with reasonable accuracy. By traversing both the river bed and the railroad cuts four distinct anticlines and four synclines were found in the township of Rockingham.

The area involved in this report lies between north latitude 43° 15′ and 43° 5′. It also falls between meridians 72° 25′ and 72° 45′ west of Greenwich. The extreme eastern part is in the Bellows Falls Quadrangle and the remainder of the area will be covered by the Townshend Quadrangle when issued (Figure 26).

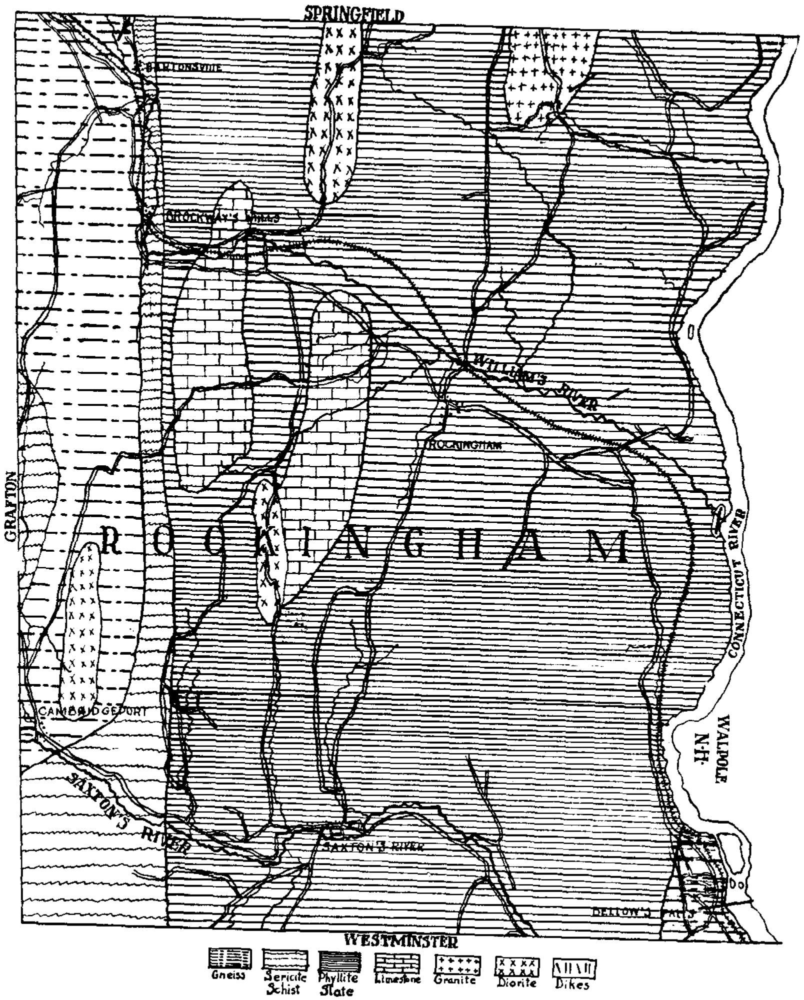

FIG. 25. Areal map of Rockingham, Vt.

There are six definite reasons for the selection of Grafton and Rockingham for field work.

1. Grafton lies directly south of Chester, whose geology and petrography was published in the Biennial Report of the State Geologist for 1927-1928, and Rockingham lies directly south of Springfield.

2. They make the work continuous in a southerly direction in the eastern half of the State.

3. They carry the field work eastward to the Connecticut River for the first time in recent years.

4. Rockingham falls in line with the erosional unconformity between the Ordovician and the pre-Ordovician, probably Cambrian, formations on the eastern side of the Green Mountains.

5. The presence of both acid and basic intrusives whose mineral composition has never been worked out and published.

6. The fact that no detailed field work has ever been done and no petrographic study ever made of either the sedimentaries or their associated intrusives.

The detailed field work was done during the summer of 1929. A part of the area was traversed in 1928. Some field work was done in 1929 in Springfield on the north, Athens and Westminster on the south and Windham on the west. Furthermore some field work was carried out on the Brattleboro Quadrangle to ascertain how the terranes in eastern Vermont tie up with those in Massachusetts. Dr. L. W. Currier has been with the author a part of the time in the field and worked out a detailed petrographic study of some of the microscopic slides.

The field relations of the different terranes in Grafton and Rockingham are difficult to determine. Grafton is hilly, glaciated and in part densely wooded. Rockingham is a little more easily worked. With a heavy glacial till and a dense growth of underbrush actual contacts between the different formations are extremely difficult to find.

Two areal maps showing the distribution of the different terranes accompany this report. A cross section of the terranes in Rockingham is also given as Figure 26 and in Grafton as Figure 28.

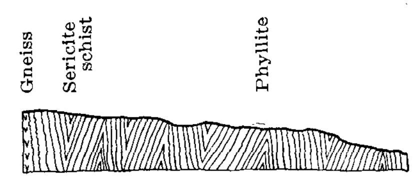

FIG. 26. Section in Rockingham, Vt.

The area involved in this report has always been mapped as purely sedimentary but both acid and basic intrusives have been discovered and so far as possible their location will be shown on the areal map. It is interesting to note that some of the rocks considered by earlier geologists as highly metamorphosed sediments are now definitely proved to be granite gneisses. The presence of a large amount of microcline in the microscopic slides substantiates this view.

Approximately 100 samples of rocks have been collected from which microscopic slides have been made for a detailed petrographic study. Without this type of detailed study it is impossible to correctly translate the results of field investigations.

DRAINAGE

The chief drainage of the area involved in this report is effected by two rivers. The northernmost of these two streams is Williams River which rises in Andover, flows in a southeasterly direction through Chester and Rockingham and empties into the Connecticut River a little north of Bellows Falls. The southernmost stream is Saxtons River which rises in Athens and Grafton, flows in a southeasterly direction and empties into the Connecticut River just south of the village of Bellows Falls. Each of these rivers receives several small streams from both the north and south sides. Many of them have only local names and need not be mentioned.

TOPOGRAPHY

There are two broad "U"-shaped valleys traversing the area covered by this report. These are the valleys of Williams River and of Saxtons River. These are pre-glacial valleys. The numerous transverse valleys are in part pre-glacial and in part post-glacial.

In the absence of topographic maps it is hard to give altitudes with a certainty when taken with an aneroid barometer. The altitude of the veranda at the Tavern in Grafton was 860 feet. Bull Hill was 1,580 feet and in the northern part of the township an altitude of 2,000 feet was recorded. The altitude in the northwest corner of Grafton is 2,220 feet and the mountain range in the western and southwestern part is 2,400 feet. The altitude of the railroad station at Bellows Falls is 309 feet, but by the river's edge below Bellows Falls the altitude falls to 250 feet. At Bartonsville station the altitude is 487 feet and at Brockways Mills 462 feet. These two stations are on the Rutland Railroad. Other altitudes in Rockingham that may be of interest are as follows: Saxtons Rivers, 500 feet; Minards Pond, 614 feet; Darby Hill, 1,160 feet; Parker Hill, 2,120 feet; Signal Hill, 1,240 feet. The topography of Grafton and Rockingham is rugged and may be regarded as in the stage of late maturity.

GLACIATION

Evidences of glaciation and the general direction of the ice movement can be found in the striations still remaining on the more resistant rocks. Well exposed outcrops of nearly pure white vein quartz and the broad dike-like quartz outcrops are particularly prone to furnish this evidence. The Cambrian quartzites as they appear in some of the higher altitudes and the more resistant beds of the Brattleboro phyllite have furnished many good examples. One of the best illustrations of glacial grooving in the State can be seen on Rattlesnake Hill, Springfield, Vermont. The variations in the direction recorded range from due south to south 20 degrees east and south 20 degrees west.

One of the most interesting features in the distribution of glacial débris is found in Grafton. About one mile northwest of the village of Grafton there is a serpentine boulder that stands in an open pasture at an altitude of approximately 1,350 feet and weighs some 75 tons. No serpentine rocks could be found in place in the immediate neighborhood. The boulder probably came from either the northwest corner of Chester or the southeast corner of Ludlow, for in these two localities the outcrops of serpentine very closely resemble the serpentine in this boulder.

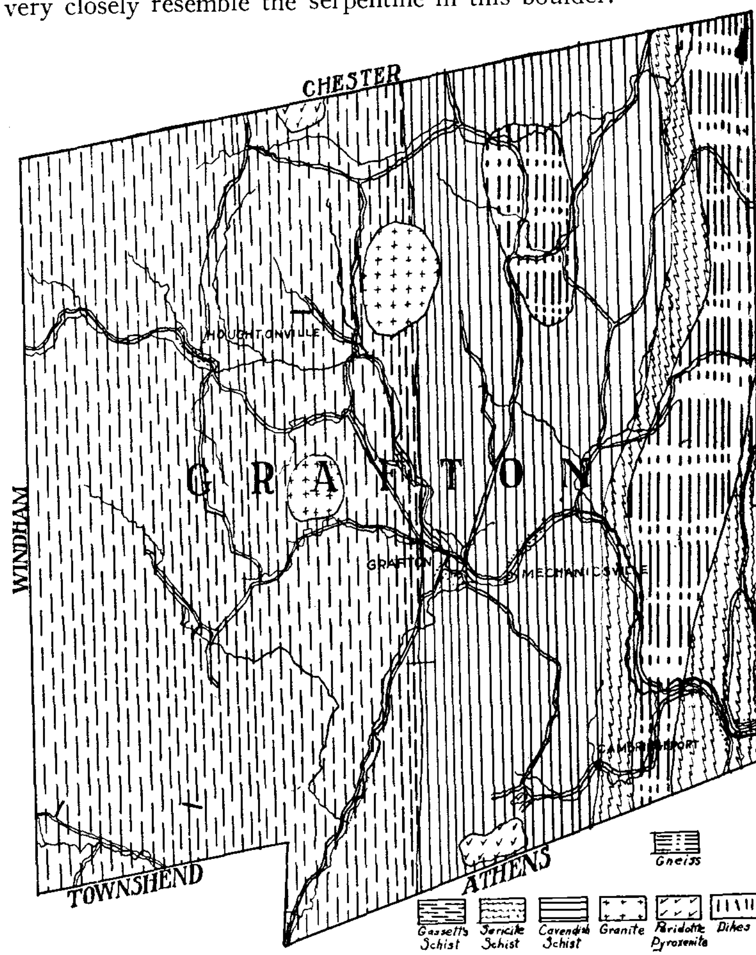

Fig. 27. Areal map of Grafton, Vt.

LAKES

There is but one small lake or pond in the area covered by this report. It is known as Minards Pond and is situated at an altitude of 614 feet. This pond is some two miles northwest of Bellows Falls and furnishes Bellows Falls with water and ice. It is in part glacial in origin and in part artificial.

GEOLOGY AND PETROGRAPHY

The geology of Grafton and Rockingham (Figures 25 and 27) is intricate and complex. The sedimentaries consist of highly folded and faulted metamorphics that are often invaded by intrusives of more than one period of introduction. The sediments range from quartzose marbles to feldspathic quartzites or gneisses with no trace of a lime content, and from slate or phyllite to highly chloritic and epidotic mica schists. In fact, some of the rocks listed as sediments are so highly metamorphosed that it is extremely difficult to prove that they were not of igneous origin. The intrusives range from very acid aplites through soda granites, diorites and diabases to the ultra-basic rock peridotite. In the petrographic laboratory under polarized light the microscope tells us what the individual constituents in both the sedimentary and igneous rocks now are, but it does not always reveal with certainty the mineral composition of the original rock. In some instances what constituents have been subtracted and what added, and under what condition various solutions were introduced we do not know.

The sediments vary in age from the Cambrian to Ordovician. There is no positive evidence of any pre-Cambrian sediments in the area covered by this report, nor is there any evidence of any sedimentary rock younger than Middle Ordovician. The intrusives range in age from the Cambrian to Carboniferous and possibly the Triassic.

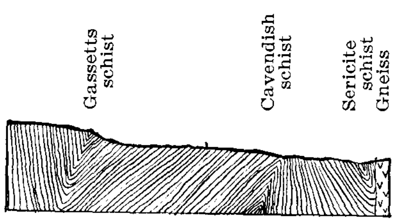

Fig. 28. Section in Grafton, Vt.

Approximately 100 microscopic slides have been examined in the petrographic laboratory. While the great majority of the slides have been made from the rocks in Grafton and Rockingham, a goodly number have been prepared from rocks collected in adjacent townships on the Vermont side of the Connecticut River and a few from Charlestown and Walpole, New Hampshire, to ascertain whether or not the phyllites and gneisses on the Vermont side of the river extend over into New Hampshire. The detailed study of these slides has

brought out several exceedingly interesting facts which may be listed as follows:

1. A large decrease in the percentage of magnetite in the pre-Ordovician terranes.
2. A rapid increase in the albite content of the sericite schists and sericitic quartzites.
3. A rapidly increasing biotite content in the sericite schists so that the rock frequently becomes a biotitic sericite schist and at times a biotite schist.
4. The feldspar of many of the igneous rocks appears to have been albitized or else the feldspar of the original rock was albite which has not been proved.
5. The granites are soda granites like that of Bethel rather than potash granites like those of Barre and Woodbury.
6. The feldspar in the pegmatite veins is mostly microcline and microperthite. In some slides there is a little orthoclase and albite to albite-oligoclase.
7. The abundance of microcline in the gneisses of wide distribution. This is regarded as one of the most important petrographic discoveries, for microcline is a pyrogenetic mineral and not one of secondary origin. This proves a large area of gneisses to have been originally granites rich in microcline.

ALGONKIAN

The Algonkian, or pre-Cambrian, terranes do not occur in Grafton and Rockingham. However, they do occur in Sherburne, Plymouth, Ludlow, Andover and Windham. The last named township lies directly west of Grafton. Now that contour maps are available as an aid in detailed field work in this section of the State it would be a valuable piece of work to follow this break in the geologic history on the east side of the Green Mountains the entire length of the State and map in with accuracy the two formations so widely different in age.

CAMBRIAN

The term Cambrian as here used denotes a group of highly metamorphosed sedimentary rocks which lie between the eastern foothills of the Green Mountains and the erosional unconformity that separates the pre-Ordovician terranes from the Ordovician. The Cambrian formations consists of a series of highly folded, feldspathic mica schists, feldspathic quartzites, chlorite schists, biotite schists, sericite schists, and sericitic quartzites that were derived from the erosion of the Algonkian land mass on the west during Cambrian times.

That these terranes listed as Cambrian are post-Algonkian in age is proved by three facts:

1. They all overlie the Algonkian gneiss that flanks them on the west.
2. They all underlie the Irasburg conglomerate which is Ordovician.
3. The lowest member of the group is the Sherburne conglomerate.

LOWER CAMBRIAN

The Lower Cambrian terranes consist of a series of highly folded and faulted metamorphics of widely varied mineralogical composition. These formations are the Sherburne conglomerate, Plymouth conglomerate, Plymouth dolomite, Albitic mica schist, Pinney Hollow schist and the Ottauquechee schist. The last is largely a black pyllite schist with slaty parting. It is the easternmost member of the terranes listed as Lower Cambrian.

If the conglomerate found by the author of this report in 1928 at Windham Four Corners, two miles north of Windham, is a true conglomerate, then it marks the base of the Upper Cambrian and the above-named formations would be Lower Cambrian. That this conglomerate lies at the base of the Bethel schist there is no doubt, but it may prove to be interformational. None of these Lower Cambrian terranes appear in Grafton and Rockingham, but they do appear in Windham which lies directly west of Grafton.

UPPER CAMBRIAN

The terranes listed in this report and in my earlier reports as Upper Cambrian comprise a series of highly folded and faulted sedimentary rocks that have been invaded by both acid and basic intrusives. The schistose rocks may be listed as chlorite schists, biotite schists, muscovite schists, sericite schists, and hornblende schists. However, not all of the hornblendic rocks belong with the sedimentaries.

Before taking up the general discussion of the above named terranes several significant questions may be raised.

1. Was deposition continuous on the eastern side of the Green Mountains throughout Cambrian times?
2. Did deposition begin with the Sherburne conglomerate in Lower Cambrian time and cease with the Middle Cambrian?
3. Did deposition begin with the Upper Cambrian and cease with the uplift that came at the close of the Cambrian?
4. Is the Middle Cambrian entirely wanting east of the Green Mountains?

The field evidence is that deposition began in Lower Cambrian time with the Sherburne conglomerate as the oldest member of the series. The presence of an apparent conglomerate in the lower portions of the Bethel schist would imply that sedimentation was not continuous during Cambrian time. If this conjecture can be proved in subsequent field work in Windham and Townshend then it seems rational to assume that the break in the continuity of deposition came in Middle Cambrian time. It is indeed unfortunate that no fossil content has as yet been found in the terranes listed as Cambrian on the east side of the Green Mountains. The rocks are highly metamorphosed, closely folded and faulted which may account for the absence of a fossil content.

BETHEL SCHIST

The Bethel schists are fine grained, greenish, schistose and highly metamorphosed sedimentary rocks which are more or less intimately associated with chlorite and epidote. They are particularly characterized by numerous eyes, or lenses, and stringers of granular quartz. The quartz lenses, or eyes, vary in diameter from a fraction of an inch up to 5 or 6 inches. The stringers vary in length from an inch up to a foot and, in a few instances, they have even greater length. The smaller of these lenses strikingly suggest elongated quartz pebbles. The quartz in the lenses, or eyes, and stringers is all of the same granular type. These schists are abundant in Windham, but it is not certain that they extend east far enough to appear in the western part of Grafton. In this densely wooded and highly drift-covered area actual outcrops were hard to find.

CHLORITE SCHIST

The chlorites are fine grained, green, schistose and highly metamorphic rocks. The mineral chlorite, or some related species of the chlorite group, is their determinant mineral. Epidote and magnetite are invariably present. Quartz grains and plagioclase feldspars are usually sparingly present. Stringers of granular quartz may appear and then the rock strikingly suggests the Bethel schist.

These chloritic rocks occur in narrow beds whose strike and dip often conform to the strike and dip of the associated sedimentaries. In such cases it is rational to assume that the chlorite schists are also of sedimentary origin. It must be remembered that in eastern Vermont chlorite schists are sometimes at angles varying from 1 to 85 degrees with the strike of the sericite schists and such chloritic rocks are highly metamorphosed basic intrusives. Beds of chlorite schist occur in the Cambrian terranes in Grafton and the extreme western part of Rockingham.

CAVENDISH SCHIST

The essential mineral composition of the Cavendish schist is quartz and biotite. It is often hornblendic and the hornblende sometimes replaces nearly all of the biotite. Among the accessory minerals epidote is very abundant. A plagioclase feldspar is invariably present in small amounts. Garnet, tourmaline, apatite chlorite, pyrite and magnetite are common. Zoisite is found in some slides, also zircon and rutile. The normal color of the Cavendish schist is a dark gray. Its texture varies from fine to medium.

In stratigraphic position this schist unquestionably underlies the Gassetts schist which belongs to the Missisquoi group. Actual contact between these two formations can be seen in the road cut a few rods north of Gassetts Station. Arguments are not conclusive that it either underlies or overlies the Bethel schist, which is regarded as the oldest of the Upper Cambrian formations in eastern Vermont. It may represent the time equivalent of the Bethel schists. It is definitely proved that it is older than the sericite schists on the east and the Gassetts schist on the west.

The Cavendish schist occupies a large area in Grafton as will be seen by consulting the areal map (Figure 27). It does not occur in Rockingham. Its strike varies from north and south to north 30 degrees east. In the eastern part of the township the dip varies from 45 to 55 degrees east. Through the central part of the township the dip varies from 35 to 45 degrees to the west. This westerly dip extends across the entire township in a north and south direction. The structure of the formation is anticlinal. It carries several more or less lenticular beds of granite gneiss which may in part be responsible for the anticlinal structure.

MISSISQUOI GROUP

The Missisquoi group of terranes comprises sericite schists, sericitic quartzites, and a medium to coarse textured, highly garnetiferous muscovite schist with minor beds of chlorite schist, hornblende schist and gneiss that may not be of sedimentary origin in all instances. This group of terranes has now been followed southward from the international boundary on the north into Windham County, a distance of nearly 150 miles. The mineralogical content of the sericite schists and the sericitic quartzites in the northern half of the State was fairly constant, but in Bethel biotite began to replace the sericite and in Windham County the rock becomes a biotite schist in some of the outcrops.

The silvery white highly garnetiferous muscovite schist that was discovered by the author in Reading, 1926, was then supposed to be only a local phase of the sericite schist. Its occurrence in Reading, Cavendish, Chester and Grafton proves it to be of fairly wide distribution. This terrane was named by the author of this report in 1928 the Gassetts schist from its occurrence in a large exposure easy of access in the road cut a few rods north of Gassetts railroad station.

GASSETTS SCHIST

The Gassetts schist is essentially a silvery white, highly garnetiferous mica schist. The texture is scaly, or the muscovite is arranged in parallel plates and is by far the most abundant constituent. It is not the fine grained, silvery white sericite of the sericite schists. The quartz grains are somewhat angular. The garnets vary in size up to an inch or even more in some instances. In form they are rhombic dodecahedrons. Well defined tourmaline and staurolite crystals are abundant. The magnetite is drawn out into parallel lines. There are a few plates of biotite and a few grains of apatite.

The stratigraphic position of the Gassetts schist is above the Cavendish schist and below the sericite schist and sericitic quartzites. Its strike varies from north and south to north 30 degrees east. Its dips vary from 35 degrees west on the east side of the formation to 80 degrees east on the west side of the terrane as it appears in Grafton. In the extreme southwest corner of Grafton the dip is 80 degrees west. This formation occupies much of the western half of Grafton and its structure in Grafton is that of a syncline. Excellent exposures of this formation can be found on the hill about one mile southwest of the village of Grafton, on the high range in the extreme southwestern part, and on the higher altitudes in the northwestern part of the township.

SERICITE SCHIST

In structure the sericite schists are finely laminated, schistose and granular. In texture they are fine to medium grained. In color they range from a silvery white to a slightly greenish tint. The green color is due in some instances to the chloritization of biotite, and in others to hornblende. In both instances the greenish tint is intensified by grains of epidote which result from the interaction of the feldspars and ferromagnesian minerals.

The only essential minerals in the sericite schists are muscovite, var. sericite, and quartz. The normal accessory minerals are biotite, albite, magnetite, pyrite, apatite, and garnet.

This formation is practically limited in Grafton to a narrow belt along the eastern part of the township and in Rockingham to a narrow belt along the western border of the township. The strike is practically parallel to the Grafton-Rockingham town line. In Rockingham the dip is about 70 to 75 degrees to the east and in Grafton about 70 to 75 degrees to the west. Its structure would be that of a narrow, close-folded anticline. It carries several beds of gneiss that appear to be of igneous origin. This may account in part for the steep easterly and westerly dips.

It carries some small beds of a sericitic quartzite, too narrow for mapable areas and, therefore, no attempt is made to differentiate the true sericite schist from the sericitic quartzite.

CHLORITE SCHISTS

There are thin beds of chlorite schist in the Missisquoi Group that conform to the dip and strike of the enclosing Gassetts schist, sericite schist and sericitic quartzite. They also occur in the underlying Cavendish schist. All such beds are regarded as of sedimentary origin for the following reasons:

1. The extreme narrowness of the beds.
2. Their conformity in dip and strike to beds of unquestioned sedimentary origin.
3. The presence of an appreciable amount of more or less rounded quartz grains.
4. The absence of any alteration by igneous intrusions in the walls of the enclosing sediments.
5. The absence of any plagioclase feldspars that could not have been derived from sediments.

If the above interpretation is correct then the age of these chlorite schists would be the same as the age of enclosing sedimentaries. These beds of chlorite schist do not occur in the Ordovician. The chlorite schists that cut across the strike of the sedimentaries are of igneous origin.

HORNBLENDE SCHIST

There are lenticular beds of hornblende schist in Grafton and Rockingham that may represent hornblendized sediments. The arguments in favor of a sedimentary origin may be listed as follows:

1. The gradation from outcrops particularly rich in hornblende to sericite schists, Gassetts schist, Cavendish schist and sericitic quartzites in which hornblende crystals are only sparingly present.
2. The occasional alternation of narrow bands particularly rich in hornblende with equally narrow bands extremely low in hornblende.
3. The bifurcation of long crystals of hornblende that appear fresh and of later generation than the main mass of the rock.

The presence of many well developed crystals of hornblende whose longer axis is across the schistosity of the rock.

5. The absence of any definite visible contact with rocks of unquestioned igneous origin.

The arguments in favor on igneous origin of many of the lenticular outcrops of rocks now listed as hornblende schist may be listed as follows:

1. The lenticular character of the hornblende outcrops.
2. The massiveness of the rock in several of its outcrops.
3. The definite rectangular jointing into small blocks from an inch to 6 inches in length as if formed by contraction during rapid cooling.
4. The presence of crystals of tourmaline which, however, are not found in all outcrops.
5. The presence of much titanite in several of the outcrops.
6. Apparent apophyses of a basic igneous rock in the enclosing schists and gneisses.
7. A close folding of the hornblendic rock with the associated gneiss. This condition can be seen a little north of Bartonsville.
8. A border zone of either quartz or pegmatite sometimes tourmalinized that bears a striking contrast in color and mineral composition with the enclosing sediments.
9. The abundance of plagioclase feldspars in certain layers so that the rock now appears as a hornblende gneiss, for rocks highly feldspathic are more apt to be of igneous than of sedimentary origin.
10. The wedging apart of beds of unquestioned sedimentary origin so that the same narrow beds pass around the hornblendic rocks. A condition that could not be obtained in sedimentation.

A condition is found in the wooded area in the extreme western part of Rockingham that seems impossible to duplicate in sedimentation. Here the hornblendic rock, probably originally a diorite, sends off numerous fingers or apophyses into the associated gneiss. The fingers cut across the gneissoid structure of the encasing rock.

ORDOVICIAN

The term Ordovician as here used embraces the series of sedimentary rocks that lie unconformably upon the east flank of the Cambrian terranes. They consist of limestones, slates and phyllite schists. They do not appear in Grafton, but they occupy all of Rockingham save the extreme western border of the township. These Ordovician terranes are essentially phyllite schists with occasional interbedded limestone and slate.

The structure of the phyllite schists is best seen by following the bed of Williams River and the railroad tracks in a north-westerly direction across the township. The structure is that of a series of close-folded anticlines and synclines. Four distinct anticlines and four equally distinct synclines were found in the phyllite. The cross section of Rockingham as shown in Figure 26 shows this complex folding. Figure 29 shows the apex of an anticline at Rockingham railroad station.

FIG. 29. Anticline in phyllite schist, Rockingham, Vt.

WAITS RIVER LIMESTONE

The Waits River limestones in Rockingham vary in color from a medium to a dark gray. A few beds were slightly banded. The only essential minerals are calcite and quartz. In some slides the calcite is perfectly recrystallized. The quartz grains are usually small and well rounded, but sometimes they appear elongated by the pressure to which the rock has been subjected. These beds are not continuous across the township. One bed is located about one mile west of the village of Rockingham. It is some three miles in length, half a mile in width and more or less interstratified with phyllite. The other bed extends south from Brockways Mills for about three miles. At Brockways Mills there is an excellent example of the interbedding of the limestone and the phyllite. This exposure is in the gorge just below the bridge across the river.

It is expected that similar beds of limestone will be found to the north of Rockingham in Springfield during the field work this summer. They have already been found to the south of Rockingham in Putney, Brattleboro and Guilford. In each instance cited the beds are interstratified with the Brattleboro phyllite.

MEMPHREMAGOG GROUP

The Memphremagog Group consists of slates and phyllites. In the northern half of the State the slate has appeared as a continuous formation. This holds especially true of the slate on the western flank of the Ordovician, from Northfield to the international boundary on the north. On the eastern side of the Ordovician the slate belt has been more broken. In the central portion of the Ordovician beds of phyllite have appeared completely surrounded by the Waits River limestone, but in Rockingham the beds of limestone are completely surrounded by the phyllite.

SLATE

The Memphremagog slate does not occur in Grafton. It does occur in four rather distinct areas in Rockingham. One lies in the wooded area in the northeast corner of the township. The other three are near Bellows Falls. Of these three, one is just west of the river road from Bellows Falls to Springfield, one is a little east of Minards Pond and on the road to the pond, while the other is on the abandoned road south from Minards Pond. These slates may represent the southern extension of the good roofing slate in Waterford which was named the Waterford slate by the author of this report in 1895. In its southern extension it was found in Barnet, Newbury, Bradford, Fairlee, Hartford and elsewhere. It has been the easternmost member of the Ordovician to the north of Windsor, but in Rockingham, Putney, Brattleboro, and Guilford the Brattleboro phyllite occurs upon both the east and the west of the slate belts.

BRATTLEBORO PHYLLITE

The term Brattleboro phyllite is applied to all the phyllites that flank the Cambrian terranes on the east in Chester, Rockingham and Athens. The phyllites extend southward through Springfield, Rockingham, Westminster, Putney, Brattleboro, Guilford and Vernon into Massachusetts. They flank the Connecticut River on the west in Vermont but extend across the river into New Hampshire in Charlestown and Walpole. The term Brattleboro phyllite was first applied by the author of this report to all the phyllites of the Connecticut Valley that are south of Windsor in the year that so much blasting was done and so much phyllite removed in Brattleoboro for the new railroad station at Brattleboro in 1915. The reasons for selecting this name were as follows:

1. At the railroad station in Brattleboro a considerable area of phyllite is exposed at different levels as a result of much blasting or quarrying.

2. Nearly all of the township of Brattleboro is covered with the phyllites.

The Brattleboro phyllite may be the time equivalent of the Randolph phyllite which lies to the west of a broad belt of Waits River limestone. The only limestones in this southern portion of the Connecticut Valley are comparatively small beds that are completely surrounded by the phyllite.

The strike of these phyllites varies from north to south to north 30 degrees east. The dip of the planes of fissility varies from 45 degrees west in the Williams River Valley to nearly 90 degrees both east and west. The planes of fissility do not always conform with the planes of bedding, for in Brattleboro planes of bedding were found dipping at an angle of 35 degrees east, while the planes of fissility dipped at an angle of 80 to 85 degrees east. The structure of the phyllites is that of close-folded anticlines and synclines.

ACID INTRUSIVES

The acid intrusives in Grafton and Rockingham consist of granites, granite gneisses and pegmatites of more than one period of introduction. The gneisses are the most abundant.

GRANITE

Granite outcrops occur in both Grafton and Rockingham, but they are not considered of large commercial significance. They are all soda granites for the plagioclase feldspars, albite to albite-oligoclase, equals or exceeds the potash feldspars, orthoclase and microcline. The essential minerals are quartz, albite to albite-oligoclase, orthoclase, microcline, biotite, sometimes a little muscovite is present. The typical accessory minerals are apatite, zircon, epidote, microlites of pyrite and magnetite with occasional scales or plates of chlorite derived from the chloritization of the biotite.

About one mile north of the road from the village of Grafton to that of Houghtonville there is an outcrop of fine grained granite that is of very light gray color. It is not as white as the Bethel granite, nor is the outcrop as extensive. The borders show a little parallelism of the ferromagnesian minerals which may be due to flowage during solidification of the granite magma. The central portion of the granite showed no parallelism whatever. The paucity of biotite is in part responsible for the light color. No quarrying has ever been done on the granite, but the granite

is susceptible of a good polish and well suited for local monumental work.

About one mile northwest of the village of Grafton there is an outcrop of fine to medium grained granite that is also of light gray color due to the small amount of biotite present. The blocks appear to be quite massive, but a judicious opening would be required to know its value.

In Rockingham there is but one granite outcrop. This is situated in the extreme northern part of the township a little to the east of the road that runs due north from the Rockingham railroad station to Springfield. A part of the granite is in Springfield. This granite is of fine to medium texture and of medium gray color. It carries more biotite than either of the granites in Grafton and is, therefore, of darker color. It is also a much larger outcrop. No quarrying has ever been done here, but the stone could be used for both monumental and constructional work.

GNEISS

Gneisses occur in both Grafton and Rockingham. They represent more than one period of introduction and possibly more than one mode of origin. Their texture and structure are widely different. Their discussion necessitates the introduction of a new term.

BELLOWS FALLS GNEISS

The Bellows Falls gneiss underlies the village of Bellows Falls, extends south into Westminster and east across the Connecticut River into Walpole, New Hampshire. It was also found in the extreme southwestern corner of Charlestown, New Hampshire. The Bellows Falls gneiss was recently blasted out of the river to widen and deepen its channel so as to lessen the danger in time of flood. This work gave many new rock exposures and fresh chips for microscopic slides.

In texture this gneiss varies from medium to coarse and in places it becomes porphyritic. Its color varies from a light or medium gray to a very dark gray color. The darker colored phases from a little distance suggest a basic igneous rock, but they are only more micaceous phases and often chloritic. The structure is gneissoid, but south of the plant of the New England Power System where many blocks have been quarried for the canal there was little if any of the gneissoid structure. This section appeared the most massive of any.

In mineral composition this gneiss carries quartz, albite to albite-oligoclase and biotite as its most abundant constituents. There is a little orthoclase, microcline, epidote, chlorite, apatite, zircon, pyrite and, in one instance, chalcopyrite was present. There are pegmatite veins rich in tourmaline and small veins of a beautiful blue fluorite in this gneiss. It carries zenoliths of some sedimentary rock which it cuts. One of these zenoliths was found some 10 feet in length. That this gneiss is an orthogneiss and not a paragneiss there can be no doubt.

There are arguments in favor of five different periods of igneous activity in the history of this gneiss.

1. An introduction of some granitic rock into Paleozoic sediments for zenoliths of some igneous rock are found in the gneiss. These zenoliths do not appear as segregations.
2. The introduction of the main granitic magma which by metamorphism became the Bellows Falls gneiss.
3. The introduction of numerous pegmatites that cut across the gneissoid structure of the rock. The fact that this structure does not appear in the pegmatites suggests that the gneissoid structure was developed prior to the pegmatitic invasion.
4. The introduction of quartz veins that cut the pegmatites. These may be contemporaneous and represent the last stages of invasion by an acid magma or high temperature mineralized solution for these veins carry tourmaline and fluorite, but both were not found in the same vein.
5. The introduction of a diabase dike that cuts across the gneiss, pegmatites and quartz veins.

The Bellows Falls gneiss was listed by C. H. Hitchcock as a protogene gneiss, one of the oldest of igneous rocks, but its age is definitely proved to be post-Ordovician for actual contacts were found where the gneiss cuts the Brattleboro phyllite which is of Ordovician age.

BULL HILL GNEISS

The term Bull Hill gneiss is new in the literature on Vermont geology. The introduction of the term seemed necessary from the rather wide distribution of the gneiss and its characteristic structure. The type locality is on Bull Hill, which is east to northeast of the village of Grafton and north of the village of Cambridgeport. It reaches an altitude of 1,580 feet, and the hill is practically all gneiss.

In structure this gneiss is pronouncedly porphyritic. The phenocrysts of feldspar vary from 1 to 3 inches in diameter, but some were measured that were 4 inches in diameter. Often the phenocrysts were elongated in the direction of the gneissoid structure of the rock with the biotite completely encircling the phenocryst of feldspar so as to suggest an augen gneiss. This gneiss is cut by numerous pegmatite veins. These often traverse across the gneissoid structure of the rock. Figure 10 shows pegmatite veins cutting this gneiss.

In the northeastern part of the township of Grafton there are excellent exposures of this same gneiss. The phenocrysts of feldspar vary in length from 1 to 3 inches. This gneiss was found in 1928 near the southeastern corner of Chester, but it was given no particular name at that time. Its structure and texture are markedly different from that of the Reading gneiss which was described in the Report of the Vermont State Geologist, 1927-1928. The Bull Hill gneiss appears to be an orthogneiss.

READING GNEISS

The Reading gneiss occurs in both Grafton and Rockingham. In Grafton its widest area is in the northeastern part of the township, but narrows toward the south and does not appear to cross Saxtons River. In Rockingham this terrane is confined to the western part of the township and extends southward as far as the village of Cambridgeport. It is usually flanked both upon the east and the west by a narrow belt of sericite schist.

The petrographic study of a large number of microscopic slides has revealed an abundance of microcline. The feldspar in some slides is nearly all microcline, which shows the characteristic grating structure. The abundance of this mineral suggests that the rock was derived from a granite rich in microcline rather than from highly feldspathic sediments. However, it may in part be a paragneiss for a few of the slides did not show an abundance of microcline.

PEGMATITE

Pegmatites occur in both Grafton and Rockingham. They are widely distributed in the gneisses and schists of Cambrian age. In general they are not regarded as commercial possibilities. This would hold especially true of the numerous pegmatites that cut the Bellows Falls gneiss at Bellows Falls.

In Grafton along the road from Grafton to Chester there are several interesting outcrops of pegmatite. On the farm of Andrew Johnson, 2½ miles north of the village of Grafton there is a vein of pegmatite with strike approximately northeast that is 7 rods long and 6 rods wide. A little quarrying has been done here.

Three miles north of Grafton the pegmatite outcrop has been opened in two places. The outcrops are approximately 20 rods in length and some 3 or 4 rods in breadth. The general strike appears to be northwest.

Three and one-half miles north of Grafton there are two veins of pegmatite about 20 feet in width. One strikes east and west, the other northwest and southeast. These pegmatites extend back into the hill for a considerable distance and in the open pasture there are some two acres well covered with pegmatite veins. It would appear that these veins intersect on the hill.

The rock cut by all these pegmatites is a granite gneiss, for in the microscopic slides examined microcline is quite abundant.

On the E. E. Wright farm two miles north of Grafton there is much pegmatite. The feldspar is pink in color but iron stained at the surface.

FIG. 30 Pegmatite dike cutting granite gneiss, Bull Hill, Grafton, Vt.

The mineral composition of these pegmatites is quartz, orthoclase, microcline, albite to albite-oligoclase, muscovite, biotite. epidote, apatite, magnetite. The magnetite is microscopic. The most interesting feature from a mineralogical viewpoint is the presence of well developed crystals of epidote. Some of these crystals are six inches in length. Some of these crystals suggest primary epidote in a pegmatite vein.

Much of the feldspar is of pink or flesh color and suggests a high grade of orthoclase. Microscopic slides reveal the fact that the potash feldspar is essentially microcline instead of orthoclase, but this does not lower the potash content and, therefore, does not diminish the commercial value. Some of the feldspars that look like perfectly good orthoclase are microperthitic. This increases the sodium content and diminishes the potash content. A good sized sample crushed, intimately mixed and carefully analyzed would be required to know the value of these pegmatites.

BASIC INTRUSIVES

Basic intrusives occur in both Grafton and Rockingham. They are associated with both the Cambrian and Ordovician terranes. They consist of diorites, diorite gneisses, diabases, pyroxenites and peridotites.

DIORITE AND DIORITE GNEISS

The diorites are granitoid igneous rocks whose chief feldspar is usually the plagioclase feldspar, andesine, and whose chief ferromagnesian mineral is hornblende. In eastern Vermont the feldspar is often richer in sodium than andesine through albitization and the hornblende is often chloritized. Augite may be present in an appreciable amount and the rock then becomes an augite diorite. The presence of a considerable amount of quartz constitutes a quartz diorite. The presence of biotite in sufficient amount gives a mica diorite. The shearing of the diorite so that ferromagnesian minerals are arranged in parallel lines gives rise to the term diorite gneiss. This gneissoid structure is present in nearly all of the outcrops of these rocks in Grafton and Rockingham. Chlorite, epidote, titanite, magnetite or ilmenite and apatite are common accessories.

In texture the diorite gneiss varies from fine to medium and granular. The crystals of hornblende vary from fine to coarse and the most of them are drawn out into parallel lines. Under transmitted light the hornblende is greenish to greenish blue. The quartz and feldspars are fine grained. Calcite is present in several of the slides examined. This mineral is here derived from the alteration of the soda-lime feldspars. In some slides biotite is present. Numerous tourmaline crystals and titanite suggest igneous activity. The percentage of hornblende varies. The center of the outcrop is sometimes richer in hornblende than the borders which will suggest to some investigators hornblendized sediments. The original rocks were probably diorites.

In Grafton these diorite gneisses are nearly all confined to the eastern border of the township and in Rockingham to the extreme western border of the township. In the wooded area on the western slope of the high ridge in the western part of Rockingham the diorite has sent off apophyses into the gneiss in a manner that cannot be explained by sedimentation. Here field evidence is a stronger argument than microscopic slides.

In the extreme northwest corner of Rockingham the diorite and gneiss are folded into sharp anticlines and synclines in a manner that baffles a sedimentary origin of this hornblendic rock.

Other outcrops are found in Grafton about 1 mile east of Houghtonville, in the southwestern part of Rockingham but northeast of Cambridgeport, in the extreme northern part of Rockingham but some 2 miles east of Bartonsville, and also some 3 miles southwest of the village of Rockingham.

DIABASE

Dikes of diabase occur in both Grafton and Rockingham. They cut both the Cambrian and the Ordovician terranes. As a rule these basic igneous rocks are high in specific gravity, dark in color, fine grained and ophitic. In some instances they show characteristic spheroidal weathering. They are usually narrow, varying from a few inches to 2 feet in width. Sometimes a dike will split so as to show two narrow dikes that can be found to merge into one main dike.

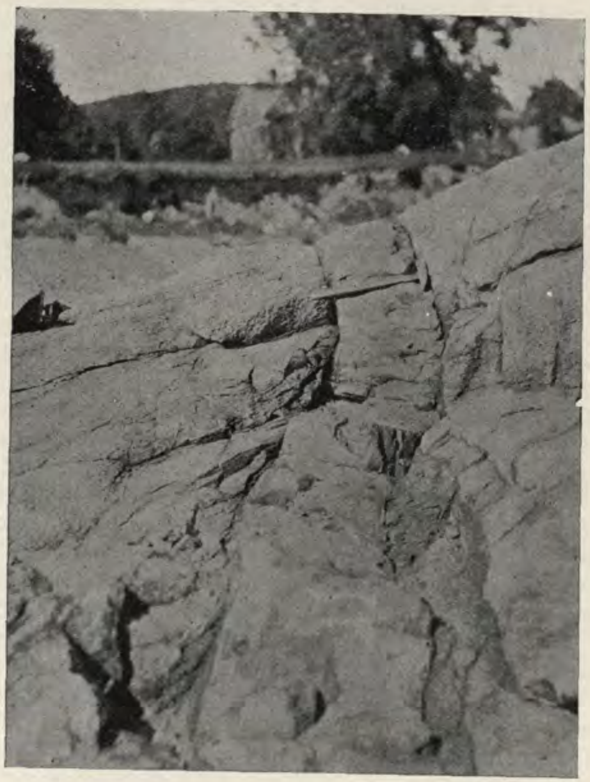

FIG. 31. Diabase dike cutting Bellows Falls gneiss, Bellows Falls, Vt.

In mineral composition these dikes consist of the plagioclase feldspar, labradorite, and the pyroxene, augite. Hornblende may be present, derived from the augite. The accessory minerals are magnetite which is abundant. A few small grains of apatite, chlorite derived from the chloritization of the hornblende, and calcite from the calcitization of the soda-lime feldspars.

In Grafton one of these dikes occurs some 2 miles northeast of Houghtonville and another about 4 miles southwest of the village of Grafton. Neither of these dikes is of easy access. In Rockingham one dike occurs in the northwest corner of the township and another in the extreme northern part of Rockingham. This dike cuts the granite already described. A third dike cuts the phyllite schist in the eastern part of Rockingham to the north of Williams River, but the most interesting of them all is the diabase dike at Bellows Falls. This dike crosses the Connecticut River some 30 rods below the dam. It passes into Vermont near the Vermont end of the railroad bridge. It extends into New Hampshire and was followed to the top of Fall Mountain. Its strike varies from east and west to north 30 degrees east. Its width varies from a few inches up to 1 foot. Its dip varies from nearly vertical to 30 degrees to the north. It cuts the Bellows Falls gneiss across the gneissoid planes. It also cuts the pegmatites and quartz veins. The dike is finer grained near the borders than at the center and suggests columnar jointing. Its easy fracture is across the dike. Near the center of the river channel the dike divides so it would appear like two very narrow dikes at a low angle with each other. Furthermore it carries zenoliths of the gneiss which it cuts and in some places stands 2 inches above the massive gneiss which suggests a possible post-glacial movement of the dike material. Figure 31 shows dike of diabase illustrating width and parting of the dike, Bellows Falls, Vermont.

By the swimming hole near the mouth of Williams River there is an outcrop of igneous rock whose original composition is unknown. It does not appear to have been a diabase. It strikes north 20 degrees east and extends across the river. It appears to be about 30 feet in diameter. Its length is unknown for it extends to the southwest in a drift-covered area.

According to Dr. Louis Wade Currier this rock appears to have been almost completely altered so that the original character is entirely obscured. It appears to have been considerably mineralized. It carries abundant lencoxene in very large patches. Secondary processes of alteration have produced chlorite, sericite and epidote. These may have been hydrothermally introduced. Feldspars and some titanium mineral may have been introduced. There is a possible remnant of some amphibole.

PYROXENITE AND PERIDOTITE

The belt of pyroxenites and peridotites that traverses Vermont in a north and south direction appears in Grafton but not in Rockingham. These pyroxenites are now altered to talc and steatite and the peridotes to serpentine.

Talc or soapstone occurs in the extreme northern part of Grafton and southern part of Chester, but the property is rather difficult of access. It also occurs on the southwest slope of Bear Mountain and near the Athens-Grafton town line. It is not certain that a part of this outcrop is not in Athens. It is about 3 miles south of the village of Grafton, and some 3 miles from Cambridgeport. The stone at one time was quite extensively quarried and cut at Cambridgeport. This steatite or soapstone is of good grade, for in samples collected around the old quarry there has been but little change in color during the many years of exposure to the corrosive agents of the atmosphere. The stone appears remarkably free from pyrite and siderite. There are many slabs of this stone along the brook at the junction of the soapstone road with the Saxtons River Road.

The age of the introduction of the pyroxenites and peridotites into Vermont terranes is regarded as Cambrian, for they abound in the terranes of Cambrian age and nowhere have they been found to cut the Ordovician formations.

PALEONTOLOGY

As yet no fossils have been found in the pre-Ordovician terranes on the eastern side of the Green Mountains. The relative age, therefore, of these formations has been determined by their stratigraphic position, continuity and lithological characteristics. The pre-Ordovician terranes as they appear in Grafton and Rockingham are unquestionably post-Algonkian, for the base of the Cambrian series is the Sherburne conglomerate which overlies the Algonkian. They occupy an inferior position to the Irasburg conglomerate which forms the base of the Ordovician in eastern Vermont. If the conjecture is correct that the Bethel schist carries a conglomerate bed in Windham then the inferior terranes between the Bethel schist and the Algonkian terranes on the west would normally be classed as Lower Cambrian and the Bethel schist with its superior members would be classed as Upper Cambrian. Therefore, the pre-Ordovician terranes in Grafton and Rockingham are regarded as Upper Cambrian.

The Ordovician terranes unquestionably overlie the Upper Cambrian with an erosional unconformity separating the two groups of formations. No new beds of graptolites were found in Rockingham and, therefore, there is no new evidence to present as to age. At the abandoned slate quarries east of Minards Pond

the slate appears graptolitic. There are patches of carbon on the cleavage planes of some of the slate that are now arranged in parallel lines, but some patches are at angles of nearly 90 degrees to the major patches. This is suggestive but not positive evidence.

The Paleontological evidence was given so fully in the Biennial Report of the Vermont State Geologist, 1927-1928, that it need not be reproduced here.

ECONOMICS

There are no known commercial metallic minerals in Grafton and Rockingham, or in their immediate environs. However, there are some non-metallic mineral products of commercial significance. The talc deposit in the extreme northern part of Grafton and the steatite or soapstone deposits on the southwestern slope of Bear Mountain have commercial possibilities. The latter deposit was worked for several years and much good stone was marketed. The quarry was abandoned many years ago, but the supply of stone was not exhausted.

The granites in both Grafton and Rockingham are susceptible of a good polish and can be used locally for monumental or constructional work. The Bellows Falls gneiss markes a good building stone. It has been quite extensively used in foundation work and in walls. The slates in Rockingham have a fairly good cleavage and have been quarried to some extent. The possibility exists of opening up fairly good quarries in Rockingham. The compact phyllite schist on the high ridge just west of Bellows Falls makes a very satisfactory foundation stone. Quarrying was discontinued here because of an injunction placed upon the work by neighbors in the immediate environs who feared damage to their property by blasting.

The sand deposits in the village of Bellows Falls are of excellent quality for building purposes and from time to time this sand has been used locally.

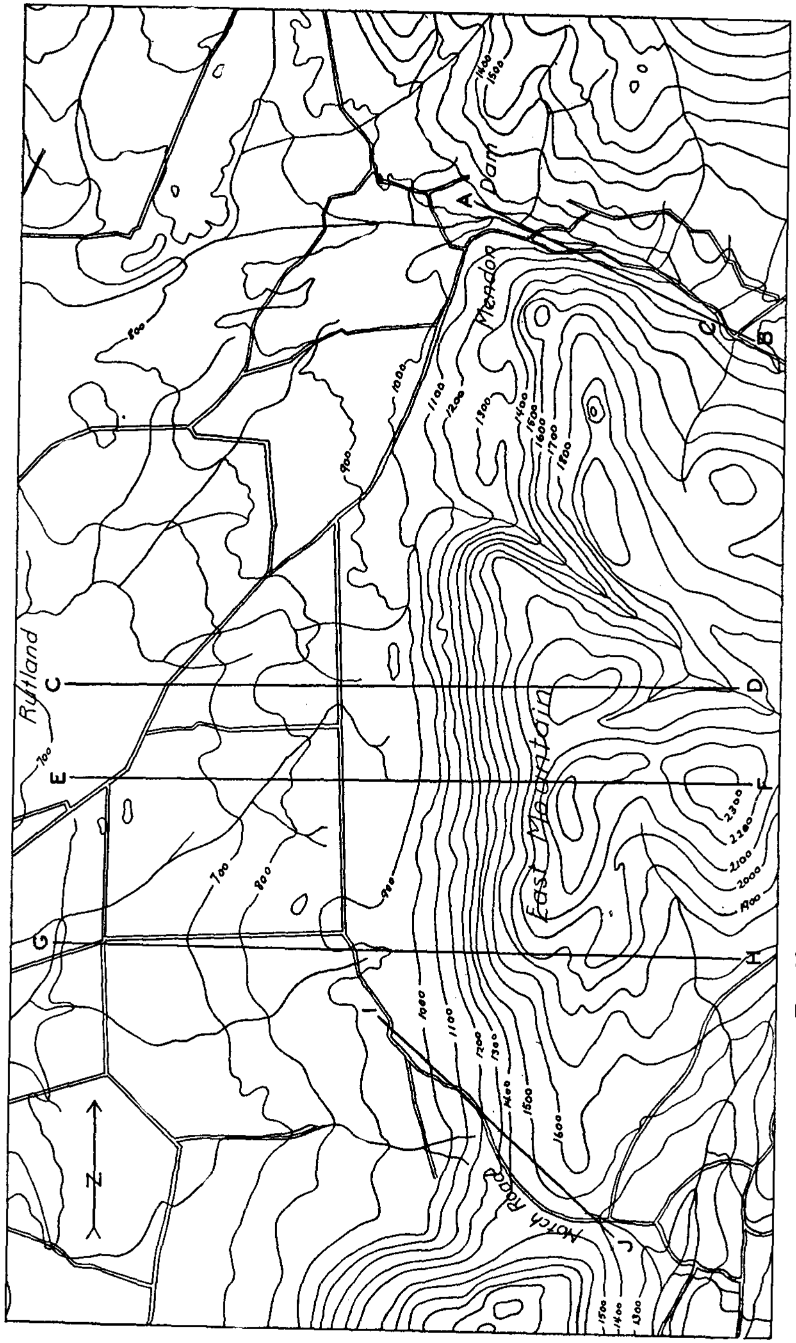

Fig. 32. East Mountain area showing section lines and topography.

THE GEOLOGY OF EAST MOUNTAIN, MENDON, VERMONT

Edward J. Foyles

INTRODUCTION

The study of East Mountain was undertaken in an effort to make progress in the understanding of the geology of the Green Mountains. A review of the literature on this subject reveals a paucity of confirmed conclusions as to the ages of the rocks; the nature, number and sequence of the earth movements which have affected them; and the processes of magmatic intrusion.

It is generally agreed that the rocks of the Green Mountains in the area studied are pre-Cambrian. This is particularly true of the understanding of the age of the Mendon series of Whittle (*Jour. Geol.,* Vol. II, pp. 408-412). This paper is often quoted by authors who have studied complex rocks in other parts of the Green Mountains, but it may be noted that no section has been found which is similar to the type section of the Mendon series as Whittle recorded it.

Although it is not purposed to attack the theories of Green Mountain geology, additional information may be gained by a study of rocks which were exposed by the flood of 1927 in Mendon. These consist of a pegmatite and granite cutting the schist, and a series of rocks extending over an east-west distance of three thousand feet. Thus an excellent opportunity was afforded to study fresh rock exposures at the western edge of the Green Mountains. (Figure 32.)

In the last three years sections were run across East Mountain and a suite of specimens was collected. Part of the present paper is based on thin sections made from this collection. In the summer of 1930 Dr. Harold L. Alling visited the area with me, and made many helpful observations. I am indebted to him for help in the field and in the study of the thin sections of the specimens collected from all sections of the mountain. Miss Evelyn Newman assisted with the drawings.

The complex structural phenomena, the absence of fossils, the impossibility of detailed stratigraphic study, the varying lithology and the obscure geologic history of this region prevent a complete account of the stratigraphic story and forbid confident conclusions on the history and age of the rocks of the area studied. In spite of these difficulties some progress in these problems is believed to have been made.

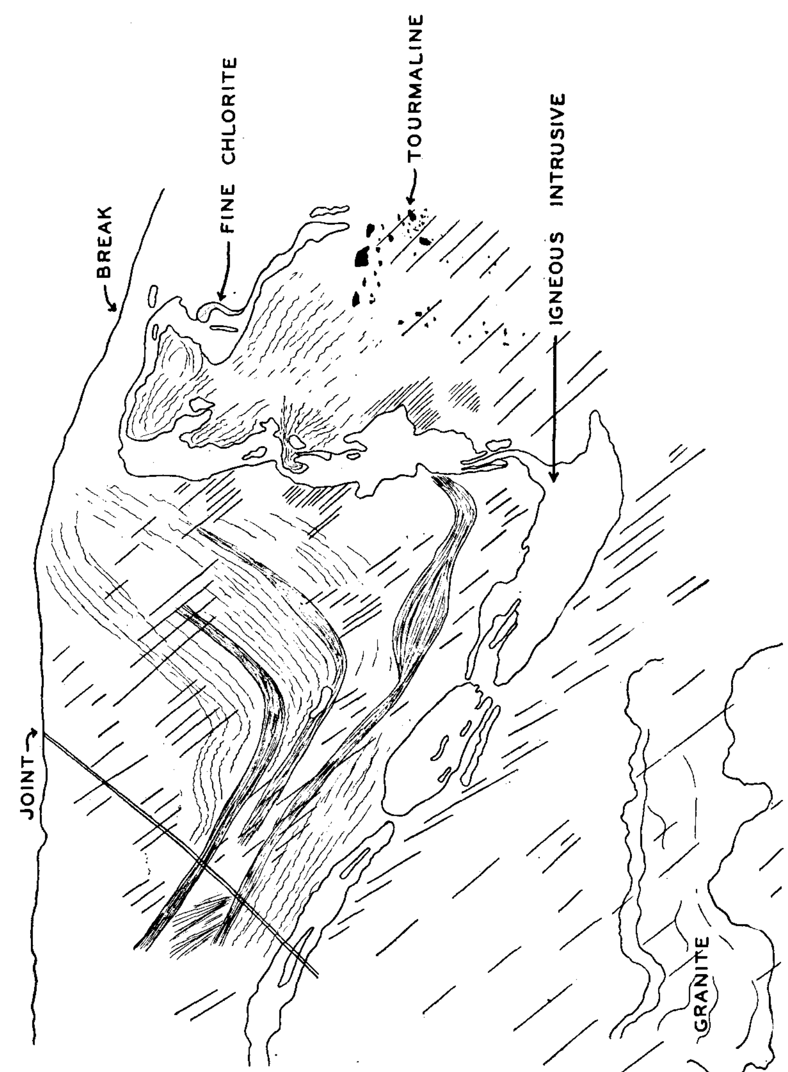

FIG. 33. Mendon between station 7 and 8. Shows two stages in Green Mountain orogeny. Granite intrusion between the two slopes.

STRUCTURE

Field observations on East Mountain show two principal types of faulting. At the north end of the mountain a new cut along the road shows overthrusting to the east (Figure 35). This type of faulting is common along the Green Mountain front and has resulted in many offsets along the front of the range.

A second type of faulting is vertical. Vertical faults with north-south strike are seen along the west face of the mountain (Figures 36-38). East-west faults give rise to valleys debouching onto the Rutland valley.

As viewed from the north, the mountain has the appearance of a block fault. This form is probably caused by thrusting from the east and stepfaulting on the west face. Evidence is apparent on the topographic sheets of a great flat overthrust plane indicating a major westward movement of the Green Mountains. The irregular line of the Green Mountain front indicates differential westward movements, but the extent of the movement is unknown. The relationships of the Green Mountains to the Rutland Valley and the Taconic range are a field for study and interpretation.

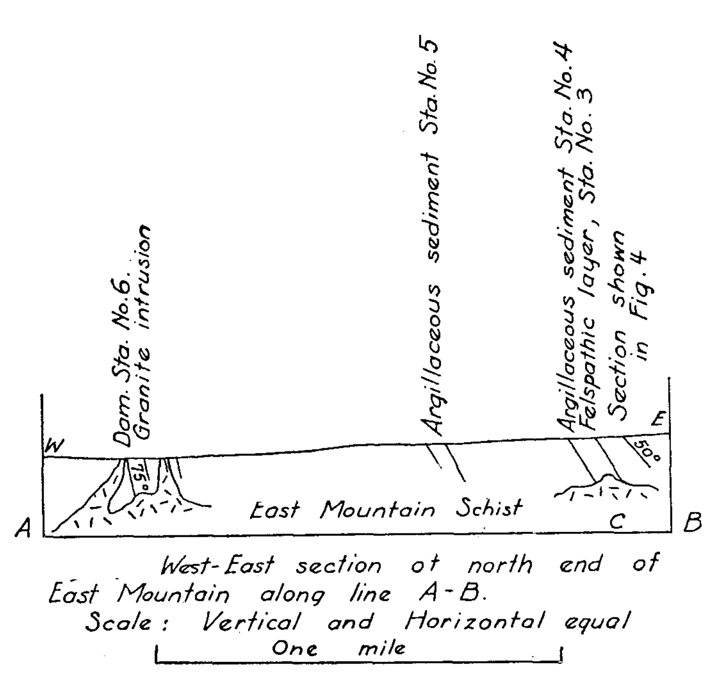

FIG. 34.

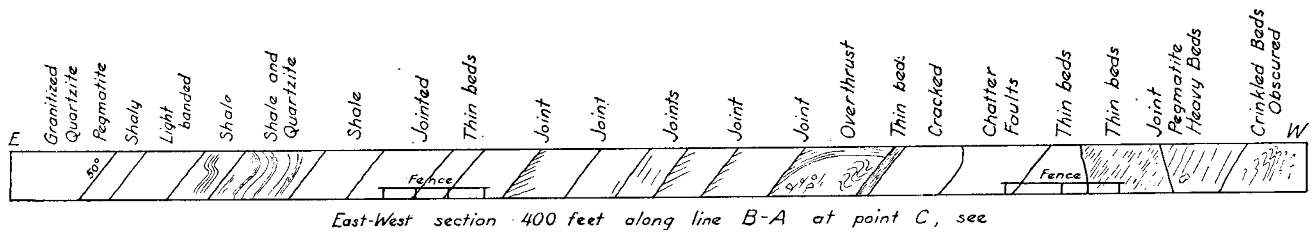

FIG. 35.

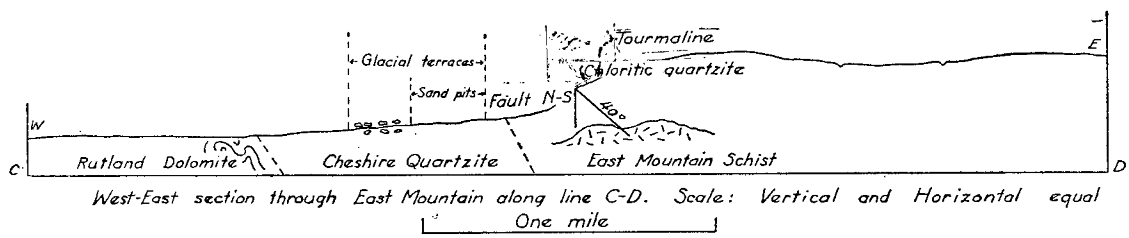

FIG. 36.

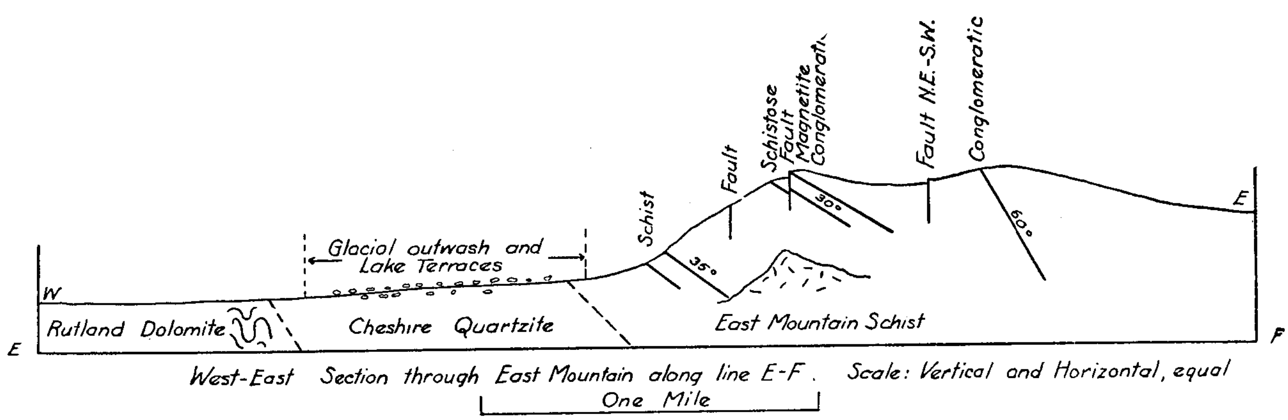

FIG. 37.

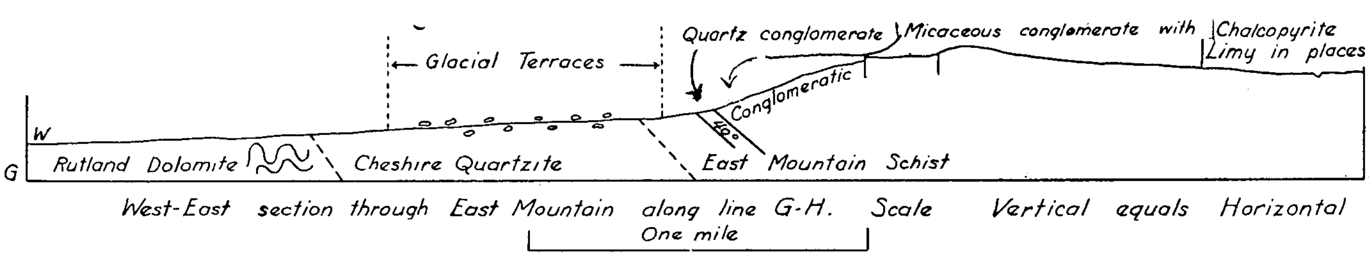

FIG. 38.

Five sections were run across East Mountain, giving a fair picture of the structure and composition of the rocks of which the mountain is composed.

Section A-B (Figure 34) includes the pegmatite and granite intrusion at Mendon dam and the freshly exposed rocks along the road at the east end of the section. The granite is found at the surface at the dam, and abundant evidence of its presence is found in the rocks at the east end of the section. Details of the east end of the section are shown in Figure 35.

Section C-D (Figure 36) illustrates the relationship of the Green Mountain front to the valley rocks. The contact between

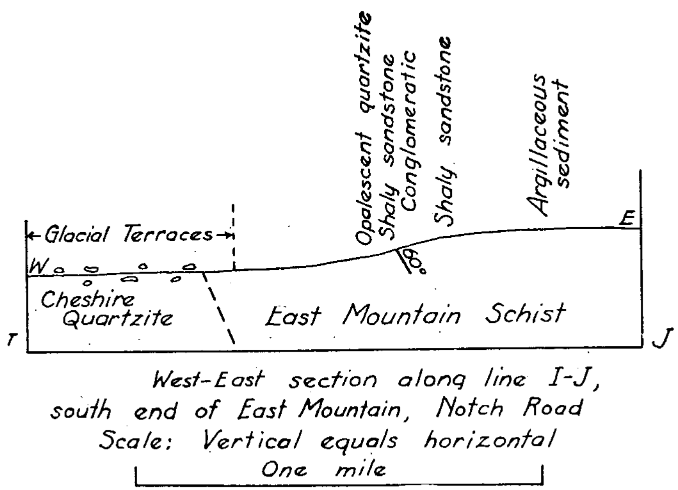

FIG. 39.

the East Mountain schist and the Cheshire quartzite is covered by glacial detritus, thus hampering a clear understanding of the nature of the contact of the two formations. Evidence of igneous intrusion is seen in the schist but not in the quartzite. The quartzite has been injected with igneous magma both to the north and the south of the area in Ripton and Arlington.

Section E-F (Figure 37) is similar to C-D in the order of the formations, the structural features of the rock and the evidence of igneous injection presented elsewhere in this paper.

Sections G-H (Figure 38) and I-J (Figure 39) carry out the regular order of rock formations and structural features. The evidence of igneous injection is not obvious, but probably is represented in specimen No. 27 from the south end of East Mountain.

The sections indicate that the rocks run north and south in parallel bands. The dip of the rocks is east and the faults are vertical with a north-south trend. The igneous injection extends north and south along the west slope of East Mountain. It is not evident in the Cheshire quartzite.

At the north end of the concrete dam at Mendon a pegmatite intrusion cut the chloritic schist of the Green Mountain front, which developed innumerable small crystals of magnetite. For a distance of 200 feet east of this occurrence granite intermingled with the schist. At one point Alling discovered structural phenomena of the schist and its relation to the granite which indicate relative times of mountain building and igneous activity (Figure 33).

The visible structures indicate that the orogeny consisted of at least two stages, with the probability that the igneous activity took place between these stages and certainly not before or after them. The igneous intrusion may have occurred during the time of the second stage, but the structure seems to indicate clearly that it was before the second stage had begun.

Stage one of the mountain building process is seen in the apparent eastward dip of the schist. This eastward dip of the rocks is constant on East Mountain. A fold in the rock is clearly seen superimposed upon the eastward dipping beds. A pegmatite follows the trend of the fold and definitely cuts and distorts the eastward dipping beds. The fold represents the second stage of orogeny. The pegmatite follows the trend of the folding and was broken during the second orogenic stage.

Another interpretation of this occurrence of rock structure explains that the folds in the rock were formed first. Igneous intrusion followed the folding and was in turn followed by a tectonic disturbance which resulted in the eastward dipping cleavage of the rock.

PETROGRAPHY OF EAST MOUNTAIN

Description of the thin slices of the rocks from stations 1 to 8 on the Mendon Road section, north end of East Mountain:

Station No. 1 (specimen No. 13):

The specimen was taken below the west end of the bridge on the south bank of the stream. The exposed rock, which is gneissoid in appearance, extends for 75 feet from the bridge westward. The beds dip generally 50 degrees east.

Quartz, feldspar and mica are abundant. There are many large specimens of plagioclase feldspar some of which are untwinned. The large feldspars are poecilitic. The slide also exhibits hornblende, apatite, perthite, zircon, biotite and garnet; microline is also present.

The rock was probably an argillaceous quartzite, possibly a conglomerate. It has been injected by igneous material as shown by the biotite and potash feldspars.

Station No. 1 (specimen No. 14):

The specimen is from the same locality as specimen No. 13. Quartzite with biotite and muscovite. From the original sediment there is plagioclase and microcline. Poecilitic feldspars are oligoclase with muscovite flakes, augite and rutile. The intrusive feldspars are microcline and plagioclase. This is a sediment which has been saturated with magma.

Station No. 2 (specimen No. 15):

The specimen was taken 100 yards downstream on the south side of the road. The beds are closely folded and are rich in tourmaline and feldspar. The rock might be called a tourmalinized mica schist or argillaceous sediment. The dominant mineral is quartz. The minerals seen through the microscope are biotite, muscovite, ilmenite, graphite, titanite, feldspars and zircon.

Station No. 3 (specimen No. 16), 1,000 feet from bridge:

The hand specimen shows large feldspar crystals with many inclusions, in a fine quartzite, with some mica. It is apparently a feldspathic layer in the ledge. It was originally an argillaceous sediment, with quartz dominant. Chlorite, zircon, muscovite, and biotite are present.

Station No. 4 (specimen No. 17), 1,300 feet from bridge:

Specimen No. 17 overlies No. 18. The specimen contains quartzite pebbles. It was originally an argillaceous sediment with quartz dominant. There are two sizes of semi-mosaic quartz. Feldspar and chlorite are prominent. Micaceous layers and epidote were noted. Not much injected.

Station No. 5 (specimen No. 18), 1,300 feet below bridge:

This is an argillaceous sediment containing less quartz than in the previous slides. The quartz is not dominant. Minerals noted are muscovite, biotite, chlorite, epidote, and carbonate. Close folding is shown in a striking manner.

Station No. 6 (specimen No. 19), 3,000 feet below bridge, outcrop 200 feet long, strike NW-SE:

An argillaceous sediment with quartz dominant. The feldspars have many inclusions. Minerals noted are quartz, plagioclase, feldspar, chlorite, biotite, muscovite. The muscovite is prominent in the ledge. May have been injected.

Station No. 6 (specimen No. 20), 3,000 feet below bridge:

An argillaceous sediment showing quartz bands in a greenish-gray rock. Minerals noted are plagioclase feldspar, quartz and large muscovite flakes.

Station No. 7 (specimen No. 21), Mendon village, east of concrete dam, north bank of stream:

Specimen in contact with pegmatite No. 22, strike N-S, dip 75 degrees east. A closely foliated chloritic schist abundant with magnetite crystals. An argillaceous sediment with quartz dominant. Mica is strung out in thin flakes. Other minerals are chlorite and feldspar.

Station No. 7 (specimen No. 22):

A hand specimen showing the schist (No. 21) and the pegmatite (No. 23) in contact.

Station No. 7 (specimen No. 23):

A pegmatite showing badly fractured feldspars with many inclusions. The slide shows mica between crystals of quartz and plagioclase.

Station No. 8 (specimen No. 24), Mendon, upper dam, 100 yards east of specimen No. 21:

An argillaceous sediment similar to No. 21. Axes of isoclinal folds dip east. Minerals noted are quartz (dominant), chlorite, biotite, muscovite.

Station No. 8 (specimen No. 24a, associated with specimen No. 24):

A cataclastic granite composed of quartz, microcline, plagioclase, poecilitic feldspars, muscovite, tourmaline, apatite and zircon. Secondary minerals have developed in the cracks.

SOUTH END OF EAST MOUNTAIN

Station No. 1 (specimen No. 25), half way up "Notch" road, Rutland:

A gneiss or schist approaching an augen gneiss. Quartz is prominent. Other minerals are mica, feldspar and microcline.

Station No. 2 (specimen No. 26), near top of "Notch":

A shaly sandstone which does not appear supermetamorphosed enough to be pre-Cambrian. Quartz and micas are prominent.

Station No. 3 (specimen No. 27), top of "Notch":

An argillaceous sediment with quartz prominent. Other minerals are poecilitic feldspars, plagioclase, micas, chlorite, graphite, augite.

SUPPLEMENTARY NOTES ON THE ROCKS NORTH, EAST AND SOUTH OF EAST MOUNTAIN

Chittenden, one-eighth mile east of corner:
Metamorphosed conglomerate. Schistose. Large quartz pebbles. Dip 60 degrees east.
Five-sixteenths mile east of corner:
Quartz weathering red. Dip 25 degrees east. Possibly an erratic.

Two miles southwest of North Sherburne:
Conglomerate. Dip east.

One and three-fourths miles southwest of North Sherburne, on the divide:
Graphitic shale highly crinkled and schistose. Strike South 80 degrees east. Specimen No. 32.

Hill northeast of Chittenden Pond:
Pegmatite: quartz, poecilitic feldspars, micas, secondary carbonate. Specimen No. 30. Siliceous limestone: microcline. Specimen No. 31. Dolomite half way up mountain. Feldspathic conglomerate above dolomite. Dip east.

Deers Leap, Sherburne Pass, Sherburne:
Green schist: quartz, dominant, lime prominent, micas, feldspar, apatite, graphite, carbonate. Specimen No. 28.

Killington Peak, Sherburne:
Schistose argillaceous sandstone: quartz, chlorite, biotite, muscovite, graphite, microcline, garnet. Dip 25 degrees west. Specimen No. 29. Conglomerate all way up old hotel trail. Possible dolomite half way up trail.

McLaughlin Falls, Mendon:
Quartzite beds, highly folded, strike north-south. Below quartzite and southeast of it are light-gray beds five feet thick.

North Clarendon, east bank of Cold River, north of covered bridge.
Pure and impure quartzite beds (dip 35 degrees west) lying unconformably on metamorphosed gravel. Some feldspar in the quartzite. Specimen No. 35.

TYPE OF MENDON SERIES COMPARED WITH EAST MOUNTAIN SERIES

The problem of the Mendon Series is of long standing. According to Whittle, who first studied the series (*Jour. Geol.*, Vol. II, pp. 408-412), the Mendon Series begins one mile north of Mendon and extends up the slope of Blue Ridge Mountain to the east. As the section goes upward it exposes older and older rocks. The section as recorded in descending order stratigraphically, but ascending topographically is: Cambrian quartzite, mica schist, micaceous quartzite, dolomite with feldspar pebbles, mica-quartz-actinolite schist, quartzite.

Sections across East Mountain do not compare with the Mendon Series. Topographically the two mountains appear similar. The quartzite lies at the foot of each mountain. Supposedly it is lower Cambrian in age. The mica schist and micaceous quartzite may be represented at the dams of Mendon Village. The dolomite is not seen on East Mountain. The mica-quartz-actinolite schist was not found on East Mountain. A quartz conglomerate varying in texture and composition was observed over much of East Mountain.

The failure of the two areas to compare in section may be explained by the varying effects of magmatic intrusion, or by the fact that the Blue Ridge Mountain rocks and the East Mountain rocks have not been sufficiently exposed to reveal the details of the sections.

SEQUENCE OF EVENTS

The oldest rocks of the area comprise the East Mountain schist. They may be divided into several facies as seen in Figure 35. Their succession and relationships to each other are not determinable with the data at hand. They have been metamorphosed by pressure and igneous injection. Their age is still problematical. Although it is generally assumed that they are pre-Cambrian, the relative degree of metamorphism of the rocks does not seem to indicate a pre-Paleozoic age.

The mountain rocks and the valley rocks have all been changed by stress and shearing. In addition, the metamorphism of the mountain rocks has been augmented by magma and hydrothermal action. If the sediments are pre-Cambrian there is little but negative evidence to prove it.

The Cheshire quartzite is lower Cambrian in age as shown by fossils in the Lake Dunmore area. The fossils listed from the east shore of Lake Dunmore are *Hyolithes communis* Billings, *Hyolithes gibbosus* Hall and Whitfield, *Nothozoe vermontana* Whitfield and *Olenellus* sp. (Rept. Vt. State Geologist, 1925-26,

p. 33). The Cheshire quartzite is referred to the Lower Cambrian by Keith (*Amer. Jour. Sci.*, February, 1923; Rpt. Vt. State Geologist, 1923-24, pp. 126-7). It is of fine-grained texture in contrast to the metamorphosed conglomerate which is seen in the East Mountain schist. This conglomerate may be Cambrian in age. The Cheshire quartzite underlies the Rutland dolomite, which is not included in this study. No sediments younger than the lower Cambrian are found in the area.

The East Mountain schists show evidence at Mendon of an early disturbance which was followed by igneous injection consisting of granite and pegmatite stringers. This in turn was followed by another tectonic disturbance. The exact times of these events is not known. The subsequent geologic history of the area is veiled in obscurity until the occurrence of glaciation.

GLACIAL

Along the foot of East Mountain there is a shelf of moraine showing glacial lake terraces. These terraces have not been studied in detail but they would undoubtedly yield valuable information on the glacial geology of this region. These moraine terraces are noted on the map of the surface geology of Vermont compiled by C. H. Hitchcock (Geology of Vermont, 1861, Vol. II). In Vol. I, p. 151, of the same publication, it states: "They are particularly abundant in the east part of Rutland, near the line of Mendon, most of the length of the town, lying at the foot of the great range of quartz rock." A great dominance of quartz boulders on the surface of this shelf, which conceals the contact between the valley rocks and the mountain rocks, indicates a quartzite band of rock lying between the Rutland dolomite and the East Mountain schist. The shelf at the foot of the mountain is composed partly of glacial and country rock washed down from the mountain side. Glacial erratics were seen on the ridge of the mountain.

TIME TABLE

Post Glacial	Changed drainage pattern; glacial lake deposits obscured by piedmont outwash.
Pleistocene	Glacial till; glacial lake alluvium and terraces; obscuring of contact between mountain and valley rocks.
Post Cambrian	Successive stages of mountain building accompanied by igneous activity.
Early Cambrian	Deposition of Rutland dolomite and the Cheshire quartzite.
Pre-Cambrian or possibly basal Cambrian	Deposition of the East Mountain schistose conglomerate.

CONCLUSIONS

The area gives evidence of being a region of ancient tectonic activity. Great faults and igneous intrusive rocks indicate active orogenetic processes throughout the length of the Green Mountains. Both the east and west sides of this belt are flanked by Cambrian and Ordovician sediments deposited in the Appalachian geosyncline. It is possible that these sediments extended across those parts of the Green Mountains which are now modified by shearing, hydrothermal action and igneous intrusion. A variety of modifications due to igneous activity are seen from quartzite simply impregnated with feldspar to complex metamorphic sediments whose original composition is obscured by many new minerals.

It is suggested that the rocks often called pre-Cambrian in this region may be metamorphosed Paleozoic sediments. Overthrusting is evident, but not to the extent of many miles. If there was tremendous overthrusting, what has happened to the rocks, other than limestones and dolomites, which must have filled the Rutland Valley? How did they overcome the barrier of the Taconic range; and if they did ride over the Taconics, why is there so little evidence of them? They should be there just as their fellow rocks are still evident in the Green Mountains.

In fact similar rocks are found in the Taconics and they may be remnants of an overthrust. On the other hand they may be part of the Taconic Paleozoic rocks and equivalent to the Green Mountain rocks. The theory that the Green Mountain rocks were thrust westward over the Paleozoics to the extent of reaching the Taconics does not merit credence until the absence of so-called Green Mountain pre-Cambrian rocks in the Paleozoic Valley is explained.

It may be pointed out that conceptions of the age of the rocks of the Green Mountain front are possibly influenced by the nature of the rocks that the geologist has been accustomed to work in. If he has been working in complex pre-Cambrian sediments he is apt to see evidence for a pre-Cambrian age in the Green Mountain front. If his experience has been in the Paleozoics he may find reasons for doubting a pre-Cambrian age for the rocks in question. The rocks of the area treated herein might be called pre-Cambrian on the basis of stratigraphic succession. On the other hand they may be called basal Cambrian on the same evidence. There is even reason for believing that they are composed of Cambrian and Ordovician sediments. Similar rocks are found in the Green Mountains and the Taconic Mountains. It is evident that a study of the ages of the rocks of the two ranges and their relationship to the Rutland Valley constitute a problem which has not been solved and upon which little progress has been made.

COMPRESSED MICA RESEMBLING GRAPTOLITES

Edward J. Foyles

A collection of rock made in northern Vermont includes specimens with peculiar markings resembling graptolites collected near the entrance in the Catholic cemetery, Clay Hill, Montpelier. It is from the Waits River limestone, which is equivalent to the lower Trenton west of the Green Mountains, and the Savoy schist in southern Vermont. In the Report of the Vermont State Geologist, Vol. X, p. 144, this formation is described by Dr. Charles H. Richardson as being interbedded in the Memphremagog slate and is tentatively placed in the Ordovician. The outcrop is figured in the above report, Plate XLVIII. The original description of the Memphremagog slate appears in Report of the Vermont State Geologist, 1907-8, Vol. VI, pp. 276-279. The dip of the rock is 75 to 80 degrees, west.

The sample discussed herein is a calcareous schist with shiny markings parallel to each other and all running in the same direction. The markings are dispersed through the thickness of the rock.

Observations with the aid of the binocular microscope show parallel shiny strips on a dull iron gray background. The shiny strips have striations parallel to the long dimension of the strips. The strips are broad and narrow in width. Approximately twenty layers of the strips are found in one inch of thickness of rock. The striations appear to be a structure of the rock and their fineness produces light reflections causing the shining. The striations are minute crumpling of isolated sections of the rock. The crumpled surfaces or strips are covered with mica. The dull portions of the rock show mica, quartz and calcite.

The phenomenon of the shiny strips is interesting because it appears to be due to organic material, closely resembling graptolites. The shiny strips are areas of stretched mica so finely crumbled that they reflect light and appear brilliant against the dull background of the rock.

MINERAL RESOURCES

G. H. Perkins

During the last few years there has been no great change in the mineral resources of Vermont. Nearly all the quarries and mines that were actively worked two years ago or more are still in operation and, as far as the Geologist has been able to ascertain, all have been carried on successfully, though with somewhat varying degrees of success. As heretofore no metals have been mined. Other minerals, as talc and asbestos, however, have been. As must always be true, the greatest mineral assets of the State are in its quarries. As all Vermonters well know, in the granite, marble and slate deposits the State has an unfailing source of wealth and a great supply for coming years. Many of the minerals, as coal, oil, ores of metals we cannot produce, but we can equal and probably exceed all other localities in granite and marble and, except Pennsylvania, also in slate. From these materials must Vermont expect large income. In the possession of these and possession in large quantity and of the most desirable quality, Vermont may heartily be congratulated. There are also possibilities, as will be noticed later, that an important income may be obtained from other minerals. I have not found it possible to obtain as full or, in some cases as certainly accurate, information as I wished but I doubt if anywhere there is any better. Obviously, the universal business depression has been felt here as elsewhere, but not to any destructive extent.

GRANITE

For many years Vermont was known as the great marble-producing State of the Union and it still leads all others, but of late years granite has exceeded marble in value and amount. The Barre men claim, and probably with reason, that Barre leads the world in production of granite as well as in quality for all purposes. All the Vermont granite now sold is of some shade of gray, from so light that at a short distance it appears white, through many shades of gray to very dark. Most of the Barre granite is sold after it has been worked and, therefore, is ready for use, but there is also a considerable quantity sold in the rough to cutters all over the country and to foreign countries. The quarries are none of them located in Barre City, but several miles distant, though all in the town of Barre. Most of the stone is not cut near the quarries, but in the manufacturing plants in the city limits. The quarries are not numerous, the manufacturing or "cutting plants" are. Since the publication of the last Report of this series there have been some changes in the granite world of Barre. A few of the manufacturing plants have gone out of business, a few have changed hands, but in most respects the business has gone on as usual.

The quarries in Graniteville, East Barre and elsewhere about Barre, as has been noticed are few in number as compared with manufacturing plants. Ten of the large companies have, since the last Report was issued, formed "The Rock of Ages Corporation." These are Barclay Brothers, Canton Brothers, E. A. Chase Granite Company, Eureka Granite Company, Grearson and Lane Company, the Lawrence Company, William Milne Company, Perry Granite Corporation, Phillips and Slack, George Straiton. The object of this combination as stated is "Uniformity of quality and stabilization of price." Most of the companies named above own and work quarries, sell the stone at wholesale, or finish it as desired. Orders may be placed with any of the above named companies or with any of the cutting plants belonging to the corporation. The granite sold by this corporation is exclusively "Barre Dark." The president of the corporation is Roy L. Patrick of Burlington. The capital of the corporation is stated at $6,000,000. Other companies are ready to supply other shades of granite, as Barre White, Barre Light, Barre Medium, etc. Two of the above list do not operate quarries and one or two are located outside of Barre, though near. Of finishing plants there are many in Barre and many in Montpelier a few miles distant. In all there are at least a hundred plants and there are others in nearby towns. In addition to the companies named as members of the Rock of Ages Corporation who operate quarries there are the following in this area:

Jones Brothers Company.
Littlejohn, Odgers and Milne.
Marr and Gordon.
Pirie Estate.
E. L. Smith and Company.
Standard Granite Co.
Vermont Quarry Company.
Wells and Lamson.
Wetmore and Morse.

There are also a few quarries that are operated more or less periodically, but not regularly. As will be seen later, there are quarries elsewhere than about Barre, some of these are large and very active. Geologically it is interesting to note that all the granite deposits are found east of the Green Mountains. Originally all were upthrusts of molten rock, forced from below the surface by some sort of volcanic action, as described in previous Reports. From the Canada line south as far as Dummerston, masses of granite are scattered and there seems to be no limit to the quantity, nor to the dimensions of blocks quarried except in the difficulty of handling. Anyone visiting quarry or manufacturing plant will not fail to be greatly interested in the manner now employed in working so hard a material. It is comparatively a short time since all cutting, turning, lettering, or whatever need be done could only be accomplished by hand, but in these later years nearly all kinds of work are done by machinery. Indeed the visitor is impressed by the similarity of these to wood working processes; much more slowly certainly, but it is almost true to say that anything that can be done in working marble or even wood can be and is done when granite is treated. I need not say that such machinery and tools as are used in sawing, carving, lettering, turning or polishing a hard material must be adapted to that special purpose, but being properly adapted and applied the work is successfully completed, and in a manner satisfactory as it could not have been not many years ago. It is evident that by the use of modern machinery, stone is handled more expeditiously and cheaply than has been possible heretofore and this can only mean that stone of every sort can be used far more freely and generally.

I think that the Barre area is widely recognized as the granite center of the world, although much granite is quarried elsewhere in Vermont and there are some very large and important quarries and mills in many other places, in this and other countries. One of the largest of the Vermont granite producing companies is The Woodbury Granite Company, with extensive quarries in Woodbury and Bethel, and finishing works in Hardwick and Bethel. This company uses several kinds and shades of gray stone, which though excellent for mausoleums and any other purpose for which granite is desired, is especially valuable as a building stone as its use in past years in several state capitols and other large and important buildings shows. Bethel granite is an almost white stone, so white that at a short distance it appears as white as white marble, as the Union Station and other buildings in Washington show. This white granite is quarried in Bethel. Other granite, as seen in the Pennsylvania State House, is gray.

As already noticed other, though smaller, granite quarries and "cutting sheds" are found in various localities between the Green Mountains and the Connecticut River. The most important quarries and mills are as follows, arranged alphabetically. Most of the companies named operate quarries, some only "cutting sheds," some both.

Barton.—Barton Granite Company; Crystal Lake Granite Company.
Beebe Plain.—Stanstead Granite Company.
Bethel.—Woodbury Granite Company.
Chelsea.—Brocklebank Granite Company.
Dummerston.—Presby-Leland Quarries.
Groton.—Bonazzi Quarry Company; Groton Quarry Company.
Hardwick.—Ainsworth and Ainsworth; American Granite Company; G. H. Bailey; Carter Quarries Company; L. J. Douglass; E. R. Fletcher; E. T. Leach; L. S. Robie; J. Walsh; Woodbury Granite Company, Inc.

Kirby.—Frechette and Flanders; Kirby Granite Company.
South Ryegate.—C. E. Gibson.
Williamstown.—Jones Brothers Company; Williamstown Granite Company.
Woodbury.—Woodbury Granite Company, Inc.

MARBLE

Unlike the granite and slate industries, with many manufacturing plants, marble is worked in only a few localities. As to marble quarries it is probable that operated and idle, there are as many as of granite and slate. As granite is confined to Vermont east of the Green Mountains, so all the commercial marbles are quarried west of the mountains and nearly all varieties in Rutland County. The only companies at present active are the following:

Clarendon.—Green Mountain Corporation (Clarendon Springs). Manufacturing plants and quarries, Clarendon, Dorset, West Rutland.
Proctor.—Vermont Marble Company. Manufacturing plants, Rutland, Proctor, Middlebury, West Rutland, Center Rutland, Pittsford, Swanton. Quarries, West Rutland, Proctor, Dorset, Pittsford, Brandon, Isle La Motte, Swanton, Danby, Roxbury, Rochester.
Rutland.—Colonial Marble Company; Office in Rutland; Quarries in West Rutland; Working plant in Rutland. Venetian Marble Company; Office in Rutland; Quarries in Pittsford.

The Vermont marbles are mostly light in color, but a very great variety of colors and shades are quarried, varying from the purest white of statuary to the clear black. I have not counted the varieties which can be quarried, but I think at least a hundred, though perhaps not more than half this number are constantly in stock. All the marble sold is durable as the inscriptions on some gravestones which are over a century old show. Some of the varieties are very attractive in color.

SLATE

A little south and west of the main marble quarries, that is of the main belt of commercial marble, is the slate belt, extending several miles from Lake Bomoseen through New Haven, Poultney and Pawlet into Wells. There is also a slate belt east of the Green Mountains, especially developed in Northfield, which furnishes a very dark or black stone. A number of quarries have from time to time been opened and worked in this belt, but for some years they have all been idle and all Vermont slate is now obtained in the western belt in Rutland County. The material found in this western belt is of varied colors, green of several shades, purple of several shades, and mottled green and purple. No red slate is found in Vermont, though directly over the state border in New York it is quarried abundantly. As in the granite industry, so in working slate, the introduction of new processes and machinery

during the last few years has greatly increased the use of slate, and it is now manufactured and used for many purposes not heretofore thought of. Most of the slate companies operate quarries, some buy their rough material from others, some supply roofing slate, some what is called "mill stock," a few only ground slate. The most recent list of these is as follows:

Castleton.—H. M. Brown and Son, ground slate; Charles Bassett, John Jones Slate Co., Lake Shore Slate Co., Criterion Slate Co., Hydeville, P. F. Hinchey and Co., McDonough and O'Day, Minogue Brothers and Quinn, Penrhyn Slate Co. (all the above supply mill stock only).
Fair Haven.—Harvey Bush Slate Co., C. R. Beach Slate Co., purple; Clark and Flannagan Slate Company, green, purple, gray, mottled; Durick Keenan and Co., mill stock only, purple, mottled; Earle and Ritchie Slate Co., purple; Eureka Slate Co., roofing only, unfading green, purple, mottled; McNamara Brothers Slate Co., only electrical slate; Mahar Brothers Slate Co., Old English Slate Co., purple, mottled, office Boston, Mass.; W. H. Pelkey Slate Co., green; Unfading Green Slate Co., A. R. Young Slate Co., mill stock only. Slate products, Fair Haven Marbelized Slate Co., Locke Slate Products Co., Vermont Milling and Products Co.
Poultney.—Auld and Conger Co., green, purple, mottled; Berdew Slate Co., Bryn Slate Co., Cambrian Slate Co., Elnida Slate Co., Eureka Slate Co., Hughes and Jones Slate Co., McCarty Slate Co., Mammoth Slate Co., New England Slate Co., Owens Brothers Slate Co., Owens and Owens Slate Co., New York Consolidated Slate Co., St. Catherine Lake View Slate Co., F. C. Sheldon Slate Co., United Slate Co., Vendor Slate Co., Staso Milling Co.
Wells.—Burdette and Hyatt, quarries in Wells; Norton Brothers Slate Co., green, purple in Vermont, red in New York; O'Brien Slate Co., purple, sea green; O. W. Owens and Sons Slate Co., green, purple in Vermont, red in New York; Progressive Slate Co., purple green in Vermont, red in New York; F. C. Sheldon Slate Co., sea green; G. W. Thomas, sea green.
West Pawlet.—Rising and Nelson Slate Co., roofing, sea green.

TALC AND SOAPSTONE

Talc is obtained in several localities, *viz.:*

Chester Depot.—American Soapstone Finish Co., Vermont Talc Co.
East Granville and Rochester.—Eastern Talc Co., mines; office Boston, Mass.
Johnson.—American Mineral Co.
Waterbury.—Magnesia Talc Co.

The talc companies are in active operation and considerable amount of the material is constantly produced.

Not many years ago several soapstone works were in apparently thriving condition, but at present there is little quarrying or manufacturing done. Most of the mills are closed, those in Chester being the only mills now working.

ASBESTOS

On the slopes of Belvidere Mountain, in the town of Eden, search for good commercial asbestos has been carried on for over twenty years, but until recently unprofitably. Much money has been expended here by several different companies, especially on the southern side of the mountain. At last, as new methods of separation (milling) have been invented and new uses for short fiber have been found, work is carried on by the Vermont Asbestos Corporation with new vigor and greater promise of success. A recent letter from Mr. T. E. Byrnes, president of the above corporation, is as follows: "The ore deposit is chrysotile asbestos and is an extension of the Canadian deposit (at Thetford, Black Lake, etc.). An adequate twenty-three mile power was built to the mine from Fairfax, new roads made and old ones repaired, new buildings constructed at the plant, etc." "Much new machinery was installed, ... to give a capacity of a thousand tons a day of asbestos rock. The old mill was completely overhauled to make room for new machinery, which assures a minimum output of two tons of finished asbestos fiber an hour. This is the present average production of the plant. The new equipment went into operation about April 1, 1930. Our fiber has during 1930 been sold and shipped to important consumers. It is believed that the property has an excellent future."

GARNET AND MICA

During the past year items have appeared in some of the papers describing in general terms a ledge near Gassetts, Vt., in the rock of which was a large percent of mica and also considerable (15 percent) garnet. To quote from one statement: "The ledge from which the ore is to be taken is at least 3,600 feet long with an average thickness of 150 feet." "The deposit comes to the surface." Not being able to visit this locality myself, I asked Dr. C. H. Richardson, who has been a worker on the Vermont Survey for many years, to investigate the deposit as he was working in the region of Gassetts. He writes as follows: "The Gassetts schist is a silvery white, highly garnetiferous muscovite schist. In addition to the garnets there are numerous crystals of tourmaline and staurolite. . . . . A mill has been constructed for the separation of the mica from the garnets, tourmaline and staurolites, but the mill was idle in August when I was there. The statement was made that the wrong type of machinery was installed . . . . and that the mill was closed only to change the machinery to get a better separation." From the above it seems that there is here a possibility of good results later.

LIME

In going over Vermont in order to examine the ledges or outcrops one comes across many old lime kilns of very simple construction and evidently used in old times for burning small quantities of limestone. Good limestone is not abundant in Vermont except in the vicinity of Lake Champlain on the western border. All of these primitive kilns have long since been abandoned, as new and far more efficient furnaces and new machinery have been invented and become available. It has required only a small number of these lime works to supply a much greater need than formerly existed and, of course, with far better results. The list below gives the addresses of the lime producing companies which during the last few years have been active in Vermont. Most of these have been in operation for a number of years, a few have not done much of late, but all are on record as active companies. These are:

Amsden.—Amsden Gray Lime Company.
Highgate Springs.—Missisquoi Lime Company.
New Haven Junction.—Green Mountain Lime Company, office Worcester, Mass.
Pownal.—Pownal Lime Company, office 11 State Street, Boston, Mass.
Swanton.—Swanton Lime Works.
West Rutland.—Vermont Marble Company.
Winooski.—Champlain Valley Corporation.

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