REPORT

OF THE

STATE GEOLOGIST

ON THE

MINERAL INDUSTRIES AND GEOLOGY

OF

VERMONT

1917-1918

ELEVENTH OF THIS SERIES

GEORGE H. PERKINS

State Geologist and Professor of Geology
University of Vermont

BELLOWS FALLS P. H. GOBIE PRESS VERMONT.

93314

STAFF OF THE VERMONT GEOLOGICAL SURVEY
1917-1918

GEORGE H. PERKINS,
  Professor of Geology, University of Vermont.

E. C. JACOBS,
  Professor of Mineralogy, University of Vermont.

HERMAN L. FAIRCHILD.
  Professor of Geology, Rochester University.

CHARLES H. RICHARDSON,
  Professor of Mineralogy, Syracuse University.

W. G. FOYE,
  Professor of Geology, Wesleyan University.

J. W. EGGLESTON,
  Shaler Fellow, Harvard University.

N. C. DALE,
  Professor of Geology, Hamilton College.

C. H. PIERCE,
  United States Geological Survey, Hydrographic Division.

D. G. GRIFFIN,
  Field Assistant.

TABLE OF CONTENTS

LIST OF PLATES

LIST OF FIGURES

STATE OF VERMONT

OFFICE OF STATE GEOLOGIST

BURLINGTON, VT., December 30, 1918.

To His Excellency, Horace F. Graham, Governor of Vermont:

Sir:—In accordance with Section 405 of the General Laws I herewith respectfully submit my eleventh biennial report as State Geologist.

During the years 1917 and 1918 the usual work of the State Survey both in field and office has gone forward.

There is always a considerable amount of correspondence necessary and each year a large number of samples of rocks and ores are examined besides samples of proposed road material.

Portions of the State hitherto unstudied, or at least needing further investigation, have been investigated and important additions have thus been given to our knowledge of Vermont geology.

A summary of this work is presented in the following Introduction.

Unfortunately the work of the Topographic Survey of Vermont which is carried on by the United States Geological Survey in cooperation with the State has been wholly interrupted by the war.

All available engineers have been called into war work, but now it is hoped and expected that this mapping so very important to the development of our State will soon be resumed.

As many know, the cost of such mapping and the preliminary surveys necessary is expensive and would be beyond the ordinary resources of the State, but thru an arrangement with the Federal Survey the work is done in the best possible manner at a fraction of the total cost so far as the State is involved. The initial cost of the field surveys is shared equally by the Government and the State and then the further cost of preparing, engraving and publishing the maps is wholly borne by the Federal Government.

There can be no doubt that in the long run these maps save many times their cost and that any appropriation by which this work can be continued is very wise economy.

More than a third of Vermont is now mapped and the maps published and to be had from the U. S. Survey or from several dealers in Vermont. Preliminary work has also been completed over areas beyond the boundaries of the published maps.

Respectfully submitted,

GEORGE H. PERKINS,

State Geologist.

INTRODUCTION

The present volume is the Eleventh Report of this series, the first having been published in 1898.

The work reported as accomplished during the two years, 1917-1918 is similar in character to that of former years, but has covered a larger portion of the State and includes important results.

As heretofore we have been very fortunate in valuable assistance, freely given by several excellent geologists whose work has added much to the knowledge of Vermont geology.

Physiography is now so generally taught in our public schools that in the first chapter the Geologist has attempted to give a somewhat detailed account of the physiographic features of the State, for surely, if any physiography is worth while that of one's own vicinity is most so.

As will be readily seen by those reading this chapter, our Vermont physiography is complicated, varied, and very interesting.

It is because of these characteristics that our scenery is so attractive and some knowledge of its why and wherefore is very desirable.

The second chapter is a concise summary by Professor Richardson of the more important geological features of eastern Vermont.

In some respects this and the preceding article follow similar lines, but this should not detract from the value of each for, while in substantial agreement, they give views from different standpoints.

In the third chapter Professor H. L. Fairchild has given a very illuminating study of some of the ancient water levels, evidences of which are not uncommon in many parts of the State.

This chapter supplements former study by Professor Fairchild, who is our best authority in this particular phase of geological study, reports of which have been published in volumes immediately preceding this.

Altogether these discussions contain by far the most complete and satisfactory statement of the causes of many of the level tracts which are scattered here and there over many parts of the State, which is to be found.

The fourth chapter gives a somewhat detailed account of the structure, and character of the rocks found within that part of the Green Mountains which is included in the recently completed "Rochester Quadrangle" by Professor W. G. Foye. The results here given will be welcomed by all students of Green Mountain geology.

Following this are two chapters in which Professor C. H. Richardson has extended his previous study of the rocks of eastern Vermont into the towns of Northfield and Roxbury and interesting observations will be noticed by those who read these chapters.

Professor E. C. Jacobs in the next three chapters discusses some features in the economic geology of the State and treats of the Copper, Talc, and Lime industries, and anyone interested in these materials will find here the latest information concerning them.

To the "List of Elevations in the State" published in the Tenth Report, a few additions should be made and these are here given.

Mr. J. W. Eggleston has furnished a structural and petrographic study of the rocks in the town of Cuttingsville. This paper was first published in the American Journal of Science, May 1918, but Mr. Eggleston has added another season's work and incorporated the results in the present publication. Professor N. C. Dale spent one season in investigating the rocks of part of the western slope of the Green Mountains and, while the full report of this work is not yet ready for publication, a brief preliminary statement is given at this time.

Mr. C. H. Pierce of the U. S. Geological Survey presents a report of the work carried on by that Survey in cooperation with this State in Stream Gaging.

Finally, there is a brief report upon the mineral resources of Vermont.

PHYSIOGRAPHY OF VERMONT

GEORGE H. PERKINS.

The physiography of Vermont, or of any region, is the record of its more recent geology, of the latter stages in the age-long process by which the present surface has come to be as it is. In some localities this record is far more complete than in others and therefore indicates far more of what has taken place in past time. In some places the story is simple and readily deciphered, while elsewhere it is complex and difficult or impossible. This is not only true of different parts of the country, but of different parts of a small area like that of this State. Where there has been great disturbance and rock masses have been thrown out of their original position, or raised from below the surface, it is more often possible to make out the past history than where there has been little thrusting and overturning.

In many parts of Vermont the immediate surface features can be understood without great difficulty, but in the mountainous regions there have been so extensive changes that it is very hard to discover, in many cases, what the original condition of the upthrust rocks must have been. A great deal has been settled as to Vermont geology, so far as it can be seen and studied, but a great deal remains uncertain.

The origin of lakes, valleys, sand hills, and plains, of many of those features which are most obvious as one looks over any Vermont landscape, can be found, but when one asks of the origin of the marble and granite there is more uncertainty until careful investigation has revealed the present structure, and from this the past history of these rocks, and when the Green Mountains and their foot hills are questioned, the answer is long in coming and thus far can only be given in part. This is because in the processes of mountain making the original materials have been so entirely transformed that the task of ascertaining their first condition and character is often almost an impossible one.

The physiography of a region, then, is its surface geology, and it will include more or less of the deeper strata, as these deep beds have, by reason of disturbance, been brought within the field of the student and their study made in some degree possible.

The increased interest and charm which a knowledge of the why and wherefore of that which is seen gives to any bit of scenery hardly needs to be mentioned, and one main reason for writing this chapter is that some of the many who ride thru the valleys and over the hills of our State may see more than the most obvious and prominent characteristics of the landscapes they must admire. If one can understand even a little of how all this came to be as it is and can know that nothing is by chance, nothing is what it is and where it is, except because of the orderly action of orderly forces which may in some measure be understood, the world which he finds about him will be transformed and glorified. Being assured that there is a reason for the sand plain and for the gravel bank or rocky ledge, for the winding stream or the green hill, for any and for all the parts which together make up a landscape, one finds a joy and an inspiration wholly different and vastly greater than can come from the usual casual glance over the same scene. Not merely to gaze at the topographical features of a bit of country, but to study them and, so far as may be, find why they are—this is to enjoy a ride or walk. Vermonters, or, indeed, any who may take a trip thru some part of the State, will seek in vain for any region which offers more interesting problems of the sort just intimated, or more varied.

There is not a little Vermont physiography, as has been noticed, that is very complex, but there is also much that is simple and to be understood with very little effort. But no pleasure can come without some effort, and those who are unwilling to work for the good they may get do not deserve to have it and will not be likely to find it. It is labor well spent that is given to gaining some knowledge of the physiography of any region which one may pass thru.

At best only a part of what has been in the geological history of any part of the earth can be ascertained. Nothing is more fully impressed upon the mind of a working geologist than that the record available for study is very incomplete. A great deal, perhaps more than appears, has been wholly effaced during the changes that have taken place while the earth was in the making, but, notwithstanding this, it is evident that many indications, if no more, of what has happened, can be found, and always a most interesting story can be made out even tho incomplete. Not only is the scenery of Vermont charmingly varied, but the geological agencies which have worked together to produce it have been of many sorts. Indeed, there are few processes of which there is anywhere record that cannot be traced in Vermont. And it is by these many forces and many activities that our scenery has been brought to its present attractiveness and also is constantly being modified.

No one would dare attempt to say how long the time during which the rocks of Vermont were accumulating, solidifying, folding, changing in every part of structure or even to some extent, composition. They have been folded, uplifted hundreds of feet and depressed at another time hundreds of feet. They have been split, broken, crushed, melted, frozen. Now violent and volcanic, now quiet and slow, now local, now extending far and wide these geological activities have gone on to make Vermont what it is. As Dr. Geikie, in that very suggestive book, *Scenery of Scotland*, has remarked, "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, in their fracture, displacement, 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 into 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."

It will be helpful if we take a general survey of the geological periods during which the making of our scenery went forward. As always, in going back towards the beginnings of anything, we finally reach the very uncertain and indefinite. Of course we must believe that there was a beginning, but when we attempt to picture to ourselves or others what that beginning was like we are at a loss what to think.

The Adirondacks are the oldest, probably, of the land in this region, and as they were formed, at least for the most part, before there was land on this side of the Champlain Valley, a good deal of the material from which the oldest part of western Vermont was built must have come from these mountains. There is, apparently, little land anywhere in the United States that is as ancient as the Adirondack region, tho there are areas which even antedate the formation of this, but they are not extensive. As the storm driven waves of the old sea dashed against the Adirondack mass and beat the hard and solid rock into sand, this was borne eastward, and in time was consolidated into the Red Sandrock which at first covered to a depth of thousands of feet the whole, or at least a large part, of what is between the Adirondacks and the Green Mountains and, perhaps, to some extent, east of these mountains.

As will be noticed later, the Sandrock Hills and the sandstone outcrops are the meager remnants of what at first was a great mass, now so nearly carried away. Mount Philo, Red Rocks, Snake Mountain and other existing masses are all that are left to tell of the former extension of Lower Cambrian beds. What of this age is in the main mass of the Green Mountains, has not yet been found. It would seem probable that in the deeper parts of the mountains there is considerable rock of the Cambrian age throughout the range, but it has not been determined except in a few localities, notably in the mountains of Rutland County. Still older rocks have been found in these mountains, Pre-Cambrian, how much older, cannot as yet be determined. It is extremely probable that throughout their entire length the Green Mountains contain rocks older than any which appear at or near the surface, as it is certain they do in some localities where the mountain structure has been most thoroughly studied. Where these very old rocks occur they must be in what may be called the foundations of the mountains. By far the greater part of the Green Mountain Range is later and consists of highly metamorphosed strata, some Cambrian and more Ordovician. To some extent this is true of the whole State.

Only very limited areas in the State are newer than the close of the Ordovician and we may consider the present land to have been formed and raised out of the ancient seas soon after the Utica which is the close of Ordovician time. From the close of this time thru many ages of great duration until the great ice age which immediately preceded the present, very little rock was formed in Vermont and for most of this period Vermont, or what is now its area, lay exposed as land to the slow, but irresistible action of the elements—the quiet action of rain, snow, frost, sunshine, water in all its forms, and whatever atmospheric agencies may have been present. It will be profitable to review somewhat in detail the history of these times during which all that we now see was formed.

As has been noticed we can only conjecture the condition of the country in the earliest period of which we have any evidence, tho necessarily there must have been those before this. Subsequent changes have obliterated all traces of the earliest times and of those which directly came before the paleozoic only imperfect remnants tell us something of the story, but from the beginning of the Cambrian on, abundant records of no uncertain interpretation are everywhere present and very obvious. So far as our certain records indicate, the New York Adirondacks, older as a whole than our Vermont rocks, were raised in a much greater mass than now, for, during a period of time so long that we dare not attempt to estimate its duration, these elevations have been wearing away and the waste of these older masses has furnished material from which the older rocks of western Vermont were built up.

At some time after the elevation of the Adirondacks, or it may be about the same time, a probably not very high fold of the crystalline Eozoic rock, upon which rested old, tho later, beds of Algonkian age, rose along the line of the Green Mountains. Thus it appears that in very early times the present Champlain Valley was outlined by the elevation of these two ranges, or ridges, and, that it is for this reason one of the most ancient of North American valleys. Although in some of its features different from its present outlines, this valley has remained much as it is today in its long and narrow form and in its boundaries, only it was at times narrower and at times broader, so far as the immediate shores of the lake are concerned, and for a long time was one with the present Hudson Valley and thus extended from the Atlantic, at New York, to the Gulf of St. Lawrence. The east and west boundaries, of course, could not vary greatly, for the ranges which made these limits did not change.

We know that the backbone of the Green Mountains, of whatever rock composed, has been deeply covered by beds of later rocks, sandstones and limestones, and as must be noticed over and over again in this account, these, at first ordinary beds of Cambrian and Ordovician material, were wholly transformed into the schists and gneiss of the mountains as now seen. Whether the elevation of the Green Mountains was single, that is, continuous for ages, for if continuous it must have gone on from some early Pre-Cambrian period to the close of the Ordovician or later, and this would mean an immensely long time, or there were two or more times of rising, one before and one at least after Ordovician time. If the latter, which I am inclined to believe more probable, then there was a time of very early elevation of unknown altitude. If this elevation was considerable then erosion reduced it to a lower height, or even to a level, over which Ordovician seas existed and deposited the materials from which the limestones, etc., were made.

Then came another time of rising after the added mass of these later beds had been received. Whether this elevation was rapid or slow is not wholly certain, but its resulting rocks indicate that it was slow and that it reached a much greater height than is now found in the mountains. This must have been, for erosion through the vast interval to be noticed presently and that of the great ice sheet which covered the highest peaks would of necessity have carried off immense quantities of material and we find this in the great sand and clay deposits familiar to us of today. This disturbance of Ordovician beds was so extensive that it covered the whole State except in the immediate vicinity of Lake Champlain. Here, as has been shown in detail in former Reports*, the beds of this age are usually not much tilted and not at all metamorphosed, but a very few miles east of the lake everything is changed so completely as to be quite unrecognizable at first examination. Certainly, no one would from a casual observation suppose that the schistose and crystalline rocks of the Green Mountains were ever the limestones and sandstones of the Chazy or other Ordovician beds, nor that those usually orderly and regular strata could by any process become the contorted and plicated beds of the mountains.

Until recently it has been supposed that the rocks east of the Green Mountains were all completely metamorphic, but Dr. Richardson's discoveries, as he has been carrying on investigations as Field Geologist of the Vermont Survey, have shown that all over the territory between the mountains and the Connecticut River, there were beds which afforded imperfect fossils which identified them as of Ordovician age. While in the mountains themselves the metamorphism of the stratified beds was not such as to greatly benefit the future State, in the marble and slate regions it was different, being less complete and perhaps affecting rocks of a somewhat different composition, though they could

---

*Tenth Report, pp. 200-231. Also previous Reports.

not have varied greatly, and as the result the commercially valuable marbles and slates were formed in the Rutland district and in Poultney, Pawlet, etc.

Here and there in the State, especially in the Champlain Valley, bands of rock from two or three inches wide to several feet, in a few cases as many as twenty, are conspicuous as they cut thru strata of very different character. These are the dikes, streams of volcanic material which were forced from below the surface directly thru the other and, of course, older rock. Very likely some of these were formed during the great transformation that came during the mountain making, but some are more recent and there there is no indication in their surroundings when the activity which caused them took place.

Then, in the Granite Hills of eastern Vermont there is proof of other, and it must have been great, disturbance for these from which all our granite is taken, could not have been produced by any little force. More will be said concerning these granite masses later. They are undoubtedly of somewhat more recent origin than the marbles and slates but just when they were raised from depths below it is not easy to decide with confidence. It at present seems most probable that the granite of Vermont was formed for the most part during or soon after the close of the Devonian age. Some of the granite, however, must be later than the main body, for dikes of granite are found in some quarries cutting the greater mass, and of course these are later.

After the granites were thrust up there does not seem to have been any commotion or great change in the land of Vermont caused by the internal forces of the earth. Change, great change, as will be shown, took place, but it was slow and quiet. With the exception noted, the enormous interval between the close of the Ordovician and the activities of Glacial time was, so far as great convulsions were concerned, much as now when, tho changes are going on everywhere, they are so slow and silent that none are aware of them.

During this quiet time, millions of years long, there passed the Silurian, Devonian, Carboniferous, Permian of the Paleozoic, the three ages of the Mesozoic and the first age of the Cenozoic. All these ages in which thousands of feet of slowly deposited rocks were laid down in other parts of the country and thousands of species of animals and plants appeared, developed generation after generation, and disappeared, and great changes in the continent took place, especially in the relative position of land and water areas—all this before the last great geological age came on the world's stage, with the exception of a small area in western Vermont where in the first part of the Cenozoic, the Tertiary, there was a small deposit of strata of which the Brandon lignite is most interesting. It is not difficult for us to understand that with such an age-long period in which to accomplish their work, the powers of the air and the waters, however slow in effecting results, must have greatly altered the face of the country so that at the close of the great interval which stretched between the Ordovician and the Pleistocene, the surface of the region was far different from its beginning.

The age immediately preceding the present, characterized as the Great Ice Age or Pleistocene, finally came. With the coming of this age the slow and regular changes which had been going on ceased and more rapid movements wrought the finishing work which brought our State into its present appearance and made the surface, at any rate, what we see it to be. The frosts and the rains, the cold of winter and heat of summer, had done much to break down and wear away rock masses, but now all changes were effected with vastly increased rapidity. As in far more ancient times the beds of slate, marble and granite had been formed, so now by the more violent activities of the Pleistocene, the soil which is all important to an agricultural region was formed more speedily and distributed in such fashion that it could be used.

It is not likely that during the great interval between the Ordovician and the Pleistocene the surface of the country remained wholly quiescent. We have, however, no indications of land elevation and depression, except locally in the region of dikes, but that during the Pleistocene the land was extensively moved up and down is plainly shown. During the early part of the Pleistocene the whole northern country was raised to an elevation several hundred feet above that which it now has. Perhaps not only the northern part, but the entire continent was raised even thousands of feet, but we have here only to consider the region which became finally our own State.

There were of course many results following this extensive uplift of the country; one was the accumulation, in incalculable masses, of snow and ice north of the St. Lawrence. Three great sheets, glaciers, are usually recognized by geologists, one, that which alone concerns us, started in Labrador from a center and moved from here to a comparatively small distance northward to the ocean, but by far the largest part of the mass moved, as all glaciers move, in a southerly direction covering the eastern states and much of the middle west with thousands of feet of ice. West of this was a still larger ice sheet, which started just west of Hudson Bay and extended over a great area in British Columbia and south about as far as did the Labrador sheet, that is, somewhat beyond the Ohio River. Then a smaller sheet occupied a narrow belt of the Pacific Coast from Alaska to the Columbia River.

How thick these ice sheets were is not determined so that geologists are agreed, but it seems certain that our Labradorean sheet must have been at least four thousand feet, for it went over the Green and White Mountains, leaving its marks upon the very summits. The crushing, grinding, wearing power of such an ice sheet it is impossible to imagine, but we cannot doubt its enormous amount, nor that it modified to a considerable extent the form and mass of all our mountains and produced much of the material now forming our soil. The ice of the Labradorean ice sheet must have been thousands of years in accumulating and moving slowly, as all glaciers move, it must have taken other thousands of years for the front to reach its southern limit. By the vast weight of such a mass of ice, too vast for computation, the earth's surface appears to have been depressed so that the several hundred to over a thousand feet of elevation which took place in the early part of the Pleistocene was followed by a corresponding depression, tho probably less than the elevation.

Then came another change in climate when the arctic conditions which had prevailed for so long were changed gradually to milder and the ice melted. How long was required for such a glacial sheet to change from ice to water cannot be guessed, but that immense volumes of water came pouring down from the melting ice cannot be doubted. This was a time of great floods, greater than ever known or imagined, and by these torrents the loose material broken up by the great glacier was distributed and the whole face of the country changed. As the pressure of the ice was removed by melting the land again rose, not to its former height, but several hundred feet. Necessarily, by the rising and falling of the land the streams and all bodies of water were materially affected, some more, others less. Lakes then existing were greatly flooded and were in some cases several times as large as now and by one sort or another of glacial action and the subsequent floods, many new lakes which have continued were formed. A few, by changes in the adjoining land were drained and only their ancient beds remain. The same conditions, in many cases, altered the courses of streams, as numerous old channels now testify, tho in Vermont these changes do not appear to have been as great as in some other parts of the country where the old river beds are directly across the modern courses. Other river channels were deeply buried beneath the gravels, etc., of glacial drift. These are not infrequently found in digging wells. In the Eighth Report of this series a brief account of the history of lake Champlain is given and a part of this refers to the Glacial Period.* As this is a typical example of what took place in the development of many lakes and ponds it is referred to here as an illustration.

After the last elevation of the land surface conditions became more as they are now than they were formerly, but as this was many thousands of years ago, a great deal of erosion has come over the surface since, thereby changing its character, more in some places, less in others. From that far remote time, when by the two ridges, mountain ranges or whatever they were, the greater outlines of the Champlain Valley were formed, until the present, it is easy to understand that changes many and great have come upon the face of this country that we now call Vermont. Changes so vast as to be quite incomprehensible. Anyone who studies the physiography of the State with any degree of thoroughness will soon be convinced that in all its history it is too great for full comprehension, but he will also be convinced that the part of it which he is able to compass is richly worth all his effort.

As has been already noticed, the long north and south shape of the area between the Adirondacks and the Green Mountains has existed from very early times. So also the area between the Green and White Mountains, tho these latter are somewhat later in origin. Not only do all the elevations extend in north and south lines, but practically all rock beds as will be shown later. Vermont really consists of three narrow strips reaching from the Canada line to Massachusetts, one, the western, between Lake Champlain and the Green Mountains, the eastern, between the Green Mountains and the Connecticut River, and the mountain range itself. Any traveller in the State knows the difficulty of going the few miles that it is necessary to pass between the east and west sides of the State, for there are few places where the Green Mountain barrier does not present an almost impassable obstacle. Certainly these mountains dominate the State and with the foot hills, occupy a considerable part of its territory, so that little of the surface is level. It is this irregularity caused by the mountains that constitutes a great part of its natural beauty.

While the Green Mountains are a far more dominating feature of our scenery than any other, yet they are not the whole, not even all of our mountains. These mountains alone extend thru the state from Canada to Massachusetts and are by much the greatest of our elevations. They are well named as nearly all the peaks are green to the very top. Black spruce intermingled with other conifers form the forests at the higher levels while hemlocks, a few pines, and various deciduous trees are found over the lower slopes. Throughout, these mountains are externally composed of schists and gneiss, but there is more or less older rock in the mass of the mountains than these metamorphosed Ordovician beds, as has been already stated.

In the northern part of Vermont the Green Mountains are not grouped in a single range, but are spread out in two rather irregular ranges which together are scattered over the greater part of northeastern Vermont. Necessarily the topography of this part of the State is very irregular and the scenery unusually picturesque, even for Vermont. About fifty miles from the Canada boundary the mountains are brought within narrower limits and from Stowe or Waterbury south there is a single well defined range and the highest peaks come in this part of the range, as Mansfield, Camel's Hump, and Killington. The "Chin" of Mansfield, 4406 feet above the sea level is the culmination of the

---

*Eighth Report, Vermont Geologist, p 44.

entire Green Mountain range, tho Camel's Hump, 4183, and Killington, 4241, are not far from the same height.

Because of the somewhat irregular arrangement of the mountains north of the Winooski River, which seems to be fairly indicated by the term scattered, the mountains are there less of a barrier between the east and west sides of the State than south of the river, so that it is much easier to find comfortable auto roads from one side of the mountains to towns on the other, north of the river than south of it, as anyone may surely find out if he attempt the trip. The Central Vermont Railroad, the main highway between Burlington and Montpelier, and the Winooski River, passes thru the mountains by an easy grade in Bolton, but I know of no other passage which can be even by courtesy called easy until we come to Summit or Mt. Holly, and that is far from level. There is a very passable, but rather hard road from Brandon thru Rochester to Bethel and a better from Rutland to Woodstock, and to a lover of fine scenery the ride over either of these is worth while for its charming features, but neither is well arranged for a railroad.

The almost universal north and south trend of the surface elevations and rock masses is not followed by the rivers for these cut thru the mountains and enter Lake Champlain from the east. This will be shown more in detail later, but it may be noticed that in their windings the larger streams, the Missisquoi, Lamoille and Winooski, find or have made a comparatively low grade thru which they each may pass on towards their final goal in the lake. The latter river, at Bolton, where it flows between Mansfield and Camel's Hump, is only about 330 feet above sea level. Farther south, where the road from Brandon to Rochester, and that from Rutland to Woodstock cross the passes, they are each more than 1400 feet above sea level, and the Rutland Railroad crosses the divide at an elevation of 1500 feet at Summit.

Most people think of all the mountains of Vermont as Green Mountains, but in reality there are three other ranges or rather groups, of far less magnitude, indeed, and for the most part, far less in altitude than the main range, but nevertheless by no means to be neglected. Each of these is of different age and structure both as to the Green Mountains and as to each other.

The Taconics.—West of the Green Mountain range and between this and Lake Champlain are the Taconics, well known to all geologists. These mountains do not reach far north in the State, but begin at Sudbury, a little south of the middle. From Sudbury the various peaks continue south thru West Rutland, Ira, Wells, Dorset, Manchester, to Pownal and on south into Massachusetts. The Taconic Mountains are rather a series of peaks than a range. The greatest of the Taconics are over 3000 feet high and are therefore of dignified proportions, such as Equinox, Bird Mountain, Green Peak, Herrick Mountain, etc. Structurally, the Taconics appear to be very complex, but little as to the details of their makeup is known, with the single exception of Bird Mountain, which Mr. T. N. Dale has studied very carefully, as shown in his report in the Twentieth Annual Report, U.S.G.S., pp. 9–23, Part II, 1898. Probably, however, the structure of Bird Mountain is not to be taken as a type of the whole group, but each mountain may well have its own more or less special structure.

The main mass of Bird Mountain, Mr. Dale finds "a large area of metamorphic grit and conglomerate alternating with beds of sericite schist." Mr. Dale's conclusions are as follows: "Bird Mountain is an open syncline within the Taconic Range and consists of about 500 feet of grit and conglomerate interbedded with muscovite (sericite) schist and underlain on all sides by schist of similar character, but frequently containing small beds of quartzite. The presence of pebbles of crystalline limestone, calcareous quartzite, and granitic quartz in the conglomerate shows that at no great distance rocks of 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." l. c. page 23.

Red Sand Rock Hills.—There is a third series of hills and low mountains north of the Taconics and of lesser mass. Cobble Hill, Malletts Head, Red Rocks, Mutton Hill, Mount Philo, Hogback Mountain and Snake Mountain are the larger of these elevations, which begin with Snake Mountain in Addison and from here are found at intervals, not far from Lake Champlain, north to St. Albans. They nowhere form a range, though Hogback Mountain is so long that it nearly constitutes a small range in itself, but are more or less isolated elevations, for the most part of no great diameter. They are entirely composed of Lower Cambrian sandstone, of usually a dark red color. In some cases, as Cobble Hill in Milton, there are shales and quartzite. These, as has been stated, appear to be remnants of an old Cambrian land which once covered a considerable part of the Champlain Valley, but which has been mostly eroded off and carried away leaving only a mass here and there to tell the story of the ancient extent of the whole deposit. As has been indicated, most of these elevations are not more than a few hundreds of feet in height, but Hogback reaches in one part to 1850 feet, and Snake Mountain is 1271, Mount Philo, 968.

So completely has the Cambrian been removed from much of western Vermont that it is impossible now to determine its former limits, but there may well have been many square miles in extent, and thousands of feet in thickness.

The Granite Hills.—The fourth series of elevations are the Granite Hills which are found east of the Green Mountains, between them and the Connecticut River. They are nearly all north of the middle of the state, as Millstone Hill in Barre, Robeson Mountain in Woodbury, Kirby Mountain in the town of the same name and a number of others. These are very unlike the others in structure and age. As to material they are all intrusive rock, granite, and do not contain any sedimentary rock. Insignificant as these Granite Hills appear to be as compared with the greater groups, they have been and for many years will be of the greatest commercial importance to Vermont as from the granite quarried from these hills millions of dollars are brought into the State every year.

Thus it appears that Vermont not only is made up of the greater range of the Green Mountains, but that there are the quite important ranges of the Taconic Mountains, the Red Sandrock Hills and the Granite Hills. As each of these differs from the rest in geological structure and age so they differ in form and a trained eye can easily distinguish any of one series from those of another. Perhaps the relative age of these four groups of mountains has been sufficiently discussed and little more need be said. The Green Mountains are the oldest, if we go back to the first formed ridge which marked the line of the future range, but they must have passed thru many changes in form and structure long after the Taconics and Sandrock mountains had appeared. Indeed, the Green Mountains were in nowise as now, with their schists, gneiss, and quartzite, until long after the days of Cambrian deposition and erosion. There are some parts of the Taconics which may be as old as the Sandrock Hills, but most of their mass seems to be Ordovician. As has been stated, the Granite Hills are probably Devonian.

Nothing is more often brought to the attention of the field geologist than evidences of vast erosion by which incredible masses of rock have been wholly or partially removed from their original position. Wherever the rocks are studied there is likely to be found proof that much of the former surface has disappeared, leaving only fragments which serve to show what has been. This is not always the case, but often it is. This is as true of Vermont as of any region. The great denudation after the Cambrian deposits had been laid down has been noticed and in the granite beds another evidence of great changes long ago effected is found in the structure of the stone. The Vermont granites have resulted from the cooling and crystallizing of molten lava.

The structure shows that this crystallization must have been carried on under great pressure and the only pressure imaginable is that from overlying beds of rock. That is, the molten material came from below and met heavy layers of some stratified rock against which it would push in vain. If this is true, then at first and for a long time, the granite did not appear on the surface at all, but was hidden beneath these superficial beds. Now, all granite is uncovered, unless glacial drift has come over it and nowhere in Vermont is it below other rock, so far as I know. Everywhere the granite ledges are swept bare of overlying material, except the sands, gravel or clay of glacial production. Such evidence can have but one interpretation, that beds of unknown thickness once covered the granites and have been so completely eroded and carried away that no trace of them has been left and we can suspect their former existence only as the crystalline structure of the underlying material is investigated. The age of these overlying beds is wholly a matter of conjecture in the present state of our knowledge of them. Coming up as the granite did beneath them they must have been there when the granite arrived and if this is Devonian or not much later, then it necessarily follows that the wanting beds were older than Devonian. It harmonizes best with what is known of the geology of the region about the granites all over the State to suppose that these overlying beds were Ordovician. Professor Richardson has found Ordovician fossils in the close neighborhood of some of the granite beds.

Materials so different as some of those in each of the groups of elevations mentioned must present different appearance after centuries unnumbered during which they have been exposed to weathering and erosion of all sorts. To the casual observer each of these systems may appear similar to the others, but it is not difficult to find variations in the main features of one from those of others. These can often be seen more readily than described, but once seen they will always be seen. In case of the Sandrock Hills there is in all of them a more or less steep cliff on the lake side and gentler slopes on the other sides. The Granite Hills are more rounded and dome shaped, while the Green mountains and Taconics resemble each other in many parts of their ranges quite closely, but there is a Green Mountain and a Taconic physiography, and the difference once seen can be usually recognized. In general, the Taconics as a whole are more complex in their present outlines than the Green Mountains.

It may be well to call attention in this connection to the great changes which have been mentioned as occurring since the beginning of both these mountain ranges. Throughout the long development of the present mountains continual and great changes have been going on so that if we could picture each as it was at one period and at another the views would be very unlike. I suppose it is impossible for anyone to comprehend the extent of these changes. As to this I cannot do better than to quote from a Bulletin by T. N. Dale from which much of what follows on this subject is taken. (Bulletin U.S.G.S. 272 Taconic Physiography, T. Nelson Dale, 1905.)

Speaking of the Taconic Area, Mr. Dale finds, after much study of some of these mountains, that probably not less than 8000 feet of rock, more rather than less, at one time existed in the higher mountains of this range, tho 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 3600 and possible 5000 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 1000 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.

One other elevation is so unlike its fellows that it is to be considered by itself as in some degree unique. This is Ascutney which rises near the Connecticut River and stands alone as a solitary summit, or rather mass. Because of Doctor Daly's careful study of this mountain we have a more fully detailed knowledge of its structure than of any other of our Vermont mountains. Bulletin 209, U.S.G.S. gives the results of Doctor Daly's investigations and to this all interested in a farther discussion of the mountain, are referred. Because of its isolated position Mount Ascutney is unusually conspicuous for an elevation only 3119 feet above sea level. There is no other peak nearer than twenty miles and the mountain stands dominant above wide stretches of lowlands on all sides. But the mountain was not always so isolated, if Doctor Daly is correct in his conclusion as to its former condition.

"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 once lofty Appalachian Mountain System where the sedimentary rocks of the range have been intruded by several stocks and thick dikes of igneous rocks. The relief features of the region discussed thus 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 stock on the north or the gneiss on the south."

Again, "This general feature of the residuals of erosion (an abrupt steepness of ascent along the radiating spurs of the main mountain just above the contact between the sedimentary and 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 namely, superior to that of the rock masses immediately surrounding. Mount Ascutney, like most New England mountains is a residual of erosion, a monadnock overlooking a dissected rolling plateau. The relief as a whole and in its details, is controlled by rock composition in a specially definite manner. The drainage of the area is that of an ancient mountain system. The general form of Ascutney was not essentially affected by Pleistocene glaciation. A veneer of pre-glacial weathered rock was removed and the rounding of the minor points accomplished by ice invasion, but the pre-Glacial Ascutney had practically the form of the present mountain."

RIVERS

Surely a most important and charming part of Vermont scenery depends upon the presence of water and fortunately the State is well supplied with streams and lakes. Streams of all varieties, from the little mountain brook that starts from a spring far above the lowlands to which it leaps and rushes, to the largest river, abound everywhere in the State, and of course have much to do with the character of the topography and during ages long passed have, as powerful agents shaped the features of the landscape as nothing else could have done. What level areas there are in Vermont are due to the action of water as they are sea floors, lake bottoms, stream flats, or delta plains. So too the gorges and ravines, which are frequent and which add so great charm to our scenery, are entirely due to stream action.

Most of the larger streams are old and, while their courses have been greatly influenced by the elevations, they have in many cases not been wholly determined by them for, as already noticed, the large rivers, unless Otter Creek be an exception, run across the mountain ranges, not along their trend, the streams from the western slopes of the mountains flowing west into Lake Champlain and from the eastern side going into the Connecticut. The larger streams, Missisquoi, Lamoille and Winooski are antecedent streams and do not directly rise in the mountains, but cut across or find a way between, to finally pour their waters into Lake Champlain. A few streams, small rivers, flow north and empty into Lake Memphremagog. A few others in the southern end of the State flow southerly and empty into the Hudson.

In a Bulletin on the Surface Waters of Vermont recently issued by the U. S. Geological Survey as Water Supply Paper 424, there is a list of streams and lakes of the State which is the most complete that has been compiled. In this list are included nearly three hundred lakes and ponds, but there are in the State a hundred more, and five hundred and fifty-eight streams, which is abundant evidence that Vermont is well supplied with water, for its entire area is only about 10,000 square miles. Sixty-five of the streams are called "rivers," but many of these are not more than large brooks except during spring floods when they are roaring, powerful torrents. So many are the streams in some parts of the State that the early settlers appear to have been wholly unable to find appropriate names for them. For example, we find in different parts of the state five "Mill Brooks," three "Green Rivers," eight "Pond Brooks," five "Dead Creeks" and eighteen "Mud Ponds." It is very obvious that any region possessed of four mountain ranges and such a large number of streams and lakes must be abounding in attractive scenery, at any rate in summer.

It would be exceedingly tedious were the mere enumeration of the names of all the streams to be given here, but of the few largest some details will not be out of place. Our four largest streams are Missisquoi, Lamoille, Winooski and Otter.

The Missisquoi is our most northern large stream. For about a third of its length this river flows north of the Canada border as it is formed in Mansonville by the union of two branches, a longer but smaller and a somewhat wider and shorter. The northern branch rises in ponds near the village of Etienne in the township of Brome, Canada and flows nearly due south to unite with the other branch not far north of the border. The southern branch rises in the mountainous part of Lowell, Vermont and flows north thru Westfield and Troy for about 18 miles and crosses the border in North Troy.

After the union of these branches the course changes to northwest for a few miles near Glen Sutton, changing to southwest which course is continued across the line at East Richford, and on thru Richford, Enosburg, Sheldon, and Highgate to Swanton village where the stream turns north, and for eight or nine miles flows in this direction to enter Lake Champlain at the large bay of the same name not far from the Canada line. Throughout its course the river is for the most part quiet and with no strong current, but at a few points there are falls and rapids. Generally the banks are low and in places the valley is wide.

As is usual in Vermont streams, or in those of any mountainous locality, because of the water coming in the spring from melting snow and sometimes from heavy rains, this river is very high and turbulent at that time while in midsummer, especially if the season be dry, the volume of water is enormously reduced. For instance in a table given in the Bulletin of the U.S.G.S. mentioned previously, we find such extremes as the following:—"Daily discharge, feet per second April 1st, 7,460," while in August this was as low as 98 feet, tho the monthly average was much more, reaching as much as 1500 feet once. The fluctuations are rapid and often considerable as a consultation of the tables given on pages 91–102 indicate.

The river has built out into Missisquoi Bay a large delta thru which it finds its way by three main channels, and there are three lesser, and two closed in ordinary water by accumulation of delta material. East of the delta there is a ridge of Utica Shale and Chazy Limestone which extends from Highgate Springs to the falls in the river at Swanton where the stream flows over the upturned edges of the black shale as is well seen from the bridge. The delta is somewhat higher than the lake as Hitchcock has shown in the Seventh Report of this series. He adds, "More than half of the original width of Missisquoi Bay has been taken up by the delta. A great bend in the river to the south of Swanton Village encloses a higher sand flat 156 feet high which is an older delta than Hog Island. Two other sandy flats rise, perhaps 40 and 80 feet above the village in going east into 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 sand is very abundant so that it is a conspicuous feature and may mark the highest marine limit."*

All the way from Lowell to Swanton the rocks along the river are metamorphic schists, tho just east of Swanton the stream passes thru Lower Cambrian beds and then the Ordovician beds mentioned, near the mouth.

The Lamoille River.—About twenty miles south of the Missisquoi is the Lamoille River. The stream rises in Greensboro in the confluence of several streams and it flows in general westerly into Lake Champlain where in Milton it ends. The whole length is somewhere about fifty miles. The course of this river is across the Green Mountains, and it flows during the first part of its bed thru crystalline schists and gneiss, but in Georgia and Milton it meets Cambrian rocks, and in Milton Beekmantown beds. It enters Lake Champlain not far south of Sandbar bridge. In many parts of its course the valley is narrow and rocky and nowhere is it very wide.

The current as far as Cambridge is slow, but from this place to its entrance into the lake it is frequently rapid. Most of its tributaries enter from the north, Browns River being the only stream of importance that flows in from the south. At the mouth is a considerable delta working out into the lake, and the great sand plain south of Milton is an older delta which rises to a height of 380 feet in places. The Cambrian hills of Milton, as Cobble, Arrowhead, etc., must have been in existence long before the delta was formed and were old when the river first came that way. The old sandbar, upon which the causeway called Sandbar bridge is built, was fordable and used as a ford between the Island and the mainland before the bridge was built and the sand of this was a part of the delta, and therefore exists because of the river.

Anciently the Lamoille appears to have emptied its waters into the lake thru two channels, the now unused one being north of the bridge. Some of the sand brought down by the river and carried out into the lake is driven by south winds upon the south shore of Grand Isle and to some extent inland where it is damaging the soil. A wide area of the lake about the mouth of the Lamoille is growing shallow from the sand brought by the river.

The Lamoille receives numerous smaller streams, chief of which are the brook flowing from Caspian Lake, Greensboro Brook, that from Wolcott Pond, Green River, Gihon River, Mill River, Browns River and others of less importance. The drainage area of this river is given in Bulletin 424 Water Supply Papers, Surface Waters of Vermont, as 720 square miles. Also

---

*Seventh Report Vermont Geologist, p 205.

"Lakes are numerous and some storage has already been developed, but opportunities for improvement are many."

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 thru Cabot in a southerly direction it passes on south thru Marshfield and Plainfield to Montpelier thru 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 thru 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 this 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) After the lake had subsided to somewhat of its present dimensions, the river for some time was very much larger than now, probably filling its present valley in many places. In a few places there are old channels, as south of the Lime Kilns in Colchester.

In many places along its course this river flows thru rock exposures. From its source to Essex the rocks are metamorphic schists and gneisses. From Essex Junction at Hubbells Falls there is Beekmantown limestone. Below the lower falls at Winooski the banks are low and for the most part clay and alluvium. The watershed of the Winooski is given in the report of the Hydrographic Survey as "Approximately 1100 square miles."

Otter Creek.—Altho this stream has been for many years called a creek, it is fully entitled to be called a river, as altho nowhere very wide, it is long and deep. The source of Otter Creek is given by some authorities as rising in a pond in Dorset and by others as formed from streams flowing in Dorset and Mount Tabor. As these streams run from the Dorset pond it matters little which source is given.

The river enters Lake Champlain at Fort Cassin about eight miles west of Vergennes, perhaps seventy-five miles from its source. Its main course is northward, and for many miles it is a deep, sluggish stream without falls or rapids, flowing thru alluvial soil. This is true for some distance south of Rutland and north as far as Middlebury where there is a fall. In Rutland the slow flowing current is also interrupted by a considerable fall. There is also a fall at Proctor, the well known Sutherland Falls. North of Middlebury there are falls at Beldens and Vergennes, and in general the current is more rapid than south. From Vergennes to the mouth the channel is deep enough to float boats of considerable size and small steamers, regularly during the summer, sail from Vergennes to several lake ports. The scenery in the immediate valley of Otter Creek is far less wild than that of the three northern streams as it is seldom near any exposed rock outcrop, but as has been indicated, flows between low clay banks and does not as do other rivers, make its way thru hills and mountains. Otter Creek is fed by numerous tributary brooks and streams, many from mountain springs, and when the winter snows melt in the spring these pour their torrents into the low-banked river and cause it to overrun its banks and flood the adjoining meadows, sometimes for many rods back from the river. Chief among these tributaries are, Mill River, Cold River, Leicester, Neshobe, Middlebury, New Haven, Lemon Fair Rivers.

In course of its wanderings Otter Creek flows thru Rutland and Addison Counties passing thru the towns of Wallingford, Clarendon, Rutland, Proctor, Pittsford, Brandon, Whiting, where it forms a boundary between this town and Salisbury, Weybridge, where it turns to the west and continues in this direction thru the town until it reaches the northern part when it resumes its usual northerly trend and goes on into Addison, Panton, Vergennes and finally Ferrisburg and into the lake. The drainage area is given in Bulletin 424, Water Supply Papers, as 615 square miles.

Such a stream as this, in general sluggish with low banks, but fed largely by rapid mountain streams would necessarily be subject to great fluctuations in its volume as seen in different seasons and would, as we have seen, be subject to extensive overflows. For example, the maximum in 1912–1913 was for March, 8000 second-feet and the minimum was for the same year 138 second-feet in September. This season was, however, exceptional and the usual variation is better shown in the year 1916–1917 when the maximum for the month of April was 4,850 second-feet and the minimum for the same year in August was 217. These measurements were taken at Middlebury.

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 3200 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. Thru 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 U. S. 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 1700-1800 feet, but the greater part of this descent is in the mountainous region in Starksboro from which it flows.

The LaPlatte 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 so that of Hinesburg Pond flows thru the LaPlatte. The total fall to the lake is about 1100 feet.

Most of that portion of the State east of the Green Mountains is drained by the Connecticut and its tributaries, but as has been shown, a very important part is drained by the Winooski and lesser areas by the Mississquoi and Lamoille.

The Connecticut according to the Water Supply Bulletin frequently cited, drains nearly four thousand square miles of eastern Vermont. Nearly all the streams of any importance flowing easterly from the Green Mountains enter the Connecticut. The few exceptions are noticed later. As is well known, this river is, throughout the entire length of the State, the eastern boundary between it and New Hampshire. At the northern line of Vermont this river is a little more than 1700 feet higher than at the Massachusetts border, and there are several large water powers along the course of the stream. Naturally, while the flow varies much at different seasons, the volume of the Connecticut varies less than that of many mountain streams. Nor is the course so irregular and winding as that of many smaller rivers.

Besides numerous brooks and small streams which enter the Connecticut, there are twelve streams, which may be called rivers, tributary to the larger river; these are all wholly within the boundaries of Vermont except one. The streams alluded to are as follows: Nulhegan, Passumpsic, Wells, Waits, Ompompanoosuc, White, Ottaquechee, Black, Williams, Saxtons, West. A few words respecting each of these will suffice.

The Nulhegan flows through the northeastern part of the state rising in the little area known as Averys Gore. The general direction is south-eastern to Bloomfield where it enters the Connecticut. The stream is formed by the union of several branches. "In the main stream and on the branches the valleys are relatively wide and flat with occasional quick stretches." On the whole, however, the current is rather rapid.

The Passumpsic River is one of the largest flowing easterly into the Connecticut. It is formed from the union of two branches in Lyndon, an east and a west. The principal stream is that which rises in Westmore and flows southerly thru Newark into East Haven, then turning west of south into Lyndon, then south thru St. Johnsbury, Waterford, and Barnet to enter the Connecticut at East Barnet. The western branch comes from near Mount Pisgah in Westmore and runs south to Lyndon. "From its source until it approaches the center of Lyndon the Passumpsic is a swift stream. It flows more slowly thru intervale meadows until it approaches the southern part of the town where there is a high fall. For the greater part of the way thru St. Johnsbury it is a swift stream, but it runs slowly the greater part of the distance thru Waterford and Barnet, altho there are some large falls in the latter town."

Wells River flows from Groton Pond and goes on thru 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 1700 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 irregular 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, thru 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 to sixty miles.

Those who are acquainted with the region indicated above will readily understand that any stream flowing thru 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, tho 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 thru 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, thru 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 thru 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 2000 feet in five miles. This also gives many excellent sites for waterpower, some of which are utilized, but many are not. The entire length is given as about 38 miles.

Black River rises in Shrewsbury, on the mountains, at a height of 3200 feet, and flows southeastward to the Connecticut at Springfield. In its course the Black River drains Plymouth Pond, and a number of smaller, and furnishes waterpower for mills in Ludlow, Cavendish, Proctorsville, Perkinsville and Springfield.

It may be noticed that there are two Black Rivers in Vermont, the second being in the northern part of the state.

Williams River is still farther south and enters the Connecticut a few miles north of Bellows Falls. Like most of our rivers it has several branches which together make up the river proper. There are the north and south branch and the Lyman branch, which combine in Chester. The source of this river would, of course, be given differently according to the opinion of the authority as to where the river began. It might be stated as in Chester, at the union of the branches, or in Andover, where these branches start.

About five miles south of Williams River the Connecticut receives *Saxtons River*. This is a comparatively unimportant stream, tho by no means to be neglected. It rises in Windham and flows at first northerly, but for most of its course southeast, turning north just before emptying into the Connecticut.

The most southern of the Vermont rivers entering the Connecticut is *West River*, a larger stream than most of the foregoing. This enters the Connecticut in Brattleboro, north of the main part of the town. It has its sources in Mount Holly, over two thousand feet up in the mountains, and flows southward thru Weston, Londonderry, Jamaica, Townshend, Newfane, Dummerston, Brattleboro, trending easterly as it passes on. There are several good sized branches. The length is given as forty-five miles.

There are a few rather inconsiderable streams flowing in southwestern Vermont into New York and emptying into the Hudson, which may be passed with a few words. These are the Hoosac, Walloomsac, and Batten Kill.

The first of these rivers does not originate in Vermont, but in northern Massachusetts. In North Adams it receives a branch which does rise in this state and the united stream flows for some miles thru a part of Vermont, running thru North Pownal and Pownal, while the North Branch rises in Stamford and flows south over the border into Massachusetts. Though an important stream in the other states, as it is one of the chief tributaries of the Hudson, it is less important in this State, as so small a part of the stream lies within our limits.

The Walloomsac is more largely in Vermont, tho it also runs into New York. In Vermont it is confined to Bennington County. Its source is in Glastenbury from which it flows westward, southwestward, and northwestward, finally westward, into the Hoosac at Hoosac Junction.

The Batten Kill 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 Batten Kill, but Mad Tom Brook which rises on Mount Tabor appears to be the beginning of the stream. From Dorset 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.

To anyone familiar with the region thru which these rivers make their way it is needless to say that everywhere the scenery is beautiful and very varied. There are good roads beside most of them, except in the more rugged portions near the headwaters, where the usual conditions found in mountainous localities necessarily prevail.

The drainage of Vermont is effected by streams running in general toward all points of the compass, that is north, south, east and west. All of these have now been taken up except the first. The streams which flow northward and consequently into the Saint Lawrence are few and none of great size, but they should be briefly 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 thru 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 thru 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 outlet of Seymour Lake, and runs thru Round Pond and Salem Pond on its course to Lake Memphremagog where, at Derby the river ends in the lake. The stream is about twenty miles long.

The *Coaticook River* is more than two-thirds in Canada, about twenty-five miles of its stream being in that province where it enters the Massawipi and thru the St. Francis flows into the St. Lawrence. Its whole length is thirty-five miles. This stream rises in a pond in Norton.

LAKES AND PONDS

The lakes and ponds of Vermont are a very important feature in its topography and, as everywhere if found in any number, add much to its attractiveness. To one at all familiar with both countries, the resemblance between Vermont or at any rate many parts of the state, and parts of Scotland must be very evident and this similarity is especially noticeable in those regions in which lakes are most abundant, for these lakes and the hills which often surround them are of the same general sort as those of Scotland.

It is not easy to state exactly the number of lakes and ponds in Vermont as no complete census has ever been made, moreover there are some which are very small and dry up during each summer, and a number of artificial lakes, some of which, like Lake Mansfield, have all the charm of those that are natural. For example, a pond like the Lake of the Clouds, below the Chin on Mansfield, altho not usually wholly dry even in midsummer, is only a small muck pond and is not mentioned in any list which I have seen. Which of these should be included and which omitted?

Perhaps no one is better qualified to speak as to this than the author of the booklets to which reference is made later on—"The Lakes of Eastern Vermont," and "The Lakes of Western Vermont," in which we find the statement that "There are in the State approximately four hundred lakes and ponds large enough to receive names and appear on maps." In confirmation of this Mr. Crockett has given me a list which contains names and certainly there are a considerable number which have never been named. In Water Supply Paper 424, there are listed but two hundred and ninety-four lakes and ponds, which is certainly far below the correct number, as is shown above. In round numbers it may be said that there are four hundred of these bodies of water within the limits of the State.

Many of these are quite small, but many are of respectable size and well deserving attention. While these charming and delightful gems which adorn our landscapes are scattered over the entire State, there are more in the northern and eastern portions than elsewhere. Some of our towns have no water body within their limits while others have several, and a few many, as Woodbury, where there are no less than thirty, and in Eden where there are twenty, but of course in these cases none can be very large.

I have not investigated all or nearly all of our lakes with such thoroughness that I can speak positively as to their origin, but I have no doubt that most, probably nearly all, are the result of glacial action. Some were caused by the scooping out of softer material in places as the ice sheet passed over it, so that after the ice melted basins of greater or less dimensions were left to fill with water, while elsewhere the movement of the ice or the torrents that followed its melting brought great masses of earth and gravel into the valleys, some of which were thus filled, in some parts a dam being formed so that the stream flowing thru filled behind the dam and made a lake; others were due to other movements.

Most of the Vermont lakes are small, that is, not more than a mile long, but, aside from Champlain which forms over half of the western boundary of the State and is not to be reckoned as a Vermont lake, there are a few of considerable size, as Willoughby, Dunmore, Bomoseen and St. Catherine. For a detailed account of the Vermont lakes the reader is referred to two booklets issued by the State Bureau of Publicity and edited by Mr. W. H. Crockett, "The Lakes of Eastern Vermont" and "The Lakes of Western Vermont." These pamphlets are very profusely illustrated and give a very good hint of the many beautiful scenes which may be found here and there in the State. Both will be found excellent guides and may be obtained by application to the Secretary of State.

Many of our lakes are high above the sea, some over a thousand feet. The highest is the little Lake of the Clouds, north of the Chin on Mansfield, which is four thousand feet above the sea level. Sterling Pond is much larger and is in the neighborhood of three thousand feet elevation. This is probably the highest real pond in the State. Of course it is the lower lakes that add most to the charm of the Vermont landscapes and afford hundreds of attractive and restful camp sites.

As to the detailed geology of our lakes little can as yet be said, for none have been carefully surveyed and most of them not at all. T. N. Dale has a few words on St. Catherine, 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 thru 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." p. 47.

Willoughby Lake is one of the larger and, as seen from its southern border, one of the most romantic sheets of water in the State. The two mountains, Hor and Pisgah, form a most picturesque foreground for the view which greets one as he approaches the southern border of the lake. While the rock about Willoughby is mostly schist and silicious limestone, the mountains are granite and intrusive, that is, these elevations, the highest, Pisgah being about 3,800 feet above sea level, were sent out from beneath the surface after the formation of the schists and limestone as volcanic masses. That they are more recent than the other rock is conclusively proved, as is noticed in the Vermont Report of 1861, by the fact that fragments of the older rock occur in the mass of the granite and therefore must have been included when the latter was in a more or less plastic condition. The schist itself is not in its original state, but has been formed by metamorphism from still older and probably, stratified rocks.

Lying as the lake does between the two great granite elevations, it is perhaps not strange that many have accounted for the basin by supposing that the two mountains were originally one mass and that they were cleft in twain by some subterranean force leaving the space now occupied by the lake between. I allude to this theory because it has often been brought to my attention, not because it has the least foundation in the geology of the region. The reason given by Mr. Hagar many years ago, in the Report on the Geology of Vermont, published in 1861, is probably correct. As those familiar with Lake Willoughby know, it fills the gap between great granite masses of which Pisgah and Hor are the culmination on either side. The space between these is filled in the bed of the lake by a hard silicious limestone and schist. It was through these beds that the granite was lifted and it is of course of later origin. By erosion and disintegration the mass of schist and limestone between the granite upthrusts was removed and the waters of the lake flowed into the basin thus left. For a full account of this see the work mentioned above, pp. 906-907.

Lakes Champlain and Memphremagog are not considered as strictly Vermont lakes for roughly speaking, half of Champlain and four-fifths of Memphremagog are not in this State. Still, they are certainly very important features in the scenery of those parts of Vermont adjacent.

Historically, Champlain is perhaps the most important part of our State, and for more than a hundred miles it forms the western boundary. The northern boundary is far less affected by Memphremagog, but it is not to be regarded as of no importance. Champlain is nearly 100 feet above sea level at ordinary times and when flooded at spring high water it may be more. The other lake is several hundred feet higher, being at mean water 665 feet above the sea.

Memphremagog is over thirty miles long and of very variable width, one to four miles, and as on the western shore it is bordered by a range of fine peaks, Owls Head, Orford, Elephantis, etc., there are many very fine views as one sails its waters. This lake is of very irregular outline, full of bays and promontories.

The various features in the topography of Vermont are such as are readily observed as one travels thru the valleys and over the hills, which together make up the scenery, and this means that the landscape, as it now appears is of late formation, at least in many of its characteristics. Necessarily all that now appears on the surface had an earlier condition and has this as foundation.

In Vermont solid rock is frequent enough everywhere in outcrops of greater or less extent and as everyone knows, where the surface is covered by sand, gravel, clay or water, solid rock is soon reached by going below the surface, and it is in this rock foundation that our most complicated and difficult problems arise. In a region in which there has been little change from first conditions the geological history can usually be deciphered without much difficulty, but there is little rock in this State which has not been changed, often very greatly changed from its original structure and character. As has been repeatedly noticed, our rocks are so changed that they are often very puzzling to a student who would understand their origin. Outside of the Champlain Valley, where unchanged stratified beds are not uncommon, a very large part of the rock masses are metamorphosed, at times so completely that it is not possible to determine certainly their source.

In the Eighth Report, pp. 17-38, is given a summary of the geological formations found in the State and to this the reader is referred, but as this volume is entirely out of print, some parts of what is there stated may be repeated. Vermont was established as a body of land in early geological time. Though probably not quite as old as eastern New York and certainly not as old as the Laurentian region of Canada, it is yet older than most of the United States and the solid foundations of its land area were laid down in what is known as Ordovician time or earlier.

While I do not wish to speak with entire confidence as to the character of the interior beds of the Green Mountain Range, yet it seems very nearly certain as has been seen, that deep in the mass of these mountains as a central axis the rocks, such as were formed in late Pre-Cambrian time and the Cambrian, are the oldest of the fossiliferous ages. In the Algonkian, just below the Cambrian there was life, but the fossils are indistinct and very imperfect for the most part. The rock of the Adirondacks is mostly Algonkian, but that of the Green Mountains, is mostly later, that is Cambrian and Ordovician, these overlying the Algonkian or Pre-Algonkian axis. But all of these beds have long since been so modified by metamorphism that from the original sandstones and limestones we have only schists and gneisses which in no way resemble the first formed beds. As the rocks of western Vermont differ from those east of the Green Mountains so the scenery of each side of the State is characterized by its own peculiar features, though there is much resemblance.

As an area of land lying between the Connecticut River and Lake Champlain, Vermont is by reason of its natural boundaries, a State long north and south, narrow east and west. Of course other boundaries could have been selected, but these are most natural. From those most remote times when the long, narrow ridge which first outlined the main mountain range was raised above the almost universal sea, it was determined that Vermont should be long and narrow.

Probably the eastern valley, that of the Connecticut, was not formed or outlined until long after the old Champlain Valley was indicated by the narrow stream which flowed through what is now the deepest part of the lake, before it was a lake. Still the Connecticut in some form or another is not a new river. Only in the immediate vicinity of Lake Champlain are there extensive beds of comparatively unchanged sedimentary rocks, though there are beds of limestone and shale east of the mountains, as Richardson has shown, which are not changed to a very great degree. In the Report immediately preceding this, the Tenth, I have described the different formations of the Champlain region and have there enumerated the beds of the Cambrian and Ordovician found in the vicinity of the lake.

As this chapter is not written primarily for those who are familiar with the ordinary terms of geology, but for all who are interested in the physical characteristics of Vermont, it may be well to show where in the accepted scale of geological time the rocks of Vermont are placed. Of the great subdivisions of geological history the Vermont beds for the most part represent only one. Commencing with the lowest of which there is any knowledge, the Pre-Cambrian, which includes several subdivisions which do 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. Altho 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 Professor 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 Thompsons 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 were 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, tho 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, tho 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 thru 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 thru 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 thru 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, tho 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 thru 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 fifteen miles wide at first and continues wide 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 these form a belt from one edge of the State to the other, of varying width, starting very narrowly 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, Dr. 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, tho 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, tho all Ordovician, extends thru 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 tho few fossils have been found is most probably of Lower Ordovician (Beekmantown) age. This limestone is often heavily outcropping, especially in the town of Hinesburg, and is extremely unfossiliferous, but in part of the outcrop, in Colchester, or 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 Dr. Richardson has explored, that is, 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, Professor 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 Professor H. L. Fairchild on some of the features of the surface geology in the Report immediately preceding and also in this. All of 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 U. S. Geological Survey, was done under 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 thru 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, tho not always, thin bedded black shale, Utica in age. 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 bordered by limestone, mostly Chazy and Trenton, with some Beekmantown and Utica. The larger islands in Lake Champlain are all of one or another or several of these rocks. For example, North Hero is entirely Utica, Grand Isle is two thirds Utica, but on the western shore are several beds of Chazy, thru 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, tho 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 the rocks 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 thru 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,which is in nearly all our town libraries, to call attention to the numerous changes in the names given to different groups of rocks and in their identification. The geological map placed near the end of the second volume of the 1861 Report is only generally useful since formations are in some cases named and placed on the map which are not found in Vermont, but through mistaken determination of the beds they were assigned to wholly wrong positions by the older geologists. Unfortunately it has not been possible to prepare a geological map of Vermont that would be accurate. There is much of Vermont which is not yet sufficiently well known geologically to be properly mapped and that large portion not yet surveyed by the U. S. Topographic Corps must wait indefinitely, for good geological maps cannot be produced until the topographic maps have been issued. The necessity for engineers in war work has put a stop to the surveying that was carried on and at present it does not seem likely that any work of this sort will be or can be undertaken. The last map issued is that of the Rochester Quadrangle which ends at the north at Breadloaf Mountain and includes the southern part of Ripton, Granville, and the western part of Braintree. The next map will follow the Rochester sheet on the north, but when it will be published no one can tell.

From what has been said it will be seen that what has since been included in the limits of Vermont was fully formed as dry land appearing above the ancient ocean level, by the close of Ordovician time. This is to say that this land is very old, but it is not saying that it was then as now in many important respects. Great areas have been raised at one time and lowered at another and, as will be noticed, vast changes have followed the original outlining of the land. What Dr. Richardson has noted in the paper which follows is true of the whole State, tho he is speaking of the central and eastern part, and it is hoped that any reader who may be interested in this paper will carefully read what Dr. Richardson has to say.

The metamorphism of sedimentary rocks has already been more than once stated. Everywhere in Vermont there are evidences of change in beds of rock. Probably these changes did not all take place at the same time, but the greater part did occur at the close of or soon after the close of Ordovician. As stated in his paper, Professor Richardson thinks that there was metamorphic activity at the close of the Cambrian and this is certainly possible, but it seems to me most probable that the greater metamorphism was after the close of the Ordovician and that then the gneiss which covers the Green Mountains, the schists and slates of eastern Vermont, and the marbles and slates of western, were mostly formed from the Cambrian and Ordovician strata. However, this is rather a matter of opinion than a proved fact. Then and later, perhaps during the following age, the Devonian, the main granite masses were forced up from beneath the surface as already indicated in speaking of the Granite Hills.

After the close of the Ordovician, so far as there is any evidence, the only disturbances that occurred were those of the formation of the granite masses and of the dikes. As has been seen, there is no certain proof of any particular time when these came except that, naturally, they must have come after the deposition of the rock through which they were thrust. Thus the vast interval, already mentioned, between the close of the Ordovician and the opening of the Pleistocene, was mainly a time of weathering and erosion. The general effect of this must have been to reduce the elevations and deepen the depressions, to lower the hills and increase the valleys, during most of the time up to the ice age, and if this process could go on indefinitely, it would bring the surface to a dead level.

The processes by which the changes in the surface are mostly brought about are:—

1. By wearing and transporting effected by streams, and of these there were many from early times. While the action of streams taken year by year was not comparable to that which occurred after the ice age, yet prolonged, as it must have been during the enormous periods that intervened between the Green Mountain uplift in its final throes and the time of the Great Glacier, the results were enormous.

2. By the atmospheric action upon rocks causing decomposition. This would vary greatly according to the kind of rock, for some sorts are considerably affected by this means while others are very slightly or not at all.

3. By frost, which in a climate where the temperature for any length of time goes below freezing, is a very powerful destructive agent, as the talus of debris seen at the base of cliffs and on mountain slopes abundantly testifies.

4. During that portion of geological time when the great ice sheet crushed the surface of our northern country it was a mighty force as it ground the mountains, tore the cliffs, broke up great masses of rock and in every manner carried devastation in its course. We are accustomed to speak of the glacial period as if there had been but one and certainly here we have no record of any other, but elsewhere there is unquestioned proof that at different times, even from early geological periods, there were ice ages. There may have been during the long interval of which notice has often been taken other and older ice ages which have come, done their great work and left no trace that has yet been found.

5. The greatly increased streams following the melting of the continental ice masses must have torn their way thru the country and produced results which are very evident today.

6. The elevation and depression of wide areas obviously

produced great results and greatly aided in increasing the intensity of some of those forces given above.

The only exception to the statement that no rocks were deposited in Vermont between the Ordovician and Pleistocene is found in the Tertiary deposits, best known about Brandon, but probably extending in a narrow belt from Colchester to Bennington. This formation includes not only the famous Brandon lignite, but the bog iron ores and variously colored clays of other parts of the area. The only fossils found in this formation, and therefore the chief indications of the character of the country at that time, are those of the lignite. As fully described in former Reports, Third and Fourth of this series, these are all seeds and fruits of plants, found only in a very small area.

It is very singular that here in this isolated region, where only Paleozoic beds, aside from these, have ever been found, there should occur this exceedingly small tract of Tertiary. In the first place, Tertiary beds are found nowhere in the northern and middle states east of the Rocky Mountains, nowhere in New England except this little strip in the Champlain Valley, a little on Martha's Vineyard, more south from New Jersey, along the Atlantic Coast, and the Gulf Border into Mexico where there is a narrow strip. In none of these localities, however, is the rock at all like that of Vermont nor are the fossils in any respect identical.

As has already been noticed, and it will be mentioned in what is to follow, the climate of the time immediately following the Tertiary was much colder than now, being that of Greenland of today, but the Tertiary plants and trees are plainly those of a much warmer climate than now and the climate of the Champlain Valley in the later Tertiaries must have been that of the Dismal Swamp of today. Another peculiarity of the Vermont Tertiary fossils is that not a single animal species has been found but more than two hundred vegetable species, most of them finely preserved. Another strange fact is that the fossils, all of which have been found in the lignite deposit at Forestdale near Brandon, are unlike any others found in other parts of the world. Diligent search in the museums in this country and Europe has revealed only resemblances and these have been found only in Bowerbanks, Isle of Sheppey and Heers Œningen species. It is all very puzzling, but geological history is full of puzzles some of which may be explained as more complete investigation furnishes more complete knowledge, and some may never be solved.

Attention has more than once been called to the changed condition of many of the Vermont rocks thru metamorphism by reason of which it is often very difficult to ascertain their age. There is another reason why it is in many cases not easy, nay, even impossible, to define the age of a bed or rock which we know must exist but which cannot be examined because covered by clay, sand, gravel and boulders. This covering, in general called drift, sometimes wholly conceals the underlying rock for several miles in all directions. Of course this difficulty is not met in hilly regions, but there the metamorphism is most in evidence. This drift so very common in all the less mountainous parts of Vermont is the evidence, or rather an important part of it, of the great ice age that immediately preceded the present. Often the present, by which I suppose is meant the time since history has been recorded by man, is spoken of as if an age quite distinct from previous or "Geological times," but really there is no difference. We are now living in an age which is as truly geological as any that have gone before. The present may differ from any one of past ages in many respects, but so do these differ from each other. The earth was not finished at the end of the ice age or technically, Pleistocene time. Its finished condition can never be reached so long as it endures in any form.

Most have some knowledge of the various phases of Pleistocene history and they need not be enumerated here except so far as may be necessary to an understanding of the general features of the age. Some have already been noticed. The Pleistocene began by an elevation of the whole northern part of the continent, the elevation increasing from south to north. This elevation slowly raised the region under consideration until in northern Vermont the land was a thousand feet or more above sea level. As most of my readers well know, upon this elevated land over most of the northern United States as well as Canada there was a vast accumulation of ice. The heat of summer at that time was not sufficient to melt the snows of the long winters. As a necessary result in course of some thousands of years the mass of ice became incalculably great and moved from centers north of the St. Lawrence in all directions, but that which concerns us was the southward movement by which all this region was covered by a great sheet of ice thick enough to move over the highest of the New England mountains, for glacier marks are found even on the top of Mt. Washington. Those who have seen what the small glaciers now active are able to accomplish in grinding, tearing, crushing, transporting will more readily understand the unspeakably vast work which the continental ice sheets must have done during the Pleistocene. At this time and by this means most of the drift, which is only found where the ice sheet operated, was produced.

In many parts of the northern United States there is evidence of several glacial periods separated by as many interglacial periods, but in Vermont thus far no evidence of more than one has been found. It would seem that if there were more, as is not impossible, all traces of them have been obliterated by the last. The accumulation of such vast masses of ice, hundreds of miles wide and thousands of feet thick upon the crust of the earth must have depressed its surface by its weight, and accordingly we find that during the latter part of the ice age the land sank far below its level at the commencement and below that which it now has. We also find that after the melting of the ice the land rose to its present height. Professor H. L. Fairchild has done more than anyone to determine the amount of the subsidence and subsequent uprising, and he is still at work on this problem. So far as Vermont is concerned those interested will find profitable reading in the opening chapter of the Tenth Vermont Geological Report in which Professor Fairchild gives the results of his work in this State. This investigator finds that the land has been raised from 100 feet at the southern limit of New York to 1000 feet in Canada, the highest elevation in northern Vermont being about 800 feet above present sea level.

Any careful observer as he journeys thru the State, will notice here and there among the uplands, level fields, sometimes large, sometimes small, sometimes at low levels, sometimes several hundred feet high. These are the old water levels at which the ocean stood at different times, for as the marine waters gradually subsided they stood here and there at lower and lower levels until the sea finally withdrew and the work of rivers began. A broad level plain at some elevation usually is proof of the presence of standing water for some time. Some of the most conspicuous of the plains in the State have a different history in that they are delta plains. Sand is always broken rock, hard rock, for soft makes mud. By the action of the glacier rock was broken up and also by other erosive agencies, running water, frost, etc., and this finely broken rock, which came largely from the older Green Mountains, was distributed by the streams which flowing into the old sea, or the lakes which came later, made deltas, which under the changed conditions, subsidence of waters, elevation of land, etc., have now become sand plains. The plain on which Essex Junction, Fort Ethan Allen, etc., are located is an example of one of these deltas. Others were mentioned in the early part of this chapter when rivers were discussed. An excellent example of some of these changes is given by Professor Fairchild in the article alluded to above, and it is so important that I think that a quotation from it will not be needless repetition.

"The waters of the Champlain sea extended southeast up the narrow Winooski Valley to beyond Montpelier, and the terracing 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, with some effect of outflow currents at the latest stage. The conditions were not those of a river but of an inlet. One conclusive proof is the occurrence of finely laminated clays. A good example is seen at Waterbury. The electric line for Stowe climbs

up the face of clay for more than a hundred feet. At least seventy are exposed. Similar clay deposits overlaid by later sands and gravel are found in all the deeper valleys and constitute the bulk of the lower plains of the Connecticut, Champlain and Hudson 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 abundant material for delta construction while the stream flow concentrated it in this section. But the existing terraces are only small remnants of the original deltas, for with the lifting of the land the vigorous rivers eroded the deposits and swept the detritus westward down stream to build plains at lower levels, even as far as Burlington."

"All the valley about Fairmont station and East Montpelier shows elegant terraces. These terraced plains extend up the Winooski River as far as Plainfield, reaching an altitude of 750 feet. The theoretic altitude of the Champlain Sea is about 680 feet. The excess in altitude of the Plainfield plains, some 70 feet, is more than can be allowed for the gradation of the delta. The explanation is at hand. Merwin located an outlet channel at the head of Hollow Brook, three miles northeast of South Hinesburg with an altitude of about 670 feet. This was the outlet of the latest and lowest glacial waters held in the Winooski Basin which we may call Winooski Lake. The high plains at Plainfield were built in the early and highest stage of this lake."

The above remarks are important especially because until recently the terraces mentioned, as have all similar, have been regarded as made by the river flow, whereas Professor Fairchild, correctly as it seems to me, accounts for them by the action of receding sea waters. Of course I do not intend to deny the existence of river terraces, but it is plainly shown by the observed surface features that most of the important terraces in Vermont, as well as in many other regions, are due to the subsiding sea waters, and to some extent, to changes in the elevation of the land.

Professor Fairchild further says, "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 height of over three hundred feet on the parallel of Burlington leave no doubt as to the sea level of the lower plains."

Into this ancient Champlain Sea flowed the larger streams that we now see tho not in the same places. To quote further from Professor Fairchild.

"In the Champlain basin deltas are found on all the streams which flow westward, emerging from the mountain front. Examples are at Forestdale, three miles northeast of Brandon, where Mill River reached the sea level waters; at East Middlebury, on the Middlebury River; at Bristol, the village standing on a beautiful delta of New Haven River. Strong deltas lie south of Hinesburg, showing clearly on the Burlington sheet of the U. S. topographic maps. Many other deltas may be found where any streams poured down from the highlands into the standing waters. It has already been stated that the heavy summit delta of the Winooski is at East Montpelier, and that of the Lamoille at Morrisville.

"It should be understood that the earliest waters flooded all the valleys of Vermont to a height correlating with the water in the open Champlain and Connecticut valleys and the evidence 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 or deltas of the flowing streams lie far inland, far east of the Champlain Valley."

Before closing this chapter the author would like to forestall certain criticism which may arise. Attention of the reader may be called to the fact, stated already, that the foregoing pages were not written for trained geologists, but for teachers or others who have some knowledge of the subject, but not enough to read with interest a more technical treatment. I would also like to explain that some repetitions which will be found by those who read the entire chapter are intentional and have been allowed for the sake of clearness of meaning and for emphasis, in order that certain matters which are regarded as especially important may be noted.

THE ORDOVICIAN TERRANES OF CENTRAL VERMONT

CHARLES H. RICHARDSON, *Syracuse University*

The early geological history of Central Vermont may be tentatively summarized as follows:

1. In early Algonkian time there occurred a period of sedimentation, which line followed the present axis of the Green Mountains.
2. The intrusion into these sedimentary beds of granitic rocks which now constitute the gneisses of the Green Mountain range.
3. At the close of Algonkian time there occurred an uplift and folding of the Algonkian sediments and associated intrusives which resulted in the metamorphism of the sedimentary beds into mica schists and the granites into gneisses. This range of mountains would represent the earliest known land mass within the State.
4. The Algonkian uplift was followed by a period of atmospheric decomposition and erosion of the land masses.
5. In early Cambrian time there occurred a submergence of large areas of Algonkian rocks and the deposition thereon of sediments derived from the erosion of the Algonkian land masses. There are no rocks east of the Green Mountains definitely known as middle Cambrian.
6. In upper Cambrian time there occurred a deposition of sediments, apparently, upon the flanks of the lower Cambrian beds, the two series being separated by a basal Cambrian conglomerate. In a few instances these later beds were highly calcareous.
7. At the close of Cambrian time a crustal movement took place which added a broad area to the Algonkian land masses. This uplift metamorphosed the Cambrian sediments into mica schists, slates, quartzites and marbles. It was accompanied by the intrusion of a wide range of igneous rocks—from fluorite granites to peridotites.
8. Atmospheric erosion followed this crustal movement in early Ordovician times.
9. In early Ordovician time there occurred a submergence of Cambrian terranes and the deposition thereon of siliceous sediments, both calcareous, and non-calcareous. This sedimentation is known to have begun as early as the Beekmantown.
10. At the close of Ordovician time there occurred another large crustal movement which metamorphosed the Ordovician sediments into slates, phyllite schists and quartzose marbles. It metamorphosed the borders of Cambrian granites into gneisses

and aided in the transition of the augite of diabases into hornblende, of pyroxenes into talc, and olivine into serpentine.

11. At the close of Devonian time there occurred another crustal movement which was accompanied by the intrusion into both the Cambrian and Ordovician sediments of granitic material in a state of fusion with super-heated water. This intrusion hornfelized the slates at or near their contact with the granite masses and developed secondary hornblende in both the schists and the marbles. It may have injected into the sedimentaries dikes of pegmatite. These Devonian granites are the commercial granites of central and eastern Vermont.

12. After the crystallization of the granites they were traversed by dikes of pegmatite and aplite. These intrusives were also injected into the sedimentaries.

13. The schists, slates, marbles and granite masses were traversed, probably in Carboniferous time by numerous basic dikes—diabases, etc. There is evidence in the microscopic structure of the granites that this intrusion was accompanied by uplift.

14. Possibly the dikes of camptonite and basalt were introduced in Triassic time. Some of the diabase dikes have been subjected to crustal movement since their introduction. Their chloritization and schistosity implies this.

15. Atmospheric erosion of the Ordovician terranes began at the close of Ordovician time and has removed thousands of feet of schists, slates, quartzites and marbles from their underlying granite masses. The main granite belt of Vermont appears as a batholith. It lies largely within the Ordovician terranes.

CAMBRIAN

The Cambrian sedimentaries in central Vermont comprise a complex series of highly metamorphic quartz conglomerates, quartzites, hydromica schists, sericite schists and a narrow band of slate. A part of the chlorite schists may be highly altered sediments. This can not hold true of all of the belts of chlorite schist, for some of them cut the sedimentaries at angles as high as 40 degrees.

Each of these Cambrian formations has been traversed southward from the international boundary a distance of approximately 100 miles. Their eastern margin lies near the central north and south line of the State. This line is marked by an erosional unconformity of equal length.

IRASBURG CONGLOMERATE

The Irasburg conglomerate, (Plate 1), marks the base of the Ordovician terranes in central Vermont. It was discovered in Irasburg, just outside of the village limit in 1904. It was then supposed to be more or less local. This conglomerate, or its

PLATE I
IRASBURG CONGLOMERATE

equivalent, has been followed southward for approximately 100 miles and northward into Canada for approximately 25 miles. In Irasburg the pebbles or boulders are all pre-Ordovician, and the matrix is all Ordovician. The pebbles are granites, porphyrites, diabases, quartzites, sericite schists and Cambrian marbles. The matrix is all Ordovician—a dark colored, siliceous lime product. The pre-Ordovician material varies in size from small and well rounded pebbles up to boulders from two to four feet in diameter. It is a metaconglomerate, for it has been subjected to a great crustal movement since its formation. The general strike of the formation is north 40 degrees east, but it sometimes varies 90 degrees in 10 feet. Its general dip is at a high angle to the west, but it contains dips in all directions.

The southern extension of this conglomerate into Northfield was discovered last Summer. In Northfield it lies at the base of the Memphremagog slates. The pebbles are all pre-Ordovician and the matrix is Ordovician slate. It is regarded as the equivalent of the Irasburg conglomerate, altho widely different in the mineral composition of its matrix.

The Coventry conglomerate, which appears some 10 miles north of Irasburg, suggests some interesting problems. Well preserved quartz pebbles appear within it varying in size from an inch up to one foot in diameter. Some of these have facets formed upon them as if by glacial action, while others are grooved or striated. The Cambrian schist fragments, sometimes more than a foot in diameter, are occasionally set at right angles to each other. It also carries angular fragments of Ordovician slate and limestone. This is also a metaconglomerate, for the lime content has been calcitized. It cannot be contemporaneous with the Irasburg conglomerate. It may have been formed at the close of Ordovician time, or it may represent a fault breccia conglomerate. Even post-Glacial faults are known to exist in the Ordovician slate.

MEMPHREMAGOG SLATES

In the more northern portion of the state the Memphremagog slates are represented by three belts that are roughly parallel with each other and separated from each other by belts of the Waits River limestone. Each slate belt passes under Lake Memphremagog and reappears on the east side of the lake in Canada.

The easternmost slate belt in its more northerly extension is a black, carbonaceous, often pyritiferous slate. To the southward it becomes a phyllite schist, which is frequently pyritiferous, garnetiferous, staurolitic and sometimes hornblendic. In no locality is it a roofing slate, but in some instances it has been used for foundations and road metal. Its southern extension is interrupted.

The central belt consist of a black clay slate with perfect cleavage. It is occasionally pyritiferous. This slate is uniform in color easily worked and well suited for roofing purposes, blackboards, sinks, stationary washtubs, etc. In its southern extension it is not continuous.

The westernmost belt is a black, carbonaceous, highly fissile slate that is well suited for roofing purposes. In its southern extension this belt also is not continuous. These slates may represent three different non-calcareous beds of Ordovician sediments, or one bed that has been repeated by a fan fold.

The Memphremagog slates have commercial possibilities in Montpelier and Northfield. The slates vary from bluish-gray to black in color. They trim easily and are sufficiently strong to permit nailing without splitting. They are carbonaceous and magnetitic. Small pyrites are sometimes seen on the sawn edges. In Montpelier there are four abandoned quarries, while in Northfield many quarries have been extensively worked, but all have now been abandoned. In one of the old slate mills in Northfield there are several thousand slate slabs of varying dimensions that have been sawn, planed, but never marketed thru mismanagement.

The general strike of these slates is north 40 degrees east, but it varies from north 30 degrees east, on the Berlin side of Montpelier, to east and west on Woodbury Mountain. The general dip is at a high angle to the west, but an easterly dip can be recorded in Northfield.

WAITS RIVER LIMESTONE

The Waits River limestone is represented in central Vermont by three different phases. Each of these phases has been continuous southward from the international boundary for a distance of approximately 100 miles. The breadth of these formations varies from 25 to 40 miles.

The Waits River phase is banded, closely plicated, variegated, or even of light gray color. In the more westerly portions it is often shaly and graptolitic. In the more massive portions it is well calcitized and susceptible of a good polish. Microscopic slides reveal these beds to be a calcite marble and quartzite combined. They are important marble reserves.

The Washington phase of this limestone is of dark steel gray color. It sometimes carries small plates of secondary muscovite and biotite. Both of these micas have also been observed in the Waits River phase. The Washington phase furnishes numerous beds of quartzose marbles that are susceptible of a good polish, cut to a fine edge, and may well be cataloged as marble reserves.

The Coventry phase is uniformly dark in color, carbonaceous and well filled with cubes of pyrite. In Northfield it is only a

PLATE II
GRAPTOLITIC LIMESTONE, MONTPELIER

few hundred feet in width. It is often interbedded with the Memphremagog slates.

In all areas where microscopic slides have proven these limestones to have been calcitized they are cataloged as quartzose marbles. Where the lime content is small, as in the sand rock ledges in Woodbury, the name calcareous quartzite is applied.

The general strike of the whole limestone area is north 40 degrees east, but there are many local and wide variations, even to an east and west strike. A major anticline traverses the entire formation, while minor anticlines and synclines appear in the more westerly portions of the formation, with a general dip to the west. The eastern side of the syncline is sometimes as low as 15 degrees, while within 25 feet the dip will be 90 degrees, or nearly 90 degrees to the west.

INTRUSIVES

The intrusives into the Ordovician and Cambrian terranes in central and eastern Vermont are widely varied. In forms they range from huge batholiths to tortuous veins less than an inch in diameter. In chemical composition they range from the acid end of the series with 80% silica to the ultra-basic consisting essentially of the one mineral olivine with approximately 40% of silica. Their mineralogical composition, and therefore their correct nomenclature, is a research problem now being conducted in my laboratory. The following have already been identified: Granites, pegmatites, aplites, quartz monzonites, vermontites, trachytes, syenites, andesites, diorites, gabbros, diabases, camptonites, basalts, amphibolites, limburgites, pyroxenites and peridotites.

The further microscopic study of material already collected will establish several additional species.

PALEONTOLOGY

When I was a student in college I was taught to believe that there were no fossils in Vermont east of the Champlain Valley. When I began systematic field work in Orange County 24 years ago I was advised not to look for fossils, for the rocks were too highly metamorphosed to contain them. When representatives of the United States Geological Survey invaded the territory the statement was made that there is no fossil content by which the age of these rocks can be determined. In view of these facts it is interesting to note that every township south of the international boundary and near the central line of the state, for a distance of approximately 100 miles, has furnished beds of graptolites, (Plate II). The breadth of the belt in which these diagnostic features are found is at least 10 miles. More than 50 beds have been found during the last three Summers' work.

They are found in both the Memphremagog slates and the Waits River limestones. Their identification so far as possible has been made by Dr. Rudolf Ruedemann, State Paleontologist, Albany, N. Y., to whom the author of this paper recognizes his great indebtedness.

Dr. Ruedemann's later reports upon the graptolitic limestones, shales and slates are of interest here. Concerning material sent from Craftsbury, Dr. Ruedemann wrote, "These suggest Phyllograptus and Diplograptus." Concerning material from Greensboro and Woodbury he wrote, "These are quite certainly graptolites, probably branches of Dichrograptus and Didymograptus." Concerning material collected on the southeast shore of Valley Lake in Woodbury, Ruedemann wrote, "Graptolites with double series of thecae (Climacograptus or Diplograptus)." These may be the last Deepkill zone or Normanskill shale (Ordovician), (about Chazy age).

Concerning the material in the shaly limestones from East Montpelier, Dr. Ruedemann wrote, "The elliptical patches might be specimens of Phyllograptus, indicating Deepkill shale (Beekmantown)." Concerning new material from the Sabin slate quarry (Plate III) in Montpelier, he wrote, "These may be worm tubes or branches of dichograptid graptolites." A Climacograptus pavus had been previously recognized from this quarry. Concerning the graptolites in the shaly limestone near the entrance to the Catholic Cemetery, Montpelier, he wrote, "Apparently a Tetragraptus, comparable to Tetragraptus amii, or serra, in size and outline. This would make it Deepkill shale (Beekmantown)." Concerning later material from the same locality he wrote, "The most remarkable graptolite is undoubtedly a Tetragraptus amii and proves the presence of the Deepkill (Beekmantown) shales. The broad patches are quite probably Phyllograptus, as the Deepkill zones are well developed in your metamorphic rocks. Also the long straight graptolites look more like forms of the Deepkill than the Normanskill zones."

Concerning material sent from Berlin-Montpelier, which was a decomposed sample of Washington marble, Dr. Ruedemann wrote, "The specimen which you sent me is quite distinctly a small Climacograptus. It shows still the characteristic outlines of the cells and the nemacaulus, also the original shape of the distal end."

Concerning new material sent from Dewey Park, Montpelier, Dr. Ruedemann wrote, "After careful study I can see at least three specimens that retain the thecae of one or both sides to such an extent that it is safe to claim them as graptolites. The limestone, then, belong to the upper-lower or middle Ordovician." These samples were in the Washington phase of the Waits River limestone—the Washington marble. Concerning material submitted from one of the abandoned slate quarries in Northfield last summer, Dr. Ruedemann wrote, "Specimen No. 1 is the best

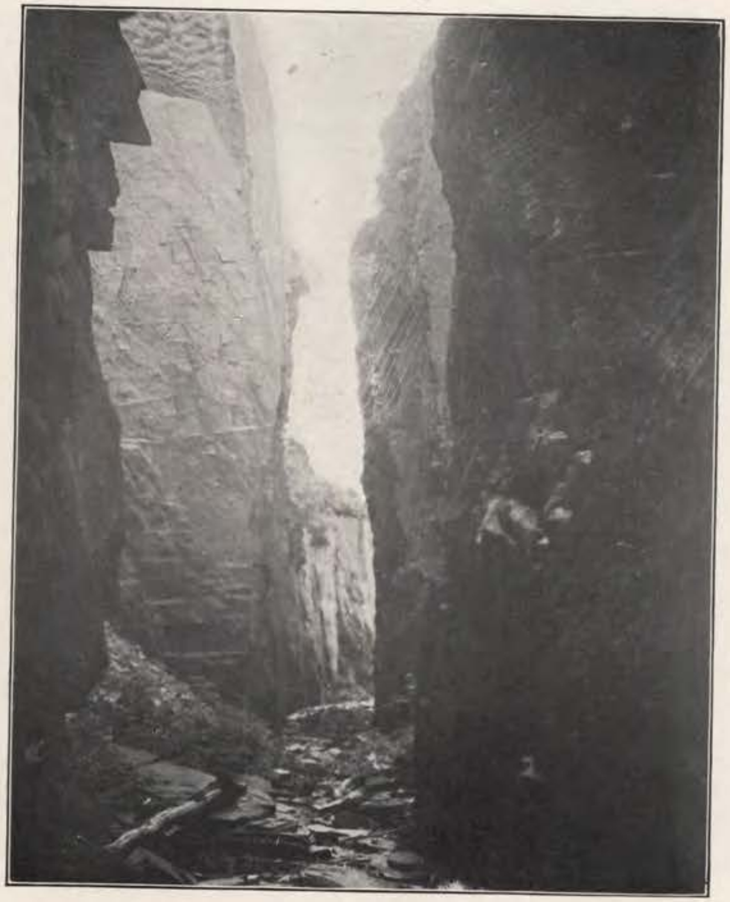


PLATE III
SABIN SLATE QUARRY, MONTPELIER

of all. It still shows in a certain light the characteristic structure of a Phyllograptus angustifolius. This indicates the Deepkill shale (Beekmantown)."

With the discovery of these diagnostic features of age in each of the three belts of the Memphremagog slates, and in each of the three phases of the Waits River limestone, it is established that sedimentation began to the east of the foot-hills of the Green Mountains in early Ordovician times, continued to middle Ordovician, and ceased with lower Trenton times. It leaves this belt of calcareous and non-calcareous sediments, approximately 40 miles in width, and stretching across the State of Vermont exactly where the author of this paper placed them from stratigraphy in 1895, as lower and middle Ordovician.

POST GLACIAL SEA-LEVEL WATERS IN EASTERN VERMONT

HERMAN LEROY FAIRCHILD
UNIVERSITY OF ROCHESTER.

CONTENTS

INTRODUCTION

In the preceding report of the Vermont State Geologist, for 1915-1916, a description was given of the upraised marine features in Vermont, especially on the western or Champlain side of the State. Only brief mention was made in that article of the Connecticut Valley features. The present writing is a more particular description of the evidences of Glacial depression and Post-Glacial elevation of the eastern border of the State.

Much of the general statement and description of classes of features in the former paper are equally pertinent here; but it is not advisable to make repetition, and the reader is asked to review the first fourteen pages of the former paper; pages 1-14 of the Tenth Report.

During the summers of 1916, 1917 and 1918 studies have been made, partly in company with Professor Perkins, the State Geologist, of the inscriptions and records left by the ocean-level or estuary waters in the Connecticut Valley; by means of which features the amount of land uplift is determined. The disadvantage in this study and description is the lack of accurate topographic maps. Only four Vermont quadrangles in the Connecticut Valley have been surveyed and published; and of these only two, the Brattleboro and Hanover, lie within the vertical range of the standing waters; and only the Hanover sheet is satisfactory in the contouring and gives precise altitude figures. Without accurate topographic and altitude maps the study is at great disadvantage; and measurements have been largely by aneroid barometer. However, great precision in recording elevations of old water planes is usually impracticable and even not essential, as features are variable in relation to the water surface. Approximate altitudes, ranging over long distances are quite satisfactory for general description.

GENERAL STATEMENT

LAND MOVEMENTS

Up and down movements of the earth's "crust" is the fundamental fact in geology. Vast areas of the continents which are now far above sea level have been beneath the ocean, as evidenced by the remains of marine animals found in the solid rocks; the latter being merely the hardened sediments deposited in the sea. Most of the rock strata of Vermont were laid down as sand, clay and lime sediments in very ancient seas. Even the crystalline rocks to the summits of the Green Mountains were probably oceanic deposits. Through all recorded geologic time the vertical movement of the earth's surface has been in progress, and is still going on. It should, therefore, cause no surprise to find that some uplift, a few hundred feet, has taken place only yesterday, geologically speaking.

The earth's superficial or crustal portion is sensitive to unequal loading, or differential pressures, and it appears that northeastern America was depressed by the weight of the long persistent ice sheets of the recent glacial time. With the removal of the weight by the melting of the ice body the land rose. The amount of Post-Glacial land uplift, and the area affected, seem to have been proportionate to the calculated thickness and extent of the latest ice sheet. Wide study by the writer has made it possible to draw a map that represents approximately the amount of Post-Glacial uplift, shown in figure 1. The position of Vermont with reference to the dome-shaped uplift causes the

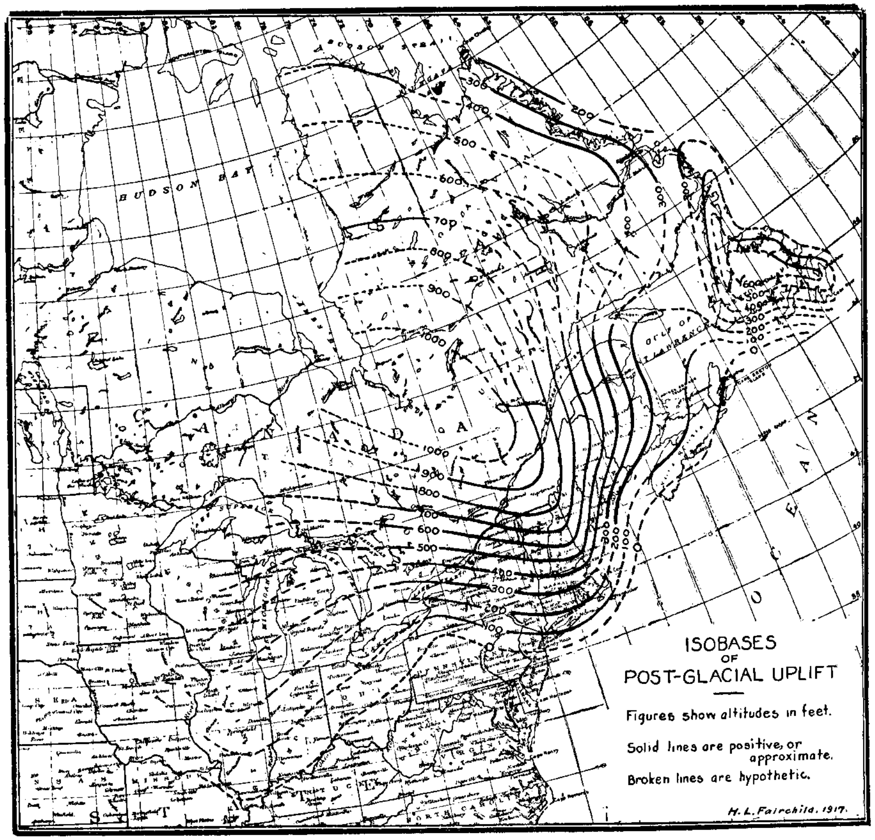
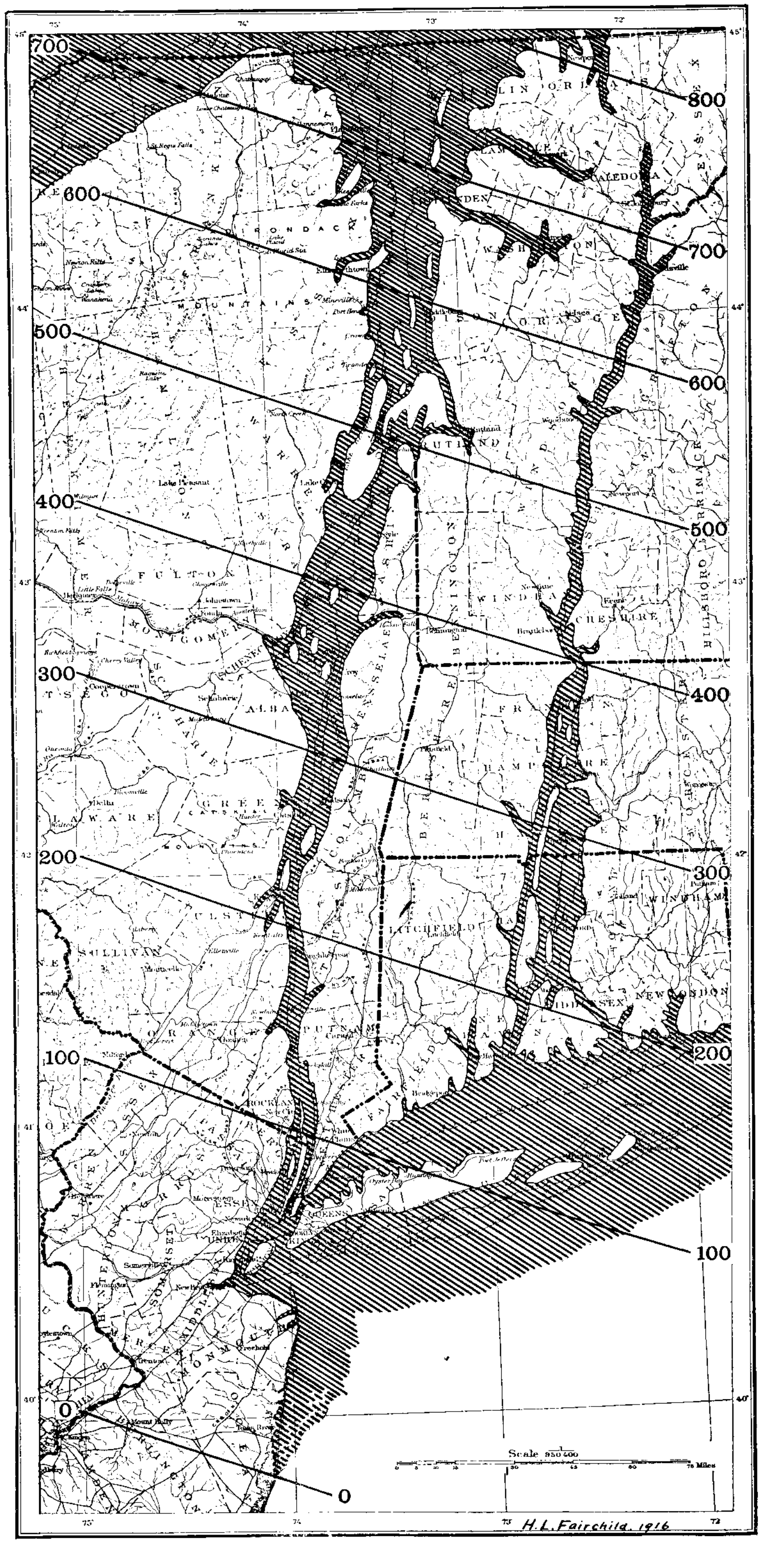

ISOBASES
OF
POST-GLACIAL UPLIFT
Figures show altitudes in feet.
Solid lines are positive, or approximate.
Broken lines are hypothetic.
H. L. Fairchild, 1917.
HUDSON BAY
GULF OF ST. LAWRENCE
CANADA
OCEAN
1000
900
800
700
600
500
400
300
200
100
0

FIG. 1



THE UPRAISED MARINE PLAIN.

lines drawn to indicate equal rise (isobases) to lie in direction somewhat northwest by southeast. Plate IV is a reduced copy of the map included as Plate I in the previous report. (No. 11 of the list of papers).

Connecticut Valley Terraces

The benches or terraces along the walls of the Connecticut Valley have been noted ever since the forests were removed. They were given fame by the writings of Edward Hitchcock (1), Charles H. Hitchcock (2, 3), Warren Upham (4, 5), and James D. Dana (6). The earliest theory, by Edward Hitchcock postulated submergence of the region, but in excessive amount. Later writers minimized or ignored the changes in land attitude. Realizing the great volume of detritus contributed by the glacial drainage, in addition to the mass from the early land streams, and not recognizing the considerable change in land level, Dana and Upham attributed the terraces to the work of an enormous river. The idea was that during the recession of the latest ice sheet the greatly flooded Connecticut River was supplied with more detritus than it could remove; and that consequently it filled or aggraded the valley; and that when the flood was spent the normal river eroded the thick deposits and in the down-cutting process produced the terraces.

The mechanical difficulties involved in the theory of river genesis of the terraces were not overlooked, and much discussion was devoted to these. But the inconsistencies and contradictions were not solved. Two of these problems may be stated, by way of illustration. At Barnet the conspicuous terraces in the open valley were measured by Upham (5, page 60) as 618 feet above ocean (the evidences of standing water reach up to 710 feet). The distance southward to the sea is about 215 miles, giving a gradient of three feet per mile. Such slope is excessive for any very large river, and the velocity of flow would sweep away everything below the size of boulders. But the lower terraces are composed of true clay, and the higher terraces are mostly sand, which is proof positive of relatively quiet waters. The matter is discussed in paper number 10, pages 229-230. Another dfficulty would be the disposal of the enormous amount of detritus derived from the excavation of the deposits. The detritus would have filled a large part of Long Island Sound but there are no suggestions of such filling or delta formation. (10, pages 230-231).

The Connecticut Valley is not alone in having conspicuous terraces and massive deposits of fine detritus at high levels. They occur the whole length of the Hudson Valley, and in great development on the slopes of the Champlain Valley, where the most vivid imagination could not attribute them to river work. They are prominent in all the great valleys of New England and in the low valleys of Canada, New Brunswick and Nova Scotia. They exist, but are not so conspicuous, in the Ottawa and the St. Lawrence valleys. As the Connecticut Valley is narrow throughout most of its length the benching of the deposits are plainly seen, and the phenomena became classic through the early geologic writings. But the features should be studied in comparison with other similar valleys.

The higher terraces in the wide valleys opening freely to the sea were not produced by flowing but by standing waters. And the standing waters were not lakes or isolated bodies of water but were arms of the sea. They were estuaries. The Hudson estuary from New York City to Albany is a present-time example. High-level benches, gravel bars and other shore features are not restricted to the valleys, but occur on slopes facing the open sea, at corresponding elevations.

Only some change in the relative height of land and sea can account for these elevated shore features; and as the sea is comparatively steady we may reasonably assume land movement. Moreover, we find that these high-level water records are practically limited to the northern territory which has recently been overspread by a continental glacier. In the weight of the ice sheet, probably two miles thick on the north boundary of Vermont, and lasting for perhaps hundreds of thousands of years we have efficient cause for the depression of the wide area.

With the recognition of glacial waters held in north-sloping valleys by the glacier acting as a dam, some geologists were inclined to refer the records of high waters even in the south-leading valleys to glacial damming. The term "glacial" has been the limbo to which these unexpected, and puzzling features have been consigned. But this is unfair and unscientific without some proof of glacial impounding. Glacial waters were not held in the broad, south-leading valleys like the Hudson, Connecticut, Kennebec and Penobscot. Marine fossils are found far inland, at high levels; up to 510 feet at Ottawa. Marine fossils are not found in the highest sea-level deposits, formed during the deeper submergence; because the flood of cold, lifeless water from the waning glacier produced physical and biologic conditions unfavorable to salt water organism. The terms "marine" and "oceanic" used in this writing are not intended to imply that the waters were saline, but to suggest their confluence with the sea. The term "marine plane" signifies the level of the ocean surface projected inland. The level connecting the highest static-water inscriptions is the uplifted marine plane of the deepest submergence. The lines in Plate IV and the diagram, figure 2, show the uplifted, summit plane, and also show the total amount of land submergence in the sea at the time the ice sheet was melting off. The study of this subject cannot properly be done by confining attention to one valley, for com-

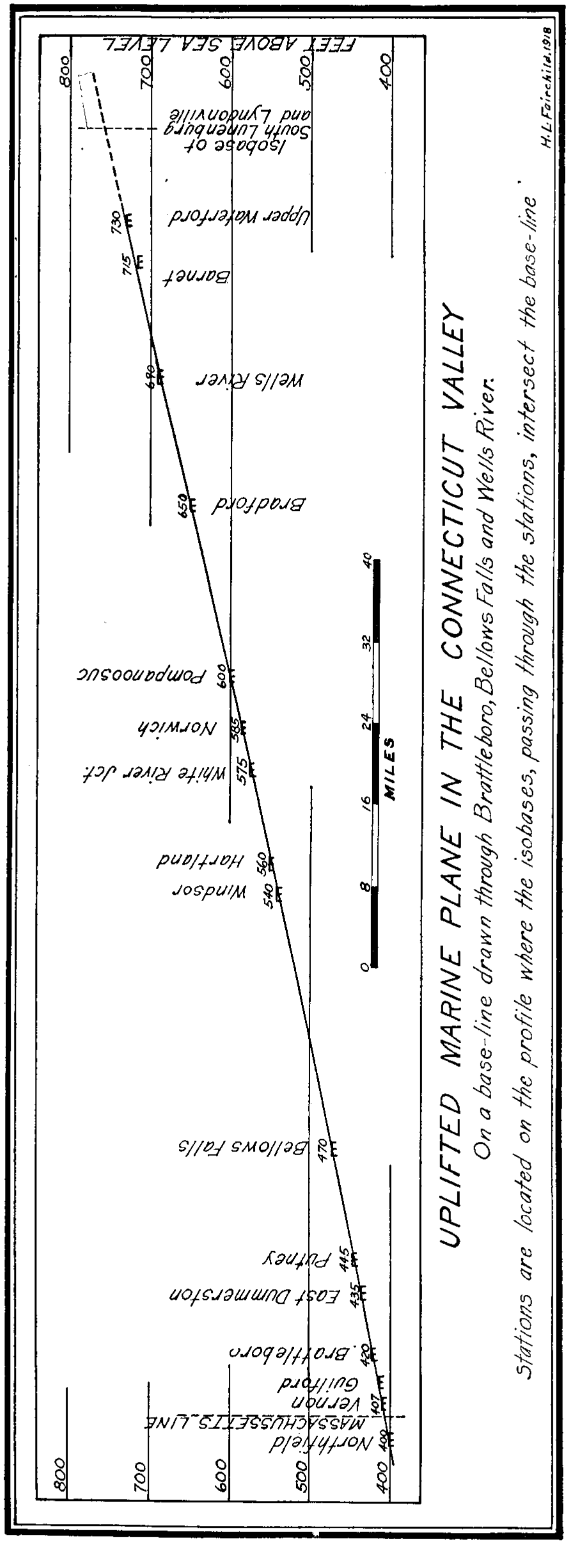


FIG. 2

parison must be made over all of the ice-weighted area of northeastern America. Figure 1 is the result of such wide study.

THE UPLIFTED MARINE PLANE

The diagram, figure 2, indicates the vertical position of some of the critical features left by the standing waters in the Connecticut Valley. In the former article, page 7, may be found description of a similar diagram for the Champlain Valley, much of which applies to this diagram. The former article also includes chapters on the character of the summit-level features of the upraised marine plane (page 8), and a description of the marine features in general (pages 9-15), all of which are appropriate in this writing, but will not be repeated.

In this study the important fact is the height above the ocean of the highest evidence of standing water in the open valley, because this gives amount of land uplift. This fact has geologic value. The height and form of the inferior terraces and their relation to the river has only a local educational value.*

AREAL DESCRIPTION

MASSACHUSETTS

Twenty years ago Professor Emerson carefully identified the summit plane of the standing water throughout the Connecticut Valley across the State of Massachusetts. His figures for the altitudes are 288 feet above tide on the south boundary of the State and 400 feet on the north line (see No. 7 of the list of writings). These altitudes were used in the first projection of the plane north and south, and have been found remarkably accurate.

As students of this interesting subject may wish to verify the plane south of the Vermont line the following localities are noted lying on the Greenfield and Warwick topographic sheets. The smooth, wide plains of clay and sand, so characteristic of all the deep valleys opening southward to the sea, are here very conspicuous. These are usually much below the summit plane, which may be represented along the sides of the valley by weak, inconspicuous and detached features. The deltas at the mouths of the tributary valleys are the best summit features; excellently illustrated at Millers Falls. Here the Millers River built an extensive delta in the earliest and highest sea-level waters. The village is in a valley that has been excavated out of the delta plain. Close west of the village a remnant of the gravel plain has altitude 360 feet, extending far to the southwest. Southeast of the village the plain is 360 feet, with the backslope rising to at least 370 feet. The theoretic height of the summit water level at this locality is 375 feet.

Examination has been made of the static-water inscriptions about Northfield and East Northfield. The lower plains are, as usual, very prominent, at over 300 feet. The creek south of Round Hill and Northfield village has a good cobble and gravel delta, which may be seen along the east and west road on the 400 foot contour of the map. Up stream, eastward the delta stuff is coarse and evidently dropped above the standing water. Westward, below the flat of rounded cobble, is a smooth gravel plain which certainly represents quiet water.

Along the mountain flank northeast of East Northfield and by the highway the shore features due to wave smoothing are evident, above the 400 foot contour. As this station is some three miles south of the Vermont state line the theoretic figure or the surface of the estuary at the state line must be raised to at least 405 feet.

On the west side of the valley the lower plains may be seen along the highways and the Boston & Maine Railroad northward from Greenfield; and from Bernardston the effects of the standing water show in the side valleys up to nearly 400 feet.

VERNON, VERMONT

The most southerly point in Vermont that has been carefully examined is the extreme southeast corner of the Brattleboro quadrangle. Here lies the west branch of Town Brook, which flows past the flag station called Central Park (Vernon, of the Brattleboro sheet of 1916), and debouches into the Connecticut River at the sharp bend of the river. West from the railroad, the elevation of which is taken as datum at 295 feet, is a sandy plain a mile wide, rising in irregular terraces. The summit of the sea-level waters is found in good form somewhat over a mile west of the railroad on the road along the north side of the brook. School No. 7 is on the smooth plain that is the highest, extensive, wave-smoothed tract. The altitude at the school is about 375 feet. An eighth of a mile west of the school the plain, at about 390 feet, abuts against a low cliff. The house of Mrs. A. N. Clark stands here. Benches of cobble and remnants of the aggraded delta occur westward to the house of L. T. Fairman, the altitude here being about 415 feet. Above this point there

---

*The study of local topographic features is of the highest educational value, and the valley terraces are an exceptionally fine subject. The measurement in height and area of the terraces, plains and cliffs, and the drawing of simple maps, gives excellent discipline in observation, precision and accuracy of record, and the handling of instruments. While the study of the features in their causal and geologic relations is of the highest cultural value. Such study should be required of every boy in the High School; and perhaps of the girls, also. It would be of much more intellectual and practical value than many of the subjects on which time is spent, or wasted. It is desirable that some of the traditional school work should be replaced by subjects that deal with the facts of life; with the realities of the physical world, of which humanity is a part.

is no stream detritus of any sort, only the bare erosion banks of the stream, in rock or drift. The standing water of the Connecticut Valley was somewhat below the coarse cobble at the delta head, and was certainly above the wide, smooth plain of 390 feet. Study on the ground placed the water level between 405 and 410 feet. By consulting the maps and diagram it is found that this is the theoretic figure for the summit marine plane at this locality.

This occurrence has been described in some detail because it is a good illustration of reliable features and of the method of study. It is also a good example of the best criteria for determining the summit plane, which are the deltas of weak streams in places sheltered from heavy storm waves. Deltas of large streams may have too great vertical range for more than approximate measurement of the water plane. Extensive plains, especially of sand or fine gravel, were usually submerged when deposited. Gravel embankment or bars, and erosion cliffs, are uncommon in the narrow Connecticut Valley; and are not conclusive proof of the earliest and highest stand of the waters.

About one and one-half miles north of Central Park Station is Vernon Station. Looking west strong terraces appear. Two bold, steep, erosion cliffs stand above the lower and smaller ones on the plain. The highest bench is one half mile away, with elevation about 365 feet; the railroad taken as 280 feet. Behind the bare terrace, in open pasture, at 365 feet, is a higher gravel plain in forest, at 385 to 390 feet. Westward across a deep cut the plain continues, abutting against a rock cliff. The gravel plain is 15 or 20 feet beneath the theoretic figure. The material composing the terraces was at least partly contributed by a stream on the north. A highway leads west up the hollow, and careful study will doubtless find summit features similar to those of the Town Brook.

GUILFORD

About three miles south of Brattleboro the village of Guilford lies at the junction of three valleys, on the remnants of the delta of Broad Brook. A handsome cobble plain stands south of the corners, carrying the Episcopal Church and cemetery, with elevation by the map of 420 feet. This plain continues down the creek, southeast, as a bordering terrace. Coarse cobble in the road cutting below the church shows typical delta structure. The road leading southwest from the corners, on the north side of the creek, is a terrace remnant of the delta, also at 420 feet. North of the corners the detrital filling in the hollow affords good opportunity for discriminating the true water level. The theoretic level here is abou 415 feet.

BRATTLEBORO

A splendid great gravel plain and other significant features related to the sea-level invasion occur about the city. The history is complex and involves glacial drainage.

The Whetstone Brook, from the west, is a vigorous stream and deserves the name of river. But the great delta, remnants of which occur in and west of the city,and the vast gravel plain, a mile wide, south of the city, was probably constructed partly by the West River, which joins the Connecticut a mile north of the city. During the last phase of the glacier in this vicinity the nose of the ice lobe in the valley forced the flow of West River along the west wall of the valley. The hollow west of the Asylum Hill was doubtless the West River channel, and the two rivers met in what is now the center of the city. At that time the detritus swept in by the rivers was dropped to form the wide gravel plain which carries the Fairground and the Catholic Cemetery. It is certain that the present gorge of the creek through the city has been excavated out of the gravel deposit which once covered all the site of the city. Remnants of the filling occur west of the city, both sides of the creek, up to the junction of two roads, within a mile of West Brattleboro. If the 400 foot contour is correctly placed, then the head of the Whetstone delta is a terrace on the south side at 420 feet. Another terrace is 25 feet lower. These are on land of R. H. Briggs. The Fairground plain is given by the map as 360 feet, reaching 380 at the west border. But taking the railroad station as 250 feet the aneroid makes the plain over 400 feet.

North of the city is a high, oval hill contoured at 500 feet. It is nearly all in forest and is part of the ground of the Insane Asylum ("The Retreat"). Cliffs of bare, rough slate testify to the eroding work of storm waves, for the rubbing ice sheet left these rocks smooth. Mere atmospheric weathering has not greatly roughened them. The wave work at over 400 feet, in erosion and removal of the glacial drift, is evident. Careful leveling, even with the aneroid, will determine here the highest reach of wave action.

The valley of West River is so narrow and steep-walled that it does not preserve the higher levels. But glacial lake deposits will probably be found in the upper portions of the valley, as the Connecticut ice lobe must have blocked the lower part of the valley for a time. The glacial history can not be easily read until the topographic maps adjacent to the Brattleboro are available.

EAST DUMMERSTON

About six miles north of Brattleboro is the village of East Dummerston, in the hollow cut by Salmon Brook. In this valley the summit marine features appear in good shape. Passing northwest from the railroad station, with altitude 260 feet, the lower terraces are conspicuous. At the west turn of the road, over a mile from the station, is a good plain under the house of John Sheldon, with altitude about 425 feet. The filling on the south is several feet higher. The summit plain shows in remnants at the Post-Office, at 435 feet, on both sides of the valley. The place of Charles O'Neil is on the terrace near the junction of the southleading road, with altitude about 435 feet. The delta here once filled the valley at the theoretic height.

PUTNEY

At Putney village, Brattleboro sheet, we find the delta of Sacketts Brook. An extensive lower plain has altitude about 290 feet. A plain at 350 feet is massive clay, with a brick factory behind the railroad station.

The south part of the village is on a wide plain, at 375 feet, declining to 365 at the front. At 400 feet a small terrace occurs in the northwest part of the village, and the summit level is found in the excellent plain at the High School, with elevation about 445 feet. This abuts against the till slope of the valley wall, and beyond the school the ground is irregular and unaffected by stream detritus. The summit level is also found northeast of the village. A fine plain carries the cemetery, at about 430 feet, while at 445 feet is a bench on the hillside by the house of O. R. Kilburn.

BELLOWS FALLS AND SAXTONS RIVER

The city of Bellows Falls is located on the terraces of the Saxtons River delta. A remnant of a high terrace stands in the center of the city, being the hill along the west side of Rockingham Street. The terraces may be seen from the cars of the Saxtons River Street Railway. The lowest plain is "The Basin," a circular meadow south of the city which was cut by the river when it was down to near the present level. The railway at the car barn lies on a high, narrow shelf-terrace, with altitude according to the railway profile of 387 feet.. About 90 feet above this is an elegant gravel plain, a fine example of the high-level marine plains. It is utilized for the Oak Hill Cemetery. Taking the railroad at Bellows Falls station as 309 feet, and the street railway tracks at the car barn as 387 feet, the cemetery plain is about 477 feet at the front and a few feet higher at the back edge, where it abuts against the steep, irregular valley wall. The theoretic marine plane here is about 470 feet.

It is probable that the Cemetery gravel plain was partly, perhaps wholly, contributed by the flow of Williams River, when the flow was confined between the west wall of the Connecticut Valley and the border of the ice sheet lobation. And possibly the material was partly derived from the outwash of the glacier. The relation of Williams River to the Connecticut Valley is similar to that of West River at Brattleboro.

Five miles, by the railway, up Saxtons River is the beautiful Barber Park. This is primeval pine forest spread over four terraces of the delta filling in the lateral valley. The railway station is given as 411 feet. The main terrace, of wide extent, is about 440 feet; and the higher ones are about 450, 475 and 500 feet. It appears that the highest terrace at Barber Park is at least 20 feet higher than the Oak Hill Cemetery plain, doubtless due to the filling, or aggradation, of the delta above the standing water.

At Saxtons River village the car tracks are given as 496 feet. Good terraces occur here; the stronger one being south of the village, carrying the cemetery and the fine old building of the First Baptist Society. The altitude of this plain is about 545 feet; and some 20 feet higher is the summit plane, with the building of the Warner Memorial Home. This, at 565 feet, is 35 feet higher than the summit terrace at Barber Park. This increase in altitude passing up the narrow valley may not be more than would be produced by the upbuilding of the delta. But we must be prepared for glacial waters in the valleys tributary to the Connecticut.

BELLOWS FALLS TO WINDSOR

No observations have been made between these two places. The railroad lies on the New Hampshire side of the valley; the stretch is difficult of access, and with no good maps. Moreover, a large part of the lower slopes and the tributary valleys are in forest. Probably the delta of Black River is at Springfield village; and the summit should be about 500 feet.

WINDSOR

The combined deltas of Mill River and Ely Brook are found at the village of Windsor. Taking the elevation of the railroad station as 321 feet the altitudes of the terraces are as follows.

The main lower plain is in the western part of the village, traversed by State Street. The High School stands at the east, or lower, margin of the plain. Here, at the band stand, the altitude is 470 feet. At the State Street School, by the rear edge of the plain, the altitude is 475 feet.

Massive clay is seen in excavations on Ascutney Street, and on State Street at 410 feet. This clay extends up to 490-495 feet, and forms the mass of the higher plain, which is now eroded into knolls and benches. The new steel reservoir is located on one of the clay knolls, and the Ely homestead is on the plain at the full height of 500 feet. Here a thin veneer of sand appears.

The head of the Ely Brook delta lies west of the Ely house and near the dam of the old reservoir. It is a small cobble plain, abutting the steep valley wall, with altitude about 540 feet. Remnants of this summit level occur both sides of the brook valley, and an excavation by the road exposes the cobble beds at the top. This altitude, 540 feet is the theoretic height for the summit marine plane at this locality.

The valley of Mill River has not been explored, but good features will surely reward search.

HARTLAND

From here to beyond Norwich we have the help of the excellent map of the Hanover quadrangle. The village of Hartland is on a rolling plain with altitude averaging 580 feet, by the map. The corners are marked on the map as 582 feet. This is about 30 feet over the theoretic plane, and it probably represents lake waters held in the valley by rock control at the ravine one-fourth of a mile south of the village. Southward, down the valley of Alder Meadow Brook, lower plains occur, the high one at approximately the marine summit, 550 feet. The lower plains are wide, the railroad station being on one at 420 feet. The U. S. Geological Survey bench mark, 441 feet, is on a boulder by the north side of the road some 30 rods west of the station.

NORTH HARTLAND
(Evarts Station)

Handsome high-level plains lie here, being the delta of Ottaquechee River. The heavy load of coarse detritus in the grasp of the early flow of the river was not deposited here, but was dropped in the upper valley at Woodstock and Quechee, in the Quechee Lake that occupied the upper valley while the rock ravine at Quechee Gulf was slowly cutting.

The theoretic summit level at North Hartland is about 560 feet. The extensive plain on which the village is built is contoured as above and below 380 feet. A plain of corresponding but somewhat higher level lies east of the river. Southwest of the village is a group of high, conspicuous knolls, composed of silt or sandy clay. The highest knoll, about one-eighth of a mile north of the road, is contoured at 580 feet. They have a roughly linear arrangement and decline in altitude southward, the lowest knoll, on the south of the road being 540 by the map. Not even a pebble was found in the district, and a cutting by the road shows 30 feet of sandy clay. The allineation of the knolls suggests an esker-like origin. The present form is erosional, and they are probably remnants of a silt deposit laid down by a glacial stream in an ice-walled channel, at or beneath the summit sea-level waters. Both north and south of the road an eroded water level is clearly seen, at 540-550 feet by the map. A mile southwest, on the west side of the valley, a distinct delta terrace appears at about 560 feet.

North of the Ottaquechee River, along the north and south road, is found the summit plain of the river delta. By the map contours the plain rises from 540 to 580 feet. The road here lies in a deep ravine cut in the fine sand. A mile north of the river, toward and at the forks in the road, sands are found at 600 feet. These higher plains probably are effects of aggradation by the land streams and the glacial drainage along the margin of the waning ice lobe, because farther northward along the road the deltas of the land streams are clear at about 580 feet.

WHITE RIVER JUNCTION

The tracks at the railroad station are taken as 364 feet. The theoretic limit of the sea-level waters is about 575 feet.

At this point, the junction with the Connecticut River of the White River, the heaviest tributary from the west, we should expect to find large delta deposits. We do find extensive plains, but somewhat inferior to the summit level; the earliest deposits of the White River having been dropped far up its valley.

Close to the village is a high hill of clay and sand which was once connected with a corresponding plain across the White River on the north. The flat top of the hill is 520 feet. Suggestions of the same level are seen across the Connecticut Valley in Lebanon. A great sandplain that approaches the summit level lies southwest of the village and is occupied by the State Fairground. The altitude at the main entrance on the west side of the Fairground is about 555 feet. In the fields on the west the evidence of wave work on the till slopes is seen up to at least 560 feet. On land of Mrs. G. Blanchard on the south side of the road the ground has been shaped into bar forms. On the east side of the Fairground the slope has been covered with windblown sand, and the inscriptions of the standing water obscured. But the rock knolls east of the plain suggest wave action.

The most significant features for determining the summit water plane are found along the north and south road some two miles southwest of the village. The topographic map (Hanover sheet) shows the road as lying at 400 feet along the foot of the steep slope, and at the head of a narrow plain. This plain is the product of stream deposit and wave distribution at the marine summit. The wave-smoothed plains reach the 580 contour; and the theoretic figure is 575 feet. At the three-corners marked as 586 feet and by the two streams which cross the road a mile south, the delta summits are about 570 to 580 feet. The delta form is good by the house of Mr. B. Wright, on the southerly stream. On the third stream from the north, two miles north of North Hartland, the rolling, knolly and probably kamy sands are at 600 feet; but the smooth sandplain begins lower, at or beneath 580 and declines to 540 feet.

VALLEY OF WHITE RIVER

The sea-level deposits and deltas in the White River Valley have not been examined and will be described only in theory. Careful study of the valley and of the lateral or tributary valleys will yield very interesting facts, which will confirm the history here outlined.

The Pleistocene history of the White River valley is tied in with that of the Dog River valley. The two valleys head in the same district, near Roxbury, and decline in practically opposite directions. The Dog valley, declining northward, holds the record of the glacial, or ice-dammed waters, while the White valley contains the detritus of the glacial overflow across the summit col of the Dog valley; and its lower stretch the deposits of the sea-level waters.

The theoretic height of the marine plane is 680 feet at Montpelier and about 660 feet at Riverton (West Berlin). The head of the Dog valley at Roxbury, and the col or divide between the Dog and the White valleys is 1009 feet.

The sea-level waters occupied the Winooski and the Dog valleys up to the summit marine plane. As expected, the Dog valley contains broad terraces and eroded gravel plains up to Riverton and Northfield Falls, at 650 to 660 feet. But the gravel deposits do not end here, as should be the case if only the marine waters had occupied the valley. The waterlaid deposits continue up the valley to the very summit, at Roxbury, because the glacial waters had filled the entire valley to the summit col. We may call the glacial waters the Northfield Lake.

The divide at Roxbury has the character of a river-swept plain. It was the outlet of the Northfield glacial lake, while the glacier was the dam on the north. The divide is a flat, swampy stretch and then narrow rock passes. Passing southward from the summit we find all the features that would be produced by a large stream loaded heavily with sand and gravel. We find extensive gravel plains, more or less eroded, and channels cut in rock; these being beyond the reach and the capacity of the present stream. The gravel and sandplains decline southward with the stream, and have a mass and height beyond the ability of the present stream. These features, partly flood-plain and perhaps partly glacial, weaken southward until below Braintree they are no more than the effect of the glacially-flooded White River, third or north branch. It must be understood that the first flow across the divide at Roxbury carried a heavy mass of detritus of the glacial drainage; but as the Northfield lake came into existence it acted as a reservoir and the outlet stream, the Roxbury river, ran clear.

Passing further down the valley, below Randolph and approaching Bethel we again find gravel terraces that are not the product of the present stream; although cut and dissected by the stream. These plains range above and below 600 feet, but have not been accurately measured. They are the deposits of the Third Branch of the White River in the summit sea-level waters. At Randolph the theoretic height is about 605 feet. With the deposition or aggradation of the river up stream, especially in the narrow valley, it is expected that the highest plains formed by the river will be higher than the level of the standing water in the estuary.

Below Bethel the terraces become higher and higher above the river, showing that these were laid in an estuary, by the tributary streams, and not under present conditions. Further down the valley the detrital plains do not occur in the open valley, but are seen as evidences of high-level water in the side valleys or embayments of the main valley, where the lateral or tributary streams built their deltas. Finally, at White River Junction we find abundant evidence of the high standing water in both the White River and the Connecticut River valleys.

LEBANON, NEW HAMPSHIRE

A full description of the Connecticut Valley features would include those of the New Hampshire side; but this has not seemed appropriate for the present writing. Indeed, such inclusion would not be practical now, as there are no topographic maps except the Hanover sheet. It seems proper, however, to briefly mention the features across the river from White River Junction, in Lebanon; and below those at Hanover.

The Mascoma River has left conspicuous and definite plains at Lebanon village and westward to West Lebanon. There is a beautiful display of terraces both sides of the valley. On the south side the wave-work is visible on the slopes to 560 feet, the theoretic height being 575 feet. In the west part of the village good terraces occur on the south side of a hill, on Mascoma Street, at 565 feet; and on the southeast side a sand terrace is 570 feet. The village square is above the marine plane, being about 588 feet. The railroad station is on the river floodplain at 580 feet. The presence of standing water in the valley is very evident up to 570 feet.

NORWICH

In this district the marine features are clear and strong; and with the precise elevations given on the Hanover sheet accurate data are available.

On the west side of the valley, west of Norwich, the work of waves on the hillside is evident; the features being similar to those in the stretch southwest of White River Junction. Streams flowing eastward, down the valley wall, contributed materials for the waves to shape. The water-plane here is 580 to 590 feet depending on latitude.

By the cemetery, on Bragg Brook, is a good place for study of delta and the combination of stream and wave work. The bench and terrace at 585 feet is positive wave work. The cobble slope at 615 feet is the aggraded delta of the weak stream, above standing water. The delta of Bloody Brook will be found a mile north of the cemetery, and at altitude about 590 feet.

Along the north and south road east of Mosley Hill the wave work is clear, but it must be discriminated from some higher glacial stream deposits which are deceptive. The level of standing water is about 585 to 590 feet, with the reach of storm waves a few feet higher. Southward the plains naturally decline. The village of Wilder is on an inferior plain at 430 feet.

HANOVER, NEW HAMPSHIRE

At Hanover we have an old and classic locality for the study of the Connecticut Valley waters. The plain that carries the main part of Hanover village and the campus of Dartmouth College is about 530-535 feet in altitude, but the extensive plain east of the village is less than 520 feet. This extensive plain was probably laid down by the land and glacial drainage forced south along the east side of the ice lobe, as the front of the glacier was abandoning this district. Southeast of the town is the conspicuous delta of Mink Brook. On the southwest side of the road the plain rises from 560 at the margin to 570 feet at the roadside; while the rocks above the road indicate wave erosion. This plain had been tentatively regarded as marking the summit of the marine flood, but there was the suggestion of a higher level in the forest on the south side of the brook which caused doubt. During the past summer this was explored in company with Professor Perkins, with fine result. Almost hidden in the pine forest is an elegant detached plain, or mesa, estimated between one and two acres in area, quite flat, and connected with the valley slope by only a narrow isthmus. Its altitude is between 585 and 590 feet, the near-by corners at 522 feet giving good datum. This isolated mesa is impossible of explanation except as a remnant of the Mink Brook delta. Its altitude is practically the theoretic figure for the locality, 587 feet. Correlating with the mesa remnant are benches or low knolls on the rough hillside toward the road corners at about 585 feet, and between these and the mesa is a bar-knoll at 585 which has been excavated for gravel.

Many evidences of the summit level of the standing water in the Hanover-Norwich district will be found by further exploration and careful leveling.

OMPOMPANOOSUC VALLEY

The railroad at Pompanoosuc station is taken 392 feet, and the theoretic figure for the marine summit is about 600 feet. With Professor Perkins the valley was explored to a point in sight of Union Village. Heavy lower clay and sand plains shut in the view at the station, and the road winds through the delta deposits, like all the roads near the Connecticut River that ascend the tributary valleys.

The summit water level is reached about two miles from the railroad, on the Waterman Hill. In front of the Truman Waterman place the clear distinction can be seen between ice-laid and water-laid materials, and the altitude is 595 to 600 feet. From this point beautiful terraces are in clear view at Union Village, two miles up the valley; and at the same height by the pocket (Locke) level. Across the valley are terraces of local brooks, with altitude within 20 feet of the 600-foot plane. Good terraces occur at all levels below the 600 feet.

Without visiting Union Village it is evident that the summit delta-filling of the Ompompanoosuc River is at and above the village. It should be the pleasure of some student of this subject to explore the valley and record the facts. The same may be said about all the lateral stream valleys between Pompanoosuc and Bradford, as the writer has made no examination.

BRADFORD

The district here, about the mouth of Waits River has been quite carefully studied; also with Professor Perkins. The railroad at the station is taken as datum, at 405 feet; and the porch of the Hotel Low as 445 feet. The theoretic plane is 650 feet.

Here the Connecticut Valley is joined by the deep, broad valley of Waits River. The summit delta plains of the latter stream have not been seen, but they must lie far up the valley, probably at East Corinth.

Extensive plains and splendid terraces occur about Bradford. They are especially conspicuous south of the village and on the south side of Waits Valley. About a mile west of the village and south of the covered bridge is the best display of terraces and cliffs that the writer has seen on the Vermont side of the Connecticut Valley. These gravel terraces lie between two creeks that flow north to Waits River; the westerly one being Brushwood Creek, which heads near the Fairlee lakes. The heavy gravel deposit here, which has been carved by waves into bold cliffs and terraces, was chiefly a kame area left by glacial drainage, with some minor contribution, perhaps, by the two creeks.

The series of terraces and cliffs record the rise of the land out of the standing waters. The following enumeration is in reverse order of their formation, or from bottom to top.

1. The present floodplain of Waits River, about 460 feet.
2. A narrow terrace; 500 feet.
3. A narrow bench, just over the large yellow barn; 525 feet.
4. The main lower terrace, with the high, conspicuous front visible from the village and valley. A broad low bar occurs on the terrace; 615 feet.
5. A broad, sloping terrace, not visible from the valley; with broad bar; 635 feet.
6. Another wide, sloping terrace, with bar form at west end; 650 feet.
7. A low shelf with bar form, at the foot of a steep erosion cliff; 660 feet.
8. A ridge of gravel knolls, not wave swept; the highest at west end, 675 feet.

The ridge of kame gravel (No. 8) clearly has been wave-cut at the west end, where an excavation reveals its structure and on the north slope where the wave-built bar (No. 7) lies at the foot of the smooth, steep erosion cliff. The south side of the kame ridge is very steep and irregular, dropping off to a deep hollow between the ridge and the till slope forming the south wall of the valley. The existence of this unfilled hollow suggests that the detritus of Brushwood Creek did not reach here effectively, but must have been dropped further south, up its valley.

The marine summit is clearly number 6, at 650 feet, with number 7 as the storm beach. The steep, smooth, straight north face of the gravel ridge is clearly the result of wave erosion. It is a characteristic sea cliff. The top of the kame is irregular, and never wave-swept.

The eroded west end of the main terrace (No. 4) shows massive clay to within 15 feet of the summit, or to 600 feet. This is within 50 feet of the theoretic marine plane, and is duplicated west of the village. Eastward, the main terrace, so conspicuous from the roads and the heights west of the village, declines and becomes fine sand. The east end, about 580-585 feet altitude becomes an extensive plain, being part of the Bliss Estate. The original extent was much greater, as a remnant of the plain, called Bliss Hill, one-fourth mile long, stands out in the Connecticut Valley, southeast of the village. This is north of the Fairlee road, by the sawmill, and is squarely in the middle of the mouth of Waits Valley. The bedded sands to the summit shows its connection with the plain on the west; while its position rules out the idea of ponded glacial water in the Waits Valley.

These excellent features and critical altitudes on the south side of Waits Valley are confirmed by phenomena on Mink Brook, west of Bradford village. Passing up the west-leading road in the village, finely laminated clay is seen at 500 feet, extending up the slope to 600 feet, where it has been exposed by stripping off the gravel, in front of the house of E. A. Bacheller. Above this point the surface deposit is gravel, showing well in the garden of Robert Peavey. Just west of the house and garden of Mr. Peavey is a stony bench by the channel of Mink Brook, at about 655 feet, which is probably the work of storm waves rolling in from the broad valley on the east. The slope south of the road is wave swept and a cliff stretches away across the fields.

Wells River

Wells River Station is taken as 462 feet. The theoretic summit plane is about 690 feet.

About Wells River and Woodsville the valley plains are inferior levels and mostly clay. North of the station at a brick factory the clay was seen up to about 560 feet; which is only 10 feet higher than the clay at Bradford.

The sand and gravel delta of Wells River must be sought up the valley toward Boltonville and South Ryegate. Passing up the valley, remnants of the high-level delta deposits are conspicuous from the train all the way to Boltonville, rising from about 530 to 650 feet. The stretch from Boltonville, 669 feet, to South Ryegate, 744 feet, was examined on foot. The standing water records are clear at Boltonville; up to 675-680 feet, at least. The delta deposits extend up the valley to within about two miles of South Ryegate, where the highest sandplain is about 690 to 700 feet. Beyond this and at South Ryegate the valley deposits are all glacial, although some kame gravels might be mistaken for delta. The head of the marine filling is between South Ryegate and Boltonville, at about the theoretic altitude, and remnants of the deposits occur all the way to the Connecticut River. The Wells River Valley deserves more careful study.

Barnet

The railroad station is taken as 464 feet; and the theoretic plane is 715 feet.

At Barnet the critical features are related to the Stevens Brook, flowing in from the west. The upper part of Barnet village is on the inferior plains of the valley, at about 585 feet. The terraces rise westward, up the valley, in succession for three miles, to the three-corners near the Barnet Center Church. The summit of the delta filling here is somewhere about 735-740 feet, which represents some aggradation of the valley deposits.

Connecticut Valley above Barnet

The Connecticut Valley has been briefly examined, through the courtesy of Mr. Milo Gibson, as far as Upper Waterford.

The terraced plains so prominent below Barnet are continued above, but rapidly decrease in volume or mass. And as the plains are not so high above the river the terracing is less conspicuous. Above the mouth of the Passumpsic River the highest standing-water features are 715 feet or over. Passing up the valley, by the road on the north side of the river, the evidences of the estuary waters rise steadily. At Upper Waterford the summit is a wide and handsome plain, with corresponding plain on the New Hampshire side of the river, at about 725-730 feet. This plain is about 50 feet above the toll-bridge and about 75 feet above the Connecticut at low water.

In this district, through Lower Waterford and Upper Waterford, the demarkation between the standing-water or estuary deposits and the glacial deposits (till and kame) on the hillsides is very clear.

The writer has not explored the Connecticut Valley above Upper Waterford; but some data are available in the description by Warren Upham (paper 5, pages 23-25). His philosophy recognized only river work, without marine submergence or change in land level. But in the study of the upper valley and the interpretation of the features the tilted uplift of the region must be taken into the account. From Northfield, Mass., to Wells River the rate of uplift along the baseline used in the diagram, figure 2, is 2.8 feet per mile. From Wells River to the isobase of Upper Waterford the slant is 2.6 feet per mile. The rate of uplift from Barnet to South Lunenburg along the course of the river will be somewhat less than the latter figure. The total amount of uplift is shown by the diagram.

It is desirable that careful study be made of the upper valley in order to learn the true history, and the following suggestions may be helpful.

At the time the ice sheet was disappearing from the headwaters of the Connecticut Valley it is certain that the flooded river had a very heavy load of detritus; and that load must have been dropped either at the head of the estuary in the sea-level waters, or in a capacious lake above the estuary. It is possible that the bouldery glacial drift was piled so deeply in the narrow valley above Upper Waterford that it served as a dam to the river, and held a lake from South Lunenburg to above Lancaster, as Upham suggests. In this case the abundant detritus in the grasp of the early river was dropped in the Lancaster morainal lake; and formed the broad plains which now have, according to Upham's maps, plates 1 and 2, an up grade of about 3 feet per mile. And further, in such case the clarified river did not have detritus to build any heavy delta in the estuary.

An alternative suggestion is that the bouldery stuff in the narrow valley below South Lunenburg and the plains above is the much aggraded marine delta of the river. The marine plane at South Lunenburg has altitude, according to the diagram, of about 750 feet, which is 90 feet beneath the valley filling according to Upham's figures on figure 2.

PASSUMPSIC VALLEY

This capacious valley, with large drainage area and numerous tributary streams, holds very heavy detrital deposits. In earlier work and in the previous paper (11) the elevated plains were supposed to represent the northward extension of the Connecticut estuary, although excessive heights were noted at St. Johnsbury. The theoretic marine plane at St. Johnsbury is about 730 feet; and at Lyndonville 740 feet. But very clear effects of standing water occur up to 755 feet northwest of St. Johnsbury, in the valley of Sleepers River; and heavy gravel plains at over 825 feet about Lyndonville. Such excessive heights above the marine level cannot be explained by the upbuilding or aggradation of delta filling. There seems no escape from the conclusion that the Passumpsic Valley waters were independent of the sea-level waters in the Connecticut Valley. But the southward direction of the valley, and the massive character of the sandplains rule out any conception of a temporary ice blockade in the southern part of the valley by any ice lobe. This valley is much more capacious than the Connecticut Valley on the same parallel, and lies more nearly in the direction of the glacier flow. Moreover, a barrier of moraine drift would scarcely endure sufficient time to permit the formation of the series of broad sandplains. A rock barrier in the path of the river would explain the features. Mr. J. M. Perham, a civil engineer at St Johnsbury drew attention to the rock pass below Inwood, at the mouth of the Passumpsic River. Examination of this channel shows that it is certainly post-Glacial. It was not the path of the river during the millions of years previous to the ice age.

If the rock barrier in the channel below Inwood held the Passumpsic waters up to the level of the high plains at Lyndonville it has suffered a surprising amount of erosion. More likely the dam was partly morainal drift. Until we have topographic maps of the region it is not practicable to locate the pre-Glacial valley of the river on this parallel, although it may be done.

It seems necessary to postulate a land-locked lake in the Passumpsic Valley, contemporaneous with the marine estuary in the Connecticut Valley. In this view the lake may be described as follows:

LAKE PASSUMPSIC

The conspicuous plains of clay and sand, with terracing, in the Passumpsic Valley and its tributaries were probably laid down in lake waters, and not in waters confluent with the sea, like the waters in the Connecticut Valley. The mouth of the Passumpsic River, about one half mile south of Inwood Station, is in a rock cut, with cascades. The rock is the schistose or slaty rock prevailing in the district. The bottom of the irregular channel is only the width of the cascading stream. The walls of the pass are flaring and rise a few hundred feet. The river channel is certainly not the path of the river before glacial time, and its life is to be measured only in tens of thousands of years. But the broad valley above, or north of the narrow pass, represents millions of years of pre-Glacial time.

When the ice sheet, in its melting, exposed this district the pre-Glacial valley of the old representative of the present Passumpsic River was blocked by glacial drift. The site of the old outlet is not known, and it is desirable that this be found. The waters in the Passumpsic and its tributary valleys stood at first at the level of the initial overflow at the Inwood pass. The highest water inscriptions in the valley will determine the height of the Inwood barrier, which might have been partly morainal drift. This impounded water may be called Lake Passumpsic. It was not a glacial lake, like so many water bodies held up by the glacier front, especially in valleys sloping toward the waning ice sheet. It was a true land-locked lake; but to whatever extent the barrier was drift it might be regarded as a morainal lake.

As the Inwood outlet was lowered by the river erosion the level of Lake Passumpsic fell accordingly. Into the lake waters the land wash and tributary streams swept clay and sand, which, with wave action, built the plains. The conspicuous benches and terraces represent the lowering of the lake surface due to down-cutting of the Inwood outlet. The terraces in the Connecticut Valley, it should be remembered, were produced by the rise of the land out of sea-level waters. The deepening of the Inwood outlet could progress only as the lake waters stood higher than the waters in the Connecticut estuary. Consequently the Passumpsic Lake waters were always somewhat higher than the estuary waters, and the latter, therefore, have no representation in the Passumpsic Valley.

Fine examples of the higher plains are seen at Lyndonville, up to at least 825 feet. This would imply that the Inwood barrier was nearly that height, for the gradient of the summit lake plane should be only the land tilt, about 2.5 feet per mile in this region.

Good plains and benches occur a short distance above St. Johnsbury, along the Sleepers River, on the Fairview and Wright farms. The extensive plain which carries Main Street in St. Johnsbury has altitude averaging about 695 feet. Boynton Hill at the north end of Main Street shows the work of standing water about the summit, at 735 to 740 feet. If this interpretation of the history is correct water records should be found about St. Johnsbury from over 800 feet down to near 504 feet, the elevation of Inwood station.

A large part of the plains is massive clay, the finer detritus that was floated out and settled in the deeper and quiet water. With the lowering of the water surface the clays were usually covered with sand and gravel swept in by the stronger currents. In manner of formation, in form and composition the lake deposits are identical with the estuarine deposits of the Connecticut Valley.

It is admitted that some element in the Pleistocene history of the Passumpsic and upper Connecticut valleys may be undiscovered, which may give a different explanation. In this subject the scientific students of the region have a fascinating problem.

A REPORT OF THE GEOLOGICAL WORK WITHIN THE ROCHESTER, VERMONT, QUADRANGLE

W. G. FOYE
WESLEYAN UNIVERSITY

The publication of the topographical map of the region about Rochester, Vermont, made possible a further study of the structure of the Green Mountains. The writer devoted the month of July, 1917, to this study and the accompanying diagram (Fig. 2) shows the parts of the area covered. The crest of the range of mountains, lying along the western border of the area, was followed from the north to the south and the rocks outcropping outside the quadrangle to the west along the boundaries of the Champlain valley were investigated that their relations with the rocks within the area proper might be understood.

LOCATION

The Rochester quadrangle lies in the heart of the Green Mountains, midway between the Champlain and Connecticut valleys, and about a third of the way from Rutland to Burlington. The meridians of 72° 45′ and 73° west longitude bound it on the east and west respectively, and the parallels of 44° and 43° 45′ bound it on the north and south.

The quadrangle includes portions of four counties, Addison, Orange, Rutland and Windsor. Hancock is the only township which lies entirely within its boundaries, but Ripton, Granville, Braintree, Goshen, Rochester, Bethel, Chittenden, Pittsfield, and Stockbridge project to a greater or less extent into the area.

A large forest preserve, donated to the United States government and to Middlebury College, by the late Joseph Battell, occupies the greater portion of the northwestern corner of the quadrangle.

AREA AND EXTENT

The quadrangle is 12½ miles wide from east to west and 17¼ miles long from north to south. Its area is, therefore, approximately 216 square miles.

POPULATION

A glance at the Rochester map shows that, estimating generously, less than a fourth of the district is populated. The precipitous hills do not lend themselves to agriculture and the woodsman alone plies his trade in the wilderness. Along the fertile valleys of the White and Tweed rivers several beautiful villages have developed. Pittsfield, on the Tweed, has a population of 402 people and is a prosperous farming and lumbering community. Stockbridge, with like industries, is situated on the White river and has a population of 737. Rochester, the largest of the towns, has built up a considerable talc industry and 1500 people live within its limits. Hancock, a delightfully secluded village nestling among the hills, has a population of 287, largely devoted to lumbering and allied industries. Granville, with its 464 inhabitants, has a small talc industry beside its lumbering and farming. A small summer colony centers about Bread Loaf Inn in the northwestern portion of the area and a

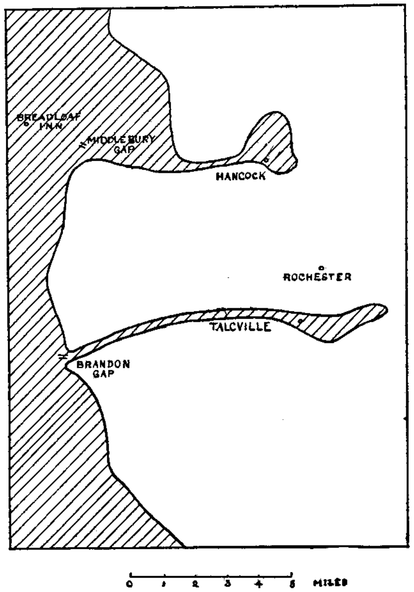


FIG. 3
SKETCH OF ROCHESTER AREA

prosperous farming community is found at Goshen Four Corners near its western boundary.

The total population of the area is approximately 3600, representing a density of 17 or 18 to the square mile.

DRAINAGE

Figure 4 shows by lines the courses of the mountain ridges throughout the area and their elevations. It also represents the drainage basins within the district. It will be seen that the divides along the western side of the quadrangle limit the waters draining westward to three small basins. The two northern basins are drained by branches of the Middlebury river, which flows into Otter creek. Other small branches of Otter creek, Sucker brook, Mill river and Sugar Hollow brook drain the southern basin. Otter creek ultimately empties its waters into Lake Champlain.

The great central portion of the area is drained by the White river and its branches. The water from the three main basins is carried away by the West Branch of the Tweed river, the West Branch of the White river and by Hancock Branch of the White river, in the order named, from south to north.

Minor basins, with steep slopes, lie to the west of the eastern range of hills and are drained by numerous short rivulets. The

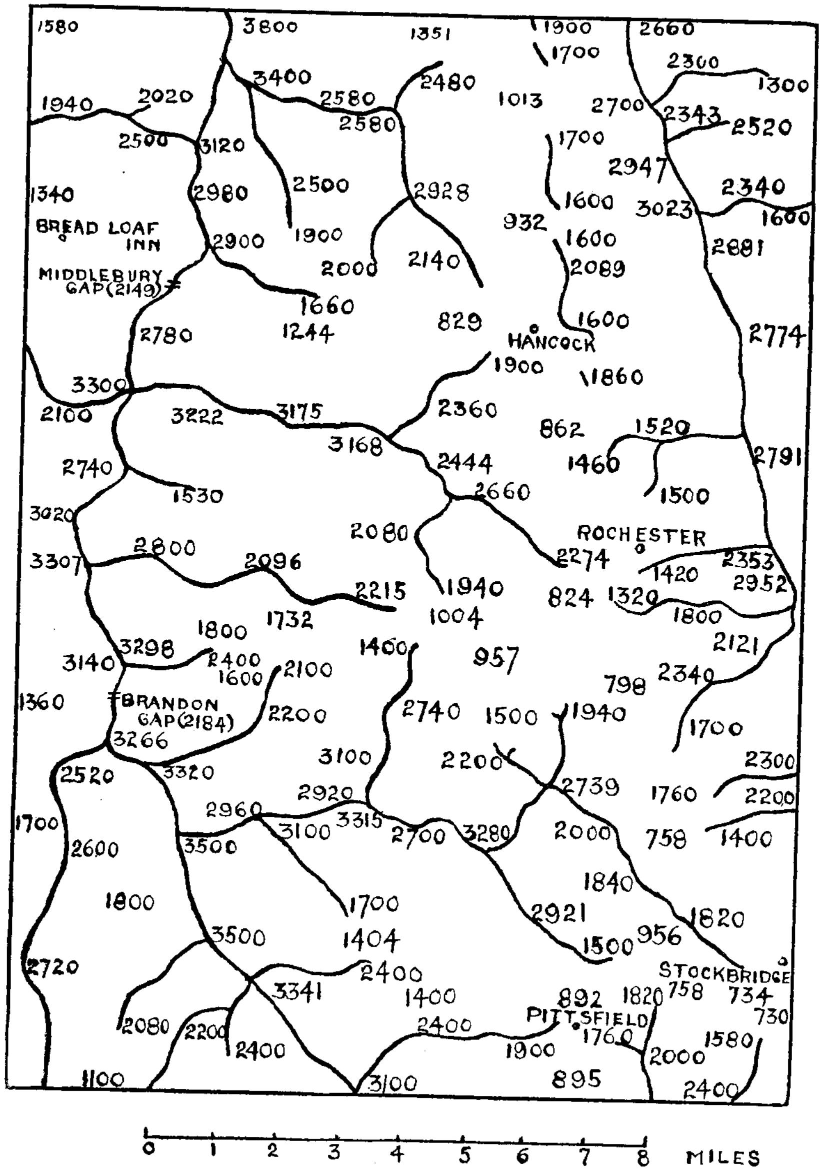


FIG. 4
ELEVATIONS OF SUMMITS ALONG SECOND AND THIRD RANGES

basins to the east of this range are drained into other branches of the White river, which unites all their waters and pours them at last into the Connecticut river.

No large lakes exist within the quadrangle. A very small rock basin, or tarn, rests in a cirque-like depression a half mile south of Middlebury gap. The depression was probably formed by a local glacier, which existed for some time after the disappearance of the continental icesheet from this region.

A second lake occupies a solution basin in limestone northwest of Mount Nickwaket on the southwestern border of the quadrangle.

TOPOGRAPHY

The highest point within the area lies along the crest leading to Bread Loaf mountain, which is situated just outside the northwestern boundary of the district. It has an elevation of 3800 feet. The lowest point is found at the southeastern border, south of Stockbridge. Its altitude is 730 feet, making the total relief of the quadrangle 3070 feet.

Two main ranges, of which the western is the higher, run north and south through the Rochester quadrangle. No rivers cut across either of the ranges. It has been customary to call the quartzite ridge, facing the Champlain valley and lying within the Middlebury quadrangle to the west, the "first range." The western range of the Rochester quadrangle, formed in part by Bread Loaf and Goshen mountains, then becomes the "second range," and Braintree mountain, along the eastern boundary, the "third range." It is interesting to note that the rivers, running from Braintree mountain to the west, drain out through gorges in a quartzite ridge into the White River, just as other rivers to the west of Middlebury gap drain out across an elevated plateau through gorges in the quartzite ridge, known as the "first range," into Otter creek.

Figure 4 gives the elevations of the summits along the second and third ranges. They vary in altitude along the second range from 2740 feet to 3800 feet and along the third range from 2640 to 3023 feet. Numerous east and west spurs branch off from the main ranges and include some of the highest peaks within the area. Thus, Monastery mountain (3222 feet) forms a portion of a ridge east of Worth mountain along the second range and Round mountain (3315 feet) forms a part of an extended east-west spur northwest of Pittsfield.

The mature dissection of the region is well illustrated by Figure 4. The numerous branches of the main rivers have isolated many small pocket-basins enclosed by spur-ridges.

Figure 5 presents a longitudinal profile along the second range. Three marked depressions, Middlebury gap (2149 feet), Brandon gap (2184 feet), and Wetmore gap (2650 feet), are prominent in the profile. They occur at rather regular intervals along the crest and their positions are probably determined by

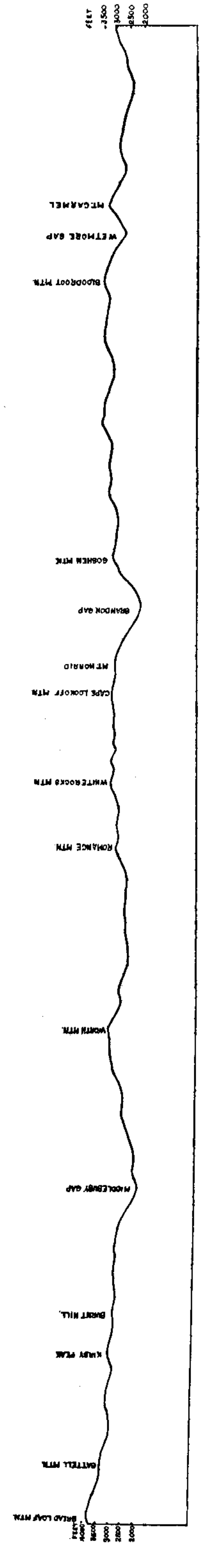


FIG. 5
PROFILE ALONG THE RANGE

the process of river spacing announced many years ago by Professor Shaler.

The irregularity of the range crest shows that all remnants of peneplain levels, which may have existed over this area in the past, have now been destroyed and long erosion has produced an insequent mountain profile. Plate V may be contrasted with Figure 5, since it shows a transverse section of the area. It also emphasizes the fact that no remnants of peneplains may be distinguished across the summit peaks, though the elevated plateau, sloping westward through Ripton and underlain by quartzite and conglomerate, probably represents a stage of erosion very different from the summits of Kirby peak and Gillespie mountain. The Ripton plateau may represent a portion of a second cycle erosion surface of the same age as the Champlain valley, which lies at a lower level because underlain by soluble limestones. The lower altitude of the Champlain valley is due in part, however, to a normal fault running along the face of the first range of quartzite.

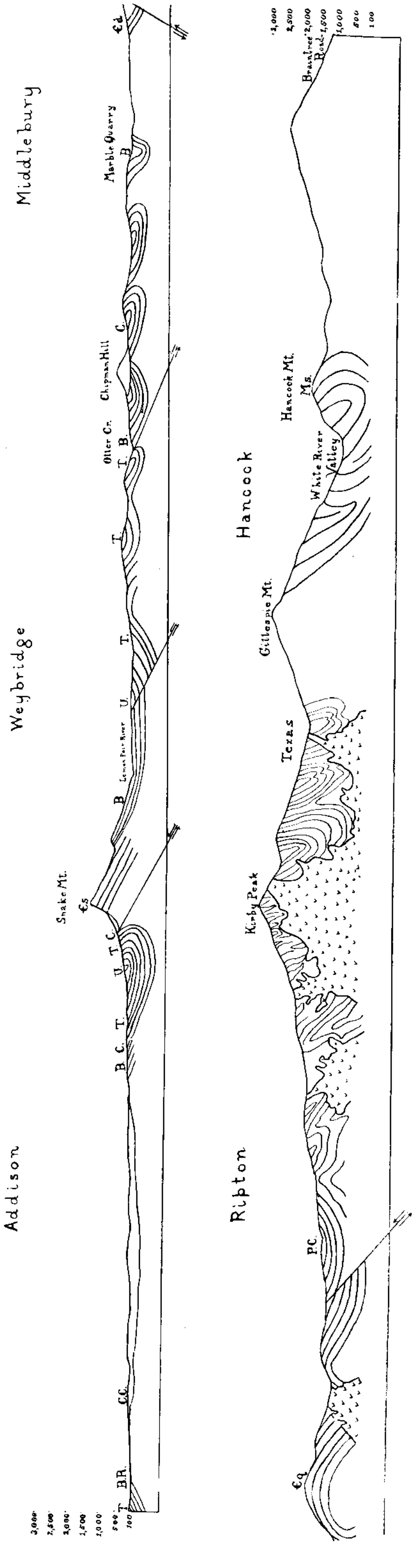
White river and its branches have had much greater erosive power in the remote past than at present and the deep valleys carved out of the hills at that time have since been filled by river alluvium. The inability of the rivers to carry their load has caused them to meander slightly over narrow but flat flood-plains. In general the flood-plains extend up the valleys to altitudes of 1200 to 1300 feet. Occasionally a single terrace has been formed, but the multiplicity of terraces shown by the branches of the Connecticut river farther south is lacking. Above the region of flood-plains the rivers run swiftly over tumbled masses of boulders, but seldom do they expose the country rock.

A glance at the Green Mountain Trail, along the course of the second range, shows that it seldom follows the summit. Instead it runs along the base of a slope which rises abruptly to the crest of the range. This slope is covered by a creeping mass of angular boulders very hard to traverse. It is believed that this slope, so out of accord with the lower slopes of the mountains, is a remnant of the bergschrund action of local glaciers long since melted away.

Unlike the White Mountains to the east, the summits of the ridges throughout this quadrangle practically never are barren of vegetation. Occasionally the fall of a wind-blown tree exposes bed-rock beneath, but in this way alone can the geologist hope to find the evidence he needs to unravel the complex structure of the hills.

GEOLOGY OF THE QUADRANGLE

The month which the writer was able to devote to the study of the Rochester quadrangle only enabled him to distinguish a few of the problems created by the great overthrusting movements which formed the Green mountains. He cannot hope to



Scale—3 inches = 7 miles.

PLATE V

CROSS SECTION FROM LAKE CHAMPLAIN THROUGH SNAKE MOUNTAIN TO BRAINTREE, VERMONT

LEGEND

Ms = Mendon Series
PC = Proterozoic Conglomerate
Cq = Lower Cambrian Quartzite
Cs = Cambrian Red Sandstone
Cd = Cambrian Dolomite
B = Beekmantown
C = Chazy
BR = Black River
T = Trenton
U = Utica
CC = Champlain Clays

do more than suggest solutions of these problems and awaits the results of further field work for confirmation or disproof of his theories.

The work already done by C. L. Whittle* in the Rutland quadrangle, just south of the Rochester area, proved a key which unlocked the mysteries of many tangled relations. Whittle discovered in that area two series of rocks, the Mount Holly series of early Algonkian age and the Mendon series of later Algonkian age, of which the latter alone is important for further consideration in this paper.

The relations of the Mendon series are best studied, as its name implies, in the town of Mendon, 8 or 10 miles south of the southern border of the Rochester quadrangle. The members of the series, as stated in Whittle's paper, are as follows:

4 Mica schist—800 feet—contains secondary quartz lenses with some secondary feldspar.

3 Micaceous quartzite—500 feet as exposed in Mount Nickwaket—pebbles of feldspar and quartz at its base by which it is easily identified—strike, west of north, and dip 80° east or overturned to the west—changes on strike to muscovite schist.

2 Pebbly crystalline limestone—50 feet, but on Mount Nickwaket 500 feet are exposed—in certain folds this layer becomes a granular mica gneiss.

1. Green muscovite schist—completes a total thickness of approximately 1300 feet for the series—grades into a flinty quartzite and metamorphosed conglomerate containing pebbles of blue vitreous quartz, gneiss and schist.

In the portions of the Rochester quadrangle visited, rocks similar to those found in the Mendon series are most abundant. It remains to be demonstrated that they form a part of the Mendon series, for very similar rocks occur in the Lower Cambrian series, outcropping in the first range and in the Champlain valley to the west.

That the various problems may be approached coherently, the several rock types will be discussed in order, beginning with those rocks whose relations are believed to be best understood. The rock types which will be discussed are:—

1. Conglomerates and arkoses,
2. Quartzites,
3. Calcite marbles, dolomites and calcereous schists,
4. Schists, including biotite schists, chlorite schists, calcareous chlorite schists, actinolite schists and tourmalinized schists,
5. Gneisses.

---

*C. L. Whittle, "Occurrence of Algonkian Rocks in Vermont and the Evidence for their Subdivision," Jour. of Geol., vol. 2, (1894), pp. 396–429.

1. CONGLOMERATES AND ARKOSES.

A—GEOGRAPHICAL DISTRIBUTION.

Conglomerates and arkoses have their greatest areal distribution along the western border of the district, west of the second range. The Ripton conglomerate, described by T. N. Dale,* extends into the northwestern portion of the quadrangle and is traceable to a line slightly east of Bread Loaf Inn. Farther east it is so metamorphosed that its conglomeratic appearance is lost. South of Bread Loaf Inn, within the map-area, the rock was not found.

On the southwestern slope of Romance mountain, in Goshen, at an elevation of 2100 feet, approximately, coarse arkoses outcrop for 200 or 300 feet as one ascends the mountain. They are very similar to other arkoses occurring just off the southwestern corner of the map-area and forming the basement of a thick bed of quartzite south of Mount Nickwaket (F 59).† This quartzite is thought to represent member 3 of the Mendon series, as it is overlain by a mica schist and not by the dolomitic limestone which overlies the Lower Cambrian quartzite.

B—PHYSICAL DESCRIPTION.

The Ripton conglomerate (F 3 and F 16) is an iron-grey rock and contains pebbles of blue quartz, phyllite, and gneiss, 8 to 10 cm. in diameter. The pebbles are distorted and elongated to a degree in the plane of schistosity. They are set in a paste composed of quartz and oligoclase, with some orthoclase and biotite. The feldspars are much altered to sericite and rhombohedra of calcite have developed between the grains of the other minerals.

The Romance arkose (F 68) is rusty yellow in color and coarse grained. It shows a schistose structure formed by muscovite fibers bending in irregular lamellae about angular bits of quartz and feldspar, 6 to 15 mm. in diameter. Microscopically, sericite is seen to replace the orthoclase and oligoclase feldspars almost completely. Calcite rhombs through the groundmass are replaced by limonite.

C—GEOLOGICAL RELATIONS

In order to understand the relations of the Ripton conglomerate it was early found that it was necessary to go outside the area represented by the Rochester map. Outcrops of the conglomerate were followed southward from Ripton to Silver Lake, east of Lake Dunmore in Salisbury. At a dam, by an abandoned saw-mill, somewhat over three quarters of a mile south from Ripton, the conglomerate was found to overthrust a chlorite schist. The hill northeast of Silver lake is composed of conglomerate, whereas the valley of the lake and the region about are underlain by quartzite and dolomite.

Dr. T. N. Dale* considers that Silver lake rests in a syncline of Cambrian limestone. The writer's study of the locality led to a different conclusion. Just above the Falls of the Lana, the Cambrian quartzite, overlooking the Champlain valley, was found to rest unconformably on the Mendon dolomite (F 39) and to have an arkosic conglomerate (F 38) at its base. The basal conglomerate of the Cambrian quartzite is so unlike the Ripton conglomerate, exposed less than a mile to the east, that the two cannot be considered of the same age. The Lana conglomerate has small pebbles of potash feldspar and includes dolomitic particles from the rock on which it rests. It is only a few feet in thickness and passes gradually into true Cambrian quartzite.

As far as the writer can discover, the conglomerate at the base of the Cambrian is never as coarse grained or as thick as the Ripton conglomerate. The latter is so like the Mendon type described by Whittle that, in view of the facts already stated, the writer believes that the relations of the rocks near Silver lake may best be explained by an overthrust fault which has carried the underlying Mendon conglomerate up and over the Cambrian quartzite.

The two conceptions of the structure at Silver lake, held by Dr. Dale and the writer, are graphically represented by the two cross-sections of Figure 6. Dale considers the rock succession to be:

3. Cambrian dolomite,
2. Cambrian quartzite,
1. Cambrian (Ripton) conglomerate

The writer interprets it rather:

5. Cambrian dolomite,
4. Cambrian quartzite,
3. Cambrian (Lana) conglomerate,
2. Proterozoic (Mendon) dolomite,
1. Proterozoic (Ripton) conglomerate.

It will be noted that the two upper members of the Mendon series are lacking beneath the basal Cambrian conglomerate, indicating an extended period of erosion between the two series. The Romance arkose is, however, thought to form the basal portion of the quartzite member of the upper Mendon series and its relations will be discussed later.

II QUARTZITE

A—GEOGRAPHICAL DISTRIBUTION

The large masses of quartzite which have persistently withstood erosion and stand as the first range of the Green Mountains,

---

*T. N. Dale, "The Cambrian Conglomerate of Ripton, in Vermont," Am. Jour. Sci., 4th series, vol. 30, (1910), pp. 267–270.

†The numbers refer to rock specimens and their thin-sections preserved in the Vermont State Museum.

*T. N. Dale, "Taconic Physiography." Bull. 272, U. S. G. S, p. 43.

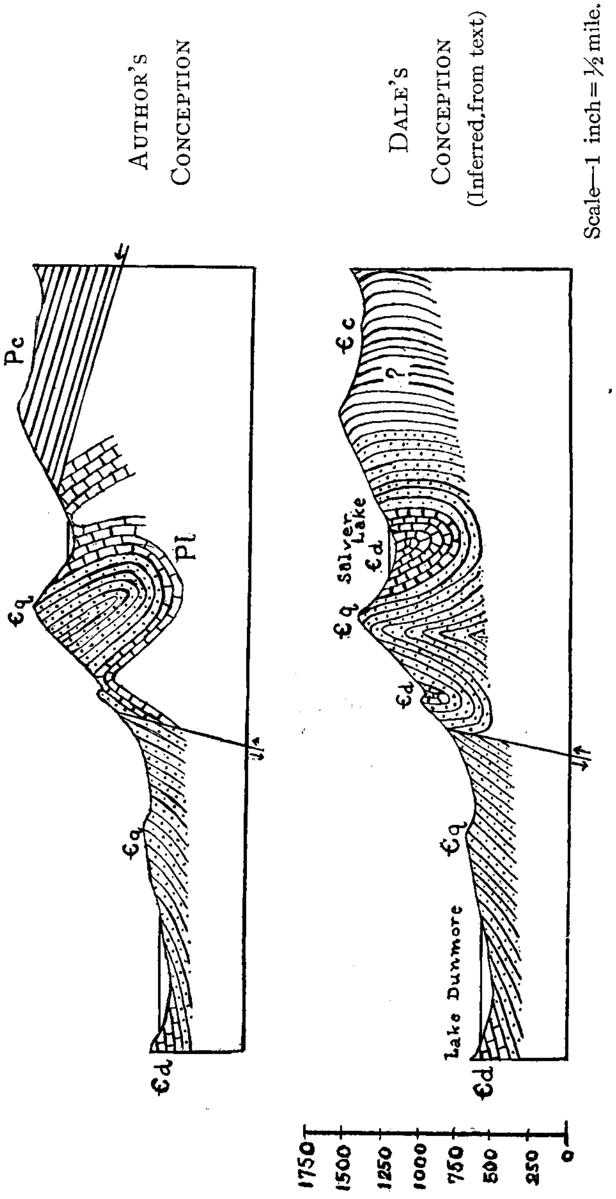


FIG. 6
STRUCTURE AT LAKE DUNMORE, VT.

LEGEND.
Pc—Proterozoic Conglomerate.
Pl—Proterozoic Limestone.
Єc—Cambrian Conglomerate.
Єq—Cambrian Quartzite.
Єd—Cambrain Dolomite.

overlooking the Champlain valley, do not outcrop in the Rochester area. They were studied at Lake Dunmore (F 48), and at Ripton gorge (F 25). Professor Seely first discovered the Cambrian fossil, Nothozoa Vermontana, at the Dunmore locality. The quartzite is overlain by a sandy dolomite.

Preterozoic (Mendon) quartzites overlie a dolomite and have at their base the equivalent of the Romance arkose, west of Holden, in Chittenden, off the southwest corner of the area. They occur in a similar position south of Goshen Four Corners, dipping eastward into the west face of the ridge north of Lookoff mountain. On the eastern side of the White river, quartzites, thought to be of upper Mendon age, form the summit and western foot of Hancock mountain, east of Hancock village (F 22).

Other quartzites, whose relations are less well understood, outcrop in the bed of the West Branch of Texas brook, east of Burnt Hill, Hancock, at an elevation of 1700 feet (F 35), and also along the Mine Railroad in Rochester (end of spur, 1350 feet, F 80).

B—PHYSICAL DESCRIPTION

Specimens of quartzite vary greatly in appearance even when found in close juxtaposition. In the hand specimens the Dunmore varieties show little evidence of individual quartz granules. A yellowish white type is composed practically of pure quartz, but a mottled gray specimen shows under the microscope a fine mosaic of quartz, perthite and calcite, with a minor amount of sericite and rounded grains of zircon. These rocks were studied that they might be compared with, and differentiated from, the Proterozoic quartzites occurring within the Rochester quadrangle.

The quartzite from Hancock mountain consists largely of quartz in distinct granules giving it a friable texture. It contains also flecks of sericite and a very little calcite. The specimens collected were banded and show minute folds. Narrow bluish gray layers, a few millimeters in width, alternate with rusty white layers, 1 or 2 centimeters in width.

The Holden and Goshen varieties are very similar to the lower Cambrian types at Lake Dunmore, but have a coarse arkose at their base, which is frequently metamorphosed to a rusty schist.

The Rochester quartzite, outcropping near the talc mines, is bluish gray in color and contains quartz, muscovite and a little calcite. Again, the variety from Burnt Hill verges into a micaceous schist, being composed of fine, friable layers of quartz, with a small amount of feldspar between discontinuous lamellae of silvery muscovite.

C—GEOLOGIC RELATIONS

Accepting Whittle's columnar section of the Mendon series as correct, the quartzites of the Rochester sheet may be assigned to three horizons. They may form a part of the Lower Cambrian series, which outcrops in the first range, or of the micaceous quartzite overlying the dolomite of upper Mendon age, or they may represent sandy layers in the Ripton conglomerate of lower Mendon age.

As previously stated, the upper Mendon and Lower Cambrian quartzites are very similar. They both have grains of feldspar in their composition, but the basal arkose of the Mendon series is much thicker and coarser than that of Lower Cambrian age. Again calcite and dolomite are more abundant in the Cambrian variety. But most important of all a thick schist series overlies the Mendon quartzite, while the Cambrian quartzite is overlain by a sandy dolomite. The position of the arkose in the series is, therefore, very important and is believed to be determinative even if the series has been overturned. If the order from bottom to top as found is arkose, quartzite, sandy dolomite, the normal Cambrian series is to be inferred. If, on the other hand, the order is schist, quartzite, arkose, dolomite, the inverted Mendon series is present

The rocks south of Goshen Four Corners, dipping eastward into the second range, by these criteria are the inverted Mendon series. The same order is seen farther north on the western flank of Romance mountain. The Holden quartzites are not overturned and show the normal order of the Mendon series. The Hancock series, on the other hand, shows the normal order as one ascends the mountain from the White river valley, passing into the core of the overturned syncline, but the reversed order as the region toward the east is traversed.

The structure about Burnt Hill and the Talc mines, in Rochester, is so confused that nothing definite is known concerning the position of the quartzites of these localities.

III. CALCITE MARBLES, DOLOMITES AND CALCAREOUS SCHISTS

A.—GEOGRAPHICAL DISTRIBUTION

Rocks of calcareous types are not abundant in the Rochester quadrangle. They occur at its southwestern border, forming a large part of Mount Nickwaket (F 58), and outcrop in the bed of Furnace brook where it flows beneath the bridge, south of Steam Mills school. North of Mount Nickwaket they dip to the east beneath mica schists, notably at several outcrops near the intersection of the parallel of 43° 50′ with the road leading south from Goshen Four Corners (F 51, F 52). They thus form an extended north and south band of narrow width in the southwestern portion of the quadrangle.

The great central mountainous area is apparently lacking in these rocks, but they are found again along the course of the White river valley. The writer did not visit these localities, but outcrops have been described by Dr. T. N. Dale,* "3 miles south of Rochester Center, on the west side of the White river valley," northwest of the F. F. Kezer's farmhouse and also in Hancock, near the Rochester line, almost due west of the bridge, crossing the White river at that point. Similar outcrops of "saccharoidal dolomite" were found by Hitchcock† near Middle Granville. Dale infers that the White river outcrops form part of a single band, extending up the river.

B.—PHYSICAL DESCRIPTION

The calcareous types collected were all white or grayish white. They vary in grain from very fine to medium. Some of the marbles show discreet calcite rhombs, 1 to 2 mm. in diameter, in the hand specimen. Friable types, occurring south of Goshen Four Corners, interbedded with schists, frequently are very arenaceous or become silvered by muscovite lamellae (F 51 and F 52). The latter rock carries minute dashes of pyrite along the planes of schistosity.

C.—CHEMICAL DESCRIPTION

The writer did not analyse any of the specimens collected. Hitchcock‡ states that the Hancock limestone has the following composition:

$Ca\,C\,O_3$	90.3%
$Mg\,C\,O_3$	6.9%
$Si\,O_2$	2.8%
Fe_2O_3	trace
	100.0%

He also gives the analysis of the Granville variety:

$Ca\,C\,O_3$	89.741%
$Mg\,C\,O_3$	4.264%
$Fe_2O_3 + Al_2O_3$	2.420%
$Si\,O_2$	4.875%
	101.30%

Though old, the analyses confirm the impression made by the hand specimens that the limestones of the White River valley are generally dolomitic.

D.—GEOLOGICAL RELATIONS

The limestones south of Goshen Four Corners are interbedded with a crenulated and tourmalinized muscovite schist. The beds dip to the eastward beneath a ferruginous quartzite, which is

---

*T. N. Dale, Calcite Marble and Dolomite of Eastern Vermont, Bull. 589, U. S. G. S., pp. 9, 20 and 22.

†C. H. Hitchcock and A. D. Hagar, "Geology of Vermont," vol. 1, (1861), p. 557.

‡Op. cit., p 557

believed to be the equivalent of the lower member, or green muscovite schist, of Whittle's Mendon series. Northwest of Mount Nickwacket, the limestone rest along a fault contact against a quartzite believed to be of Cambrian, but perhaps of upper Mendon, age.

In all known occurrences in the White River Valley the limestone outcrops west of the river and 200 to 750 feet above its bed. It dips eastward and apparently underlies the quartzite forming the crest and foot of Hancock mountain.

Figure 6 is a generalized cross-section presenting the writer's conception of the relations of the Mendon series to other rock series from Hancock mountain and the White river valley on the east, across the second range to the quartzite hills of the first range on the west. The dip of the overthrust fault plane to the west is exaggerated. In the field it varies from 20° to 30°.

IV. SCHISTOSE ROCKS

A—INTRODUCTION.

The greater portion of the Green Mountain ridge is composed of schistose rocks. Gneisses are common, but never so abundant. For the purposes of this report the schistose types may be grouped into five classes.

Class I—Biotite schists,—composed of quartz, oligoclase or albite and sometimes microperthite or orthoclase, sericite and biotite.

Class II—Chlorite schists,—composed of quartz, oligoclase or albite, sericite, chlorite and epidote.

Class III—Calcareous chlorite schists,—composed of oligoclase, sericite, chlorite biotite, epidote and calcite.

Class IV—Actinolite schist,—composed of quartz and actinolite, with small amounts of oligoclase and chlorite.

Class V—Tourmalinized schists,—composed of quartz, albite, muscovite or chlorite, with tourmaline.

B.—BIOTITE SCHISTS

1. GEOGRAPHICAL DISTRIBUTION

The Ripton conglomerate has been traced by successive stages of metamorphism into a schist of the type described under Class I (F 10). Rocks of this variety are common all about Bread Loaf Inn (F 12) and are found west and south of this locality. They (F 17) are overthrust onto a calcareous chlorite schist, south of Ripton, near an abandoned sawmill. The exact locality is a mile to the west of the northwestern boundary of the Rochester area. Other conglomerates, transi-

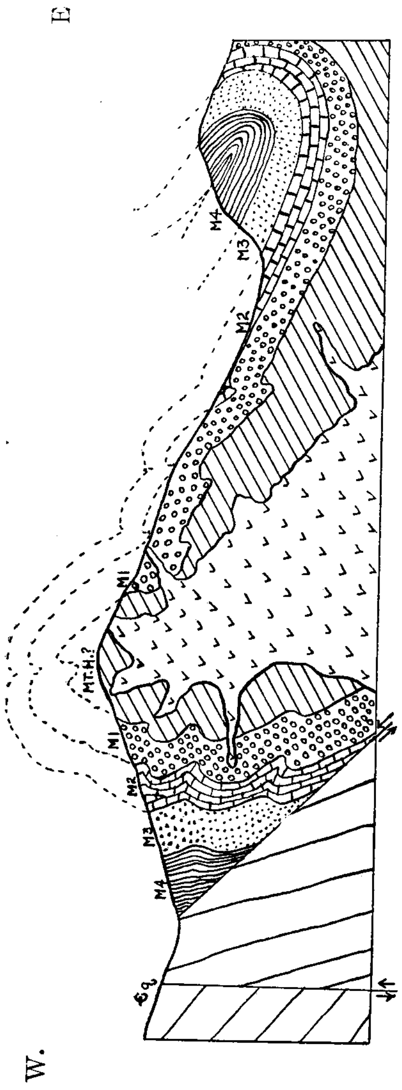


FIG. 7
GENERALIZED CROSS SECTION, ROCHESTER AREA

tional to schists, rest upon lower Cambrian quartzite, along an overthrust fault plane east of Silver lake, 2½ miles west from the west central border (F 40).

Rocks similar in type to the above, but so far removed from outcrops of Ripton conglomerate that their relation cannot be determined, are found at the summit of the road passing through Brandon Gap (F 62 and F 70), and on the southwestern slope of Romance mountain at an elevation of 2400 feet,—thus overlying the arkose at that locality (F 65).

Three other localities at which rocks of this type outcrop are (1), along the ridge north of Lookoff mountain and south of Goshen Four Corners (F 54), (2) in the valley of Furnace brook, just south of Steam Mill school-house (F 57), and (3) on the northwestern slope of Bloodroot mountain, just south of Bee brook (F 72).

2.—PHYSICAL DESCRIPTION

The typical biotite schist as found north of Bread Loaf Inn, where it is transitional into the Ripton conglomerate, is iron-gray to black in color and has "augen" of blue quartz or of quartz and feldspar, about which the schistose paste of biotite, quartz and feldspar flows.

Under the microscope the feldspars are seen to be replaced by sericite. All the minerals, quartz, oligoclase-albite, sericite and biotite are completely oriented in the plane of schistosity and garnets are frequently present.

3 —GEOLOGICAL RELATIONS

The Ripton conglomerate itself was not found in an overthrust position on the Mendon dolomite east of Silver lake. A biotite schist, similar to that traceable into the Ripton conglomerate near Bread Loaf Inn, was, however, so found and although the contact was not seen, it was believed to be a fault-contact, since normally the Cambrian quartzite rests on the Mendon dolomite as seen at Lana Falls, and evidence of overthrusting was found elsewhere along the same line.

The thick conglomerate, acting as a competent layer, has been thrust up and over rocks of much younger age and thereby has been transformed to a biotite schist along the plane of overthrusting. The writer believes that a dip-fault has broken the overthrust near Sucker Brook and erosion along the fault-line has pushed the edge of the overthrust further east, south of the fault plane. The overturned Mendon series forms the western flank of the second range from Romance mountain southward, and does not bridge the valley to the first range as it does near Ripton.

C.—CHLORITE SCHISTS

1.—GEOGRAPHICAL DISTRIBUTION

Chlorite schists are very common near the summit of the second range. They occur at an elevation of 2050 feet west of Middlebury Gap (F 1), and underlie most of the country drained by Texas brook, Hancock (F 20). They outcrop at a lower level and farther from the range crest, east of Brandon Gap, near the village of Robinson. Other types, quite unlike the ones just mentioned, were found on the eastern slope of Hogback mountain in the northern part of Goshen (F 69).

2.—PHYSICAL DESCRIPTION

The chlorite schists from the range crest have a shimmering green or bronze color on the plane of their schistosity, but perpendicular to their schistosity, thin layers of pure white quartz or of mixed quartz and feldspar are prominent between very thin lamellae of chlorite and muscovite. The feldspar is oligoclase or albite and is frequently present as angular bits irregularly oriented in a mat of sericite. Abundant, well formed microcrysts of zoisite are disseminated through the rock.

The schist from Hogback mountain lacks the quartz layers, and the microscope shows a fine mosaic of oligoclase, with a smaller amount of quartz filled with shreds of chlorite and muscovite. Large plates of biotite are scattered through the green groundmass and are very distinct in the hand specimen.

3.—GEOLOGICAL RELATIONS

The relations of the chlorite schists from the crest of the second range are so complicated that nothing can be deduced from the facts now known. They may represent a portion of Whittle's Mount Holly series.

The Hogback schist forms a part of the overturned anticline, west of Romance mountain, and dips beneath the Mendon arkosic quartzite. It resembles the schist of upper Mendon age, which overlies the micaceous quartzite near Holden, Chittenden township (F 61).

D.—CALCAREOUS CHLORITE SCHISTS

1.—GEOGRAPHICAL DISTRIBUTION

Only two calcareous chlorite schists were collected. One of them was found underlying the overthrust Ripton conglomerate, near an abandoned saw-mill, south of Ripton (F 18). The other forms the central core of the overturned syncline of

Hancock mountain (F 21), and outcrops at an elevation of 1000 feet, as one passes up the road leading to Braintree, 2½ miles north of Hancock (cp. Fig. 7).

2.—PHYSICAL DESCRIPTION

The two specimens are quite unlike in appearance. That lying beneath the Ripton conglomerate is dark green in color and is composed of chlorite, forming a matted groundmass through which flakes of biotite, 2 to 3 mm. in diameter, are disseminated. Occasionally, pyrite cubes, 5 to 6 mm. on a side, are also present. Microscopically, bent and distorted laths of oligoclase may be seen altering to sericite and patches of calcite, as well as minute microcrysts of zoisite, indicate that secondary alteration has gone on extensively.

The rock from Hancock shows little evidence of alteration in the hand specimen. It appears to be composed of minute plates of chlorite, with occasional small octahedra of magnetite. The microscope shows, however, that 50 per cent of the rock is calcite. Quartz is lacking, but angular bits of obligoclase are common.

3.—GEOLOGICAL RELATIONS

The chlorite schist from Ripton is so similar to that from Hogback mountain and from Holden that it is believed to belong with them to the upper Mendon series. Thus, the lower Mendon (Ripton) conglomerate is thrust over the upper Mendon schist at this point, whereas farther south it rests on the lower Cambrian quartzite. The calcite in the rock is probably of secondary origin.

The schist from Hancock mountain was definitely determined to overlie quartzite. If it is true that the latter rock is of upper Mendon age, then the calcareous schist lies above it in the same series. It is possible that a ferruginous clay was deposited farther west, near an old shore-line, whereas to the east a marl was laid down in quieter waters. The calcareous schists associated with the talc deposits of eastern Rochester may be of similar age.

E.—ACTINOLITE SCHIST

1.—GEOGRAPHICAL DISTRIBUTION

But one specimen of actinolite schist was collected within the Rochester quadrangle. One other was found east of Goshen village, 1½ miles northwest of Goshen Four Corners. The specimen within the area outcrops just west of the summit of Cape Lookoff mountain at an elevation of 3200 feet.

2.—PHYSICAL DESCRIPTION

The two types are similar in appearance. They are composed of many minute greenish to silver-gray needles, all arranged in parallel position. The microscope reveals a mosaic of quartz grains filling the interspaces between the actinolite fibers. A little muscovite and chlorite and a few small bits of oligoclase, isolated in the quartz grains, are also present.

3.—GEOLOGICAL RELATIONS

Nothing could be determined concerning the age or relations of these rocks.

F.—TOURMALINIZED SCHISTS

1.—GEOGRAPHICAL DISTRIBUTION

Tourmalinized schists outcrop at the falls of Texas brook, in Hancock and are found on the Chittenden road, a half mile south of Goshen Four Corners.

2.—PHYSICAL DESCRIPTION

The variety found at Texas Falls does not differ from the other chlorite schists described under section C from the same locality. The white veins are more abundant and feldspars form a larger percentage of the rock.

The Goshen schist is a beautiful silver-gray rock, striped with fine crenulated layers of chlorite. Minute scales of muscovite rub off very easily and are intermingled with quartz granules.

3.—GEOLOGICAL RELATIONS

The tourmalinization of schists of the ordinary types was probably effected by the intrusion of deep seated granites. Such granites are exposed by erosion in the southern part of Rochester, within the core of the second range.

V. GNEISSES

A.—GEOGRAPHICAL DISTRIBUTION

The gneisses of the area are the least satisfactory of all the rocks to study. Their relations are much confused because of the intrusion of granites and the mashing of the structure of the entire region.

Orthogneisses form a number of domal hills, 1800 or 1900 feet high, north of Bread Loaf Inn, Ripton (F 11). Other gneisses associated with them were produced by the intrusion of granites into the Ripton conglomerate, followed by later dynamic metamorphism (F 29 and F 31).

Gneisses, whose relations are entirely unknown, were collected from the top of Burnt Hill, Hancock (F 2 and F 34), from an outcrop by the roadside, east of Silent Cliff, Middlebury Gap (F 7), from Worth mountain (F 4), and from a locality west of Robinson, on the Brandon-Rochester road (F 90).

B.—PHYSICAL DESCRIPTION

Orthogneisses north of Bread Loaf Inn are pink, fine grained rocks, composed of feldspar and biotite, with a large amount of secondary zoisite. The feldspars are largely albite and microperthite, but a small amount of microcline and orthoclase are present.

Just outside the area, to the northwest, large Carlsbad crystals of orthoclase have developed in the Ripton conglomerate. The introduction by pneumatolitic agents of albite and microperthite gives the feldspar bands a pinkish appearance, which is entirely lacking in schists produced by simple pressure metamorphism.

The typical gneiss from the heart of the second range is grayish white, normally, but it is often tinted greenish drab by the amount of chlorite present. Layers of finely granulated quartz, 2 to 5 mm. in thickness, are separated by paper-thin lamellae of muscovite or chlorite The various minerals are present in approximately the following proportions:

Granular quartz................	60 to 70%
Oligoclase or albite..............	10 to 20%
Muscovite.....................	10 to 15%
Accessory minerals.............	2 to 5 %

Accessory minerals include biotite, chlorite, magnetite and rounded grains of zircon. Occasionally the amount of albite increases till it is in excess over quartz.

C.—GEOLOGICAL RELATIONS

The intrusion of granites into sedimentary rocks has developed most of the gneisses of the Rochester area. A few orthogneisses have been described. Most of these rocks outcrop along the crest of the second range, but some are found in the intervening valleys. Northwest of Bread Loaf mountain, towards Camels Hump, intrusions appear to be more common than within the Rochester area itself.

RELATIONS OF THE ROCHESTER AREA TO THE CHAMPLAIN VALLEY

While studying the geology of the Rochester area, the writer became interested in the relations of the rocks of the area to those of the Champlain valley, toward the west. The cross-section shown in Plate V has been prepared from various sources and represents the main topographic features between Lake Champlain and Braintree, Vermont, along a line stretching from Addison to Snake mountain, thence to Ripton and Braintree. C. H. Hitchcock[*], in the year 1884, sketched a similar section along a line slightly farther north, but since that time a considerable body of data has been gathered and these data have been utilized in the preparation of the generalized section here given. The maps by Professor H. M. Seely, of Middlebury College,[†] and Dr. T. N. Dale[‡] and the cross-section of Snake mountain, by the Reverend Mr. Augustus Wing, have been made use of, but the writer is responsible for most of the inferred structural relations.

The lower Ordovician rocks of the Champlain valley are closely folded in many shallow puckers between more profound overthrusts shown in the figure. West of Snake mountain, the Champlain clays, analogous to the Leda clays farther north, conceal the underlying rocks. East of the mountain, metamorphism has destroyed most of the fossils and the rocks were once included by Ebenezer Emmons in his Taconic system. The exact relations of the Cambrian red sandstone, forming the summit of Snake Mountain, to the white quartzite lying along the face of the first range, is still unknown. Chipman Hill is a prominent mound of terminal moraine, rising immediately back of the town of Middlebury.

Slightly east of the normal fault, which has dropped the Cambrian dolomite and the underlying Cambrian quartzite along the eastern edge of the Champlain valley, the quartzite of the first range is intruded by a coarsely porphyritic granite, occasionally bearing tourmaline. The only contact effect appears to be the production of a graphitic schist near the intrusion.

The writer knows of no direct evidence within the region which differentiates the overthrusting movements whereby the Proterozoic, Ripton conglomerate was shoved over the Cambrian dolomitic limestone, from the later movements of the Taconic revolution, forming the overthrusts of the Champlain valley.

---

[*] C. H. Hitchcock, "Description of a Geological Section crossing New Hampshire and Vermont," Concord, N. H., (1884).

[†] H. M. Seely, "Preliminary Report on the Geology of Addison County," 7th Annual Report, State Geologist of Vermont (1910), plate 48.

[‡] T. N. Dale, "The Commercial Marbles of Vermont," Bull. 521, U. S. G. S., plate I.

Conclusions

The study of the Green mountains of the Rochester map-area has made clear several conclusions in the mind of the writer.

(1) The rocks of the area are mainly the continuation of Whittle's Mendon series, from the Rutland quadrangle northward.

(2) The Ripton conglomerate is not of Cambrian age, but is the basal layer of the Mendon series.

(3) The structure of the second range is a geanticline overturned towards the west. The core of the anticline is formed in part of the Ripton conglomerate metamorphosed to schist and in part of the Mount Holly series.

(4) The Mendon series occurs on the eastern side of the second range as a series of ridges, of which Hancock mountain forms a part, immediately east of the White river valley.

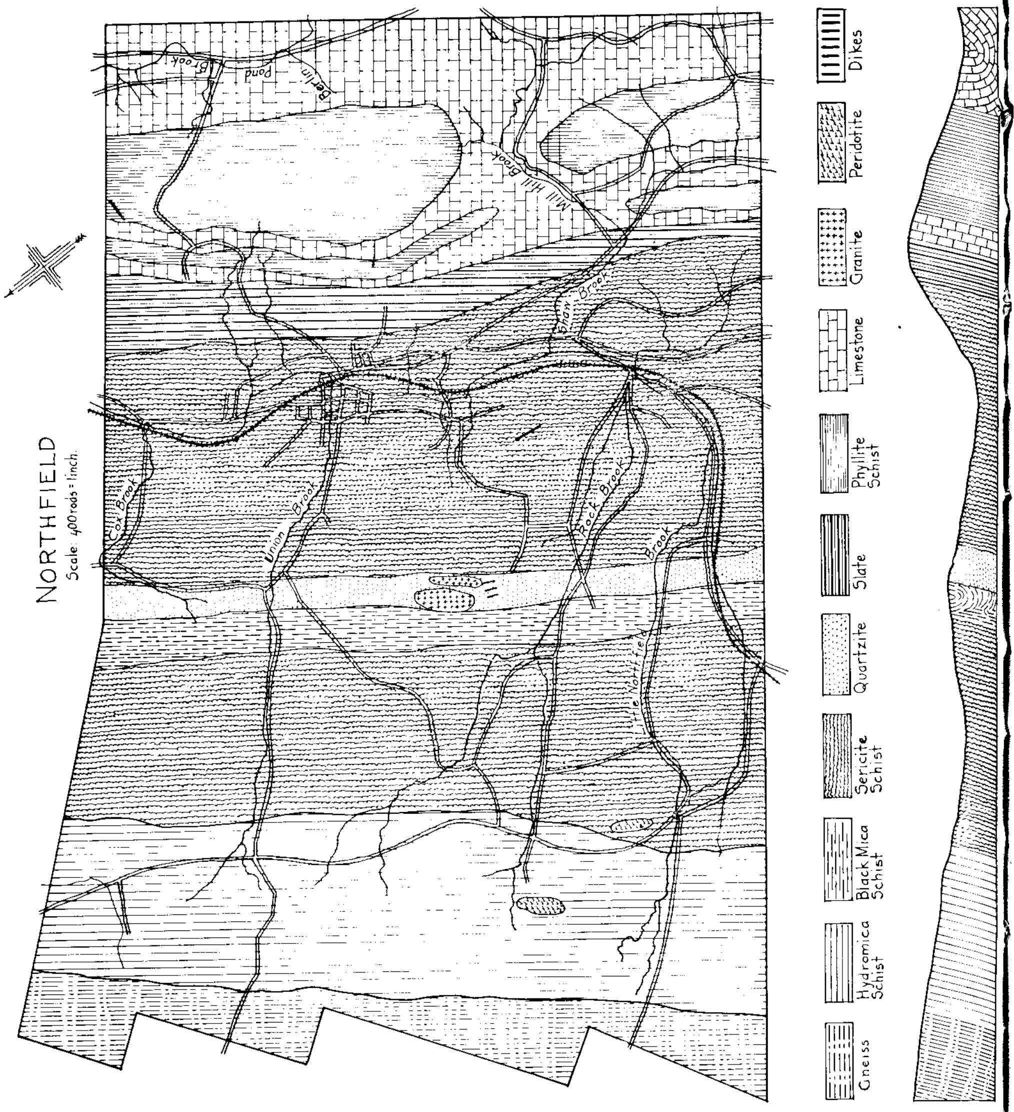
It should be recognized that the statements in this paper are tentative. They rest on data gathered during a short stay in a rugged region, where outcrops are few. Further time must be devoted to the solution of the following problems:

(1) The relation of the red Cambrian sandstone of the Snake mountain (Taconic) overthrust block to the white Cambrian quartzite of the first range.

(2) Criteria for the differentiation of the white quartzites of the Mendon and the Cambrian series.

(3) Criteria for the differentiation of the metamorphosed portions of the Mendon series from the older Mount Holly series.

(4) The time relations of the overthrust and normal faultings within the Green mountains.



Section Scale, 2000′ = 1″

PLATE VI

GEOLOGICAL MAP OF NORTHFIELD

THE TERRANES OF NORTHFIELD, VERMONT

CHARLES H. RICHARDSON AND SAMUEL H. CAMP,
SYRACUSE UNIVERSITY

INTRODUCTION

The present report upon the Terranes of Northfield, Vermont, is of necessity brief. It must be considered only as one of progress in the solution of the intricate geological problems of the eastern half of the State. The first named author traversed this area in reconnaissance work in 1895, 1896, and 1897. In 1905 he visited all of the slate quarries in Northfield. It was not, however, until the summer of 1917 that detailed study could be given to the field. The time available has proven inadequate for a complete study of all of the field relations, the mapping of the area involved without the use of topographic maps, the collection of all possible museum specimens of the different types of rocks and minerals, the preparation of microscopic slides and the desired chemical analyses. Even now problems remain unsolved for want of time to carry out the necessary microscopic study.

In the summer of 1913 the second named author of this paper, a graduate student of Syracuse University in the Department of Mineralogy, was one of the party working out the Geology and Mineralogy of Hardwick and Woodbury, Vermont. As the problems involved in Northfield are much the same as those in the more northern area, the former experience was extremely valuable. Charles K. Cabeen and Rufus I. Rogers, both major students in Mineralogy, were members of the party in the field work for 1917.

The area chosen is practically the geographic center of the State, and is further situated some ten miles south of Montpelier, the capital of the State. It is further situated near the southeastern corner of Washington County.

There are three reasons for the selection of the area. (1) It lies south 40 degrees west from the area covered by the first named author of this report in the former reports of the State Geologist. (2) It falls in the line of the erosional unconformity between the Upper Cambrian and the Ordovician formations represented in the eastern half of the State. (3) The economic possibilities of the slate.

Some work was done in Moretown and Berlin on the north, in Williamstown on the east, in Roxbury on the south, and in

Waitsfield on the west. The total number of rock specimens collected in the eastern half of the State and placed in the State museum at Montpelier is eight hundred and seven. A large number of samples were collected for microscopic slides for petrographic study, and many photographs were taken in the field.

An areal map showing the geographical distribution of the terranes within the area involved accompanies this report as Plate VI. A cross-section is drawn practically thru the center of the township and at right angles to the strike of the different formations. This protracted section also accompanies this report.

The authors recognize herewith their great indebtedness to Dr. Rudolf Ruedemann, State Paleontologist, Albany, N. Y., for his services in the identification of graptolites from both the limestones and the slates, and for his examination of other forms strikingly suggestive of fossils. It is especially gratifying to have found these diagnostic features of age in both the limestones and the slates in every township south from the international boundary, a distance of nearly 100 miles. Our indebtedness to T. Nelson Dale of the United States Geological Survey is also expressed for his work on the slate formations of Northfield.

DRAINAGE

The drainage of Northfield is wholly to the north. It is effected by Dog River and Berlin Pond Brook. The former with its tributaries, Cox Brook, Union Brook, (on all existing maps incorrectly called Jones Brook) Rocky Brook, and Little Northfield Brook to the west, and Shaw Brook to the east, drains the western and central portions of the township thru Berlin to the Winooski River at Montpelier Junction. The Winooski empties into Lake Champlain at Burlington. Berlin Pond Brook drains the extreme north-eastern portion of the township and empties into Berlin Pond in Berlin, from whence it flows into the Winooski River below Benjamin Falls.

Cox Brook rises in Moretown, flows southeasterly thru the southwestern part of Berlin into Northfield and empties into the Dog River at Northfield Falls. Union Brook, Rocky Brook, and Little Northfield Brook, all have their source in the Waitsfield Mountains and empty into the Dog River in the township of Northfield. The first joins Dog River at Northfield village; the second near the Harlow Bridge of the Central Vermont Railroad; the third about one-half mile south of the Harlow Bridge.

Shaw Brook rises in Roxbury to the south, flows in a northerly direction, and is joined at South Northfield by Mill Hill Brook

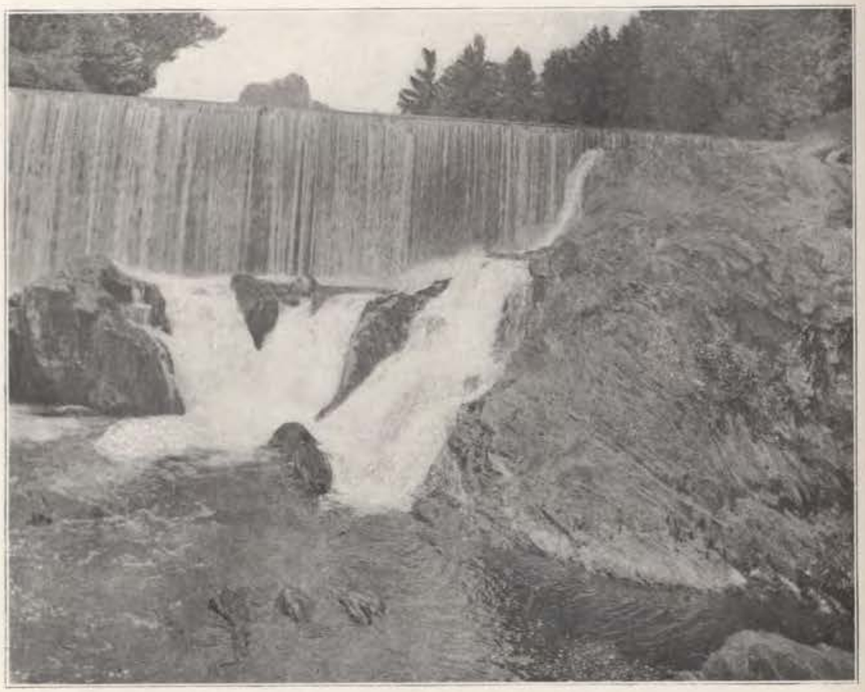


Plate VII
Falls of the Dog River, Northfield Falls

which rises near the Williamstown line. Shaw Brook flows into Dog River about one-half mile north of the Harlow Bridge.

Excellent water powers are produced by many of these streams as is shown at Northfield Falls on the Dog River where the Davis woolen mills are situated. (See Plate VII.)

These streams flow in their old pre-Glacial valleys as is shown in the case of the Dog River tributaries which have cut out deep V-shaped, transverse valleys in the morainal material down to the old, water-worn, pre-Glacial beds. Between Northfield and the Berlin town line the course of the Dog River has shifted somewhat to the west of its old pre-Glacial valley.

The only railroad traversing Northfield is the Central Vermont which runs parallel with the Dog River.

Topography

Northfield lies between the parallels 44 degrees 5 minutes and 44 degrees 12 minutes north latitude, and longitude 72 degrees 35 minutes and 72 degrees 48 minutes west of Greenwich.

The valley of the Dog River in Northfield is broad, U-shaped, and roughly parallel with the three ridges which traverse this area longitudinally. The smaller streams emptying into the Dog River have cut deep V-shaped, transverse valleys thru these ridges.

The sericite schists and the quartzites which compose the lowest portion of the Dog River valley extend from a line about 100 yards east of the river westward up to the first ridge where a belt of black mica schist appears This ridge is about 1200 feet in height. West of this ridge there is an upland valley predominated by sericites and quartzites. From this valley the surface rises to the summit of the Northfield-Waitsfield range of mountains whose crests attain an elevation of approximately 2500 feet.

Just east of the crest of this range, and parallel with it, there is a belt of hydromica schist.

The high ridge to the east of the Dog River valley consists of slates, phyllite schists, and limestones. It may be regarded as the southern extension of Berlin Mountain. This mountain in Berlin is approximately 2400 feet in height. Paine Mountain in Northfield 2350 feet in height, and Turkey Hill is about 2200 feet in height. Shaw Mountain to the south is approximately 2000 feet in height. The limestones predominate in the valley east of this ridge.

Glaciation

The township of Northfield is mantled with morainic material to such an extent that the geologist is seriously hampered in the study of the field relations of the different terranes. This holds especially true along the line of contact between the Cambrian and Ordovician terranes. It renders the actual contact almost impossible to find. A little trenching at South Northfield where the two different outcrops are within 50 feet of each other would reveal the actual contact.

Evidences of glaciation and the general direction of the ice movement are the striations still remaining on the more resistant rocks of the region. The well exposed outcrops of nearly pure white, secondary, vein quartz show striations upon their smoothed and polished surfaces. The resistant phyllites are perhaps the best preservers of this evidence, altho the Cambrian quartzites in the western portion of the township occasionally afford excellent illustrations.

The general trend of the ice is well known to have been in a southeasterly direction, but there were other movements, perhaps somewhat local, in a southwesterly direction. The slates at the top of the Dole-Brill quarry showed striations south 20 degrees east. In the eastern half of the township observations were made showing the direction of the moving ice to be due south. The rounded and polished quartzites on the first ridge to the west of Northfield village showed striations extending south 30 degrees west.

Another evidence of glaciation is the boulder strewn fields, pastures, and wood-lots. Boulders of the brecciated Coventry conglomerate were discovered just north of the Dole-Brill slate quarry. As the type locality for this conglomerate is in Coventry, more than fifty miles to the north, these boulders must have been transported a greater distance than is generally accredited, or else they came from some more southerly extension of the conglomerate now covered by glacial debris. The size and angularity of the boulders suggests the latter theory as probable.

About three miles west of Northfield up Rocky Brook and near the base of Burnt Mountain there are many boulders of augen gneiss. Some of these are ten feet in diameter. The size of the boulders and their angularity suggests transportation for only a short distance. It is, however, supposed that there are no outcrops of augen gneiss in Vermont, but the size of these boulders implies the presence of augen gneiss in place in the eastern foothills of the Green Mountains. If more time had been available a careful study would have been made of the so called bastard granites that form the crest of the Northfield-Waitsfield range of mountains. As these outcrops were said to be in Waitsfield they were not visited.

The presence of many terraces in this area is another evidence of glaciation. This feature is especially noticeable along Cox Brook and Union Brook in the northwestern part of the township. One terrace in the western part of Northfield has an altitude of 1125 feet which would easily connect it with the high terraces found in Berlin and Calais.

The buildings at Norwich University are situated on sand and gravel filling the valley to a considerable depth. Typical cross-bedding due to shifting currents is well illustrated in some of the excavations. The railroad station at Northfield is at an altitude of 739 feet. The Weather Bureau is 848 feet. Jackman Hall is 876 feet above sea level.

Geology

The geology of Northfield is intricate and complex. The terranes consist of a series of highly crumpled, folded and faulted metamorphic rocks, dipping always at a high angle, and cut by intrusive masses of both acidic and basic character. The sedimentaries as well as the intrusives differ widely in age, as well as in their mineral composition. A careful study of their field relations has been absolutely necessary to avoid the introduction of errors in their interpretation. Many microscopic slides have been prepared to aid in this interpretation, and new slides from material collected this summer are in the process of preparation. Even with these aids there is a wide chance for error.

The western part of the area involved the stratigraphy must be determined by field relations, altho slides have been made from each formation. In the central and eastern part of the area covered by this report it has been our good fortune to discover graptolites in both the slates and the limestones. This feature will be discussed under the caption of Paleontology.

Algonkian

In Algonkian time there appears to have been an area of sedimentation to the west of the central meridian of the State. This was followed by the introduction of granitic rocks into the sedimentary beds. These granites are the present gneisses of the Green Mountain range. At the close of the Algonkian there occurred a crustal movement which metamorphosed these earliest sediments into schists and the granites into gneisses. The movement was accompanied by folding and elevation. The earlier mountain system of the State was thus formed. These rocks comprise the major anticline of the Green Mountains which stretches southward from the international boundary on the north to Massachusetts. The Green Mountain gneiss is flanked upon either side by a series of highly metamorphic schists. This gneiss appears in the extreme western portion of Northfield, and from its strike in numerous places where outcrops appeared it stretches the entire length of the township. This area falls along the crest of the Northfield-Waitsfield Mountains, which are either densely wooded or burned over and now covered with a dense growth of underbrush. The so-called bastard granite of this range and the augen gneiss, found in numerous large boulders, belong here. Augen gneiss is known to have resulted from the metamorphism of highly feldspathic sediments. This ridge, from a scientific standpoint, is worthy of careful investigation, which could not be given it in the time at our disposal.

CAMBRIAN

The term Cambrian as here used signifies a group of highly metamorphosed sedimentary rocks which lie between the eastern foothills of the Green Mountains and the erosional unconformity that separates the pre-Ordovician from the Orodvician formations. They consist of black pyritiferous mica schists, hydromica schists, sericite schists, chlorite schists, and quartzites.

In early Paleozoic time a submergence of a large area of Algonkian rocks occurred. From the erosion of these Algonkian land masses sediments were derived and deposited upon the submerged Algonkian terranes. At the close of the Cambrian a crustal movement occurred which metamorphosed these sediments into the various schists already enumerated.

HYDROMICA SCHIST

The hydromica schists lie on the east side of the Northfield-Waitsfield range, and to the east of the outcrops of Green Mountain gneiss. They are fine grained, greenish, micaceous rocks which are more or less associated with chlorite. In some instances the formation appears as a chlorite schist. According to Prof. C. H. Hitchcock, the prevailing mica of the hydromica schists was originally biotite. If the mica was biotite it has in many instances been altered to chlorite. Chlorite schists can result from the crushing and excessive shearing of basic igneous rocks. The hydromica schist is markedly different in its physical characteristics from the sericite schist. This formation has been traced southward all the way from the international boundary to Northfield.

BLACK PYRITIFEROUS MICA SCHIST

The black pyritiferous mica schist that appears so abundantly in Troy, Westfield, Lowell, Middlesex and Moretown appears also in Northfield. Here it predominates on the first ridge west of the Dog River valley.

The typical pyritiferous mica schist carries an abundance of quartz, and a black to greenish black hydrated mica. In this formation there are many crystals of pyrite. In many cases the schist at the surface is pitted by cavities formed by the oxidation of the pyrite, and the subsequent leaching out of the secondary minerals formed during this oxidation. Sometimes the crystals exceed an inch in diameter. Where the large pyrites are absent this schist sometimes becomes splintery.

SERICITE SCHIST

This terrane has been continuous from the international boundary on the north to the south as far as our work has been extended. Thruout this entire distance of nearly 100 miles it flanks everywhere the Ordovician terranes on the west and becomes the easternmost member of the Cambrian group. It is the predominating formation in Northfield. It appears both upon the west of the black mica schist and to the east and west of the quartzites. Its combined breadth is much greater than that of any other single formation. The sericites are interbedded with more or less quartzite, and perhaps much of the material mapped in as other formations of Cambrian age should have been mapped as sericite.

The sericite schists present a light colored appearance on their weathered surface and from a distance may be mistaken for granite. The sericite schist is a fine grained rock containing quartz and silvery muscovite (sericite) as essential minerals and garnets, magnetite and pyrite as secondary constitutents. It is often quite magnetitic. This phase can be seen at Northfield Falls, where fine and perfect octahedrons of magnetite have been obtained. On the western side of the Dog River in Northfield this terrane becomes decidedly talcose. In some instances good talc can be obtained. Near the Fair Grounds the talc predominates and samples collected have been cataloged as talc schist.

Where the muscovite mica (sericite) predominates the terrane is everywhere classified as a sericite schist. Where the quartz grains are in large excess over the mica, as on the Moses King farm in Northfield, the rock is cataloged as a quartzite.

The general strike of the sericite schist is north 40 degrees east but there are many variations. The general dip is at a high angle to the west, but small, well defined synclines are also observed in this formation.

QUARTZITE

The Cambrian quartzite has been a continuous terrane from the international boundary on the north as far southward as our work has been carried. In many sections it has been flanked both upon the east and the west by the sericite schist. It occurs on the higher altitudes of the first ridge west of the main valley and in the valleys where erosion has been carried to its lowest depths in Northfield.

In texture this quartzite is fine grained but it sometimes carries quartz pebbles, of small dimensions. It consists essentially of quartz and silvery muscovite (sericite). In some specimens biotite is present. It frequently carries a small amount of magnetite and pyrite. Garnets have been observed in this formation. The quartzites often carry secondary quartz in their fracture planes.

The general strike of this formation is north 40 degrees east, yet there are some striking variations. In a series of sharply folded anticlines and synclines on the Moses King farm about one mile west of the village of Northfield, the strike varied from north 75 degrees east to north 60 degrees west. The dip varied from 75 degrees east to 75 degrees west. The normal dip of this formation is from 80 to 85 degrees west.

There are no slates of Cambrian age in Northfield altho some of the fine grained sericite schists approach a slate in their fissility and in the more northerly portions of Vermont, as in Troy, they have been locally classified as slates.

ORDOVICIAN

The term Ordovician as here used embraces a group of metamorphic sediments that lie to the east of the Cambrian terranes already described. These two groups are separated from each other by an erosional unconformity. This unconformity has been followed southward from the international boundary as far as our work has been carried, which is a distance of approximately 80 miles.

The Ordovician terranes consist of a basal conglomerate, limestones, marbles, quartzites, phyllite schists and slates.

In Ordovician time there occurred a submergence of a large area of Cambrian rocks and the deposition thereon of sediments resulting from the erosion of the Cambrian land masses, together with calcareous sediments largely of organic origin. At the close of the Ordovician a crustal movement accompanied with elevation and complex folding took place which metamorphosed the Ordovician sediments into limestones, marbles, quartzites, schists and slates.

IRASBURG CONGLOMERATE

The Irasburg conglomerate which lies at the base of the Ordovician was first discovered in the southern part of Irasburg in 1904 and has been followed southward into Roxbury. In Irasburg the pebbles are all pre-Ordovician and the matrix is Ordovician limestone. In Northfield the matrix is Ordovician slate and the pebbles are pre-Ordovician. In some instances the pebbles have been elongated and present a schistose structure. They vary in size from a fraction of an inch to six inches. The conglomerate occurs in the lower part of the slate formation and can be seen in Shaw Brook at South Northfield. It was in this brook near the Vermont Black Slate Company's quarry that the Northfield phase of the conglomerate was discovered. If it does not represent the southern extension of the Irasburg con-

PLATE VIII

WESTERLY DIP IN LIMESTONE—PAINE MOUNTAIN, NORTHFIELD

glomerate then it is its geological equivalent. If the term Northfield was not already pre-occupied I would call this basal conglomerate in Northfield the Northfield conglomerate. Its strike is north 35 degrees east and its dip 80 to 85 degrees west.

WAITS RIVER LIMESTONE

The Waits River limestone does not cover so extensive an area in Northfield as it does in the towns to the northward for the more western location of this township leads to the greater predominance of the sericite schists and Cambrian quartzites. The formation in Northfield includes a series of limestones, quartzose marbles, calcareous quartzites, and interstratified phyllite schists.

The Washington phase of this limestone is a dark gray siliceous variety, some beds of which yield a massive marble susceptible of a high polish. As this marble weathers to a rusty brown on long continued exposure to the atmosphere it is best adapted for decorative interior work. This dark siliceous variety is abundant on the west side of Berlin Mountain, Paine Mountain, Turkey Hill, and in portions of the Mill Hill Brook. It also occurs along the Northfield-Williamstown town lines. In Williamstown there are large areas of this massive marble. It is best cataloged as a marble reserve.

The true Waits River phase is a light gray siliceous banded variety, which in these more westerly townships often becomes shaly, and occurs along the Northfield-Williamstown town lines in the southeastern part of Northfield. The shaly graptolitic limestone of the Berlin Pond Brook and Shaw Brook valleys represents this variety. It occurs also on Paine Mountain and Turkey Hill. It is often interstratified with phyllite schists. This shaly phase of the limestone has predominated in all of the more western townships all the way southward from the Canadian line. The shaly character of this limestone and its high westerly dip is well illustrated by Plate VIII.

The Coventry phase of this limestone is very dark gray and well filled with pyrite. The belt is generally very narrow. It occurs in Northfield to the east of the main slate belt. It is generally intimately associated with interstratified phyllite schists, and often the entire area has to be mapped in as phyllite, because of the predominance of the phyllite.

Where the quartz grains predominate the rock is classified as a calcareous quartzite, which is in no way to be confused with the Cambrian quartzite which is non-calcareous. When the calcite grains predominate the rock is classified as a quartzose marble. Perfect cleavage is often observed in the calcite in these marbles. Slides from the marbles in the western part of Brookfield show this characteristic. The microscopic slides of the calcareous quartzites reveal well rounded quartz grains with small crystals of calcite, the calcite comprising less than 50 per cent of the rock. In the quartzose marbles the calcite crystals with their perfect cleavage is in excess of the quartz grains, ranging from 55 to 75 per cent of the rock mass. In both cases secondary muscovite, biotite, and phlogopite have been observed. Muscovite is by far the most common of the micas present. Small pyrites are frequently observed. Carbon serves as the pigment. This is definitely proven in microscopic slides from Brookfield.

The general strike of these limestones and marbles is north 40 degrees east but there are many local variations. On the west side of Berlin Mountain a group of twenty-five anticlines rising in exposure from four to ten feet in height were encountered within a very small area. A few synclines were also noted. The material is mostly shaly, graptolitic limestone. The strike varies from north 80 degrees east to north 40 degrees west. The pitch of the strike is about 30 degrees north. The complexity of this structure is due to intense folding and transverse faulting.

The beds of limestone on the western side of this terrane are more shaly than those on the eastern portion of the arc covered by this report. To the east where the more massive limestones predominate the area is mapped in as calcareous. To the west where the thin calcareous beds are so intimately interstratified wlth the non-calcareous members the area is mapped in as slate or phyllite, according to the character of the cleavage and the degree of metamorphism.

MEMPHREMAGOG SLATES

The western belt of the Memphremagog slates does not form a continuous terrane from the Canadian line as stated in the Vermont Report of 1861. The belt is broken in Craftsbury and Hardwick to reappear again in Woodbury. It then forms a continuous belt southward thru Northfield into Roxbury. How much farther to the south it is continuous is only a matter of conjecture. It is known to appear in Barnard. The breaks in Craftsbury and Hardwick are probably due to the fact that erosion has been extended below the lower beds of the slate in these two localities.

In Northfield the slates form a continuous belt on the western flank of the ridge just east of Dog River. In the northern part the belt is approximately one mile in width, and narrows somewhat as it approaches the southern part of the township. The slate is closely associated with thin beds of limestone anp phyllite.

The slates vary in color from a bluish gray to a black. They are fissile and can be easily trimmed to any desired size. They are strong enough to be nailed without splitting, and possess

PLATE IX
EASTERLY DIP IN SLATE, NORTHFIELD

the characteristic slate ring. They carry carbon as a pigment. Occasional small crystals of pyrite and magnetite are seen on the sawn edges. Some of these slates do not effervesce in cold dilute hydrochloric acid, but where they are closely associated with the limestones there is some effervescence.

The general strike of this slate belt is north 40 degrees east, but there are many local variations, as there have been in the other formations. The general dip is at a high angle to the west, but dips to the east were recorded in many instances. This easterly dip can be seen in Plate IX. The hammer hangs in a vertical position. In some instances what appears as an easterly dip at the surface may result from ice action during the glacial period. Where this easterly dip is extended down thru the quarry it can not be ascribed to ice action. An anticlinal structure is pronounced in some of these abandoned quarries. This characteristic has also been photographed.

In the center of an abandoned quarry on the western slope of Paine Mountain the dip of the cleavage in the slate is 85 degrees east and quickly changes to 85 degrees west. This anticlinal structure was found in several of the quarries. At the Dole-Brill quarry, at South Northfield, a small quartz vein shows a displacement of nearly two feet due to transverse faulting. Some twenty rods to the west of the Vermont Black Slate Company's quarry the Cambrian formations appear as lying over and above the Ordovician slate with an overthrust to the east. Such an overthrust is recorded by B. K. Emerson in Massachusetts. Several samples of the Cambrian material in Northfield were collected this summer, 1918, for microscopic slides which may prove the material to be highly altered, basic, igneous rocks that have brought up with them inclusions of Cambrian material. Large inclusions have already been catalogued in the granites of Woodbury and also in the Boutwell, Milne and Varnum Company's quarry at Graniteville, Barre, Vt.

PHYLLITE SCHISTS

In Northfield the phyllite schists comprise two lens-shaped bodies roughly parallel with the strike of the limestones and slates. The two lenses are cut by Mill Hill Brook. The phyllite schists are more resistant to erosion than the limestones and marbles and therefore form the more prominent ridges in the eastern part of Northfield.

The phyllite schists have a fine grained texture which at times becomes coarser near contact with intrusives. The schist consists of quartz, muscovite and biotite. It is often characterized by minute plates of ottrelite set transverse to the planes of foliation. These plates are the largest and most abundant where the metamorphism has been the greatest. Crystals of magnetite, pyrite and garnet are not uncommon. Magnetite frequently forms the nucleus of the ottrelite spangle. Epidote and secondary hornblende are common near the contact of these schists with intrusives. In many cases the phyllites are highly graphitic.

The graphitic and garnetiferous phase of the phyllite schist occurs interbedded with a shaly graptolotic limestone on the slopes and crest of the first hill south of Paine Mountain. The strike is north 30 degrees east and the dip 75 degrees west. Another small area occurs along the Williamstown west town line. It is characterized by well defined and large crystals of pyrite. The strike here is north 40 degrees east and the dip 80 degrees east. This variation in dip suggests an anticlinal structure in the eastern part of Northfield or else an overturned structure. The extreme eastern portion appears synclinal.

The phyllite schists in their northern extension in Newport and Coventry form a part of the Memphremagog slates. South of Coventry where the metamorphism has been greater they appear as schists, altho in some localities they still possess the slaty ring and cleavage.

Acid Intrusives

GRANITES

The uplift that occurred at the close of the Ordovician caused sedimentation to cease in northeastern Vermont and atmospheric erosion to begin. At the close of the Devonian another crustal movement occurred which was accompanied by the intrusion into the sericite schists, Cambrian quartzites, phyllite schists, quartzose marbles, limestones and slates, granitic material in a state of fusion with superheated water. These intrusions induced further changes in many of the sedimentaries and in places injected them with dikes of pegmatite and aplite. Acicular crystals of secondary hornblende appear in the phyllites, limestones and marbles as products of contact metamorphism. Epidote is occasionally found in the Ordovician limestones and marbles, and zoicite in the Cambrian quartzites and sericite schists.

Soon after the crystallization of the granites they were traversed by dikes of pegmatite and aplite. The granites of the main Vermont and Quebec belt are Devonian. Altho that belt lies east of the area covered by this report there is no reason why the granites in Northfield should not be classified also as Devonian.

The granites in Northfield occupy a relatively small area. An abandoned granite quarry exists upon the Moses King farm about two miles west of Northfield village. At the quarry the outcrop suggests a stock, but in an adjacent pasture where no quarrying has been executed the outcrop appears to be in the form of a dike.

PLATE X

ORBICULAR GRANITE, MOSES KING FARM, NORTHFIELD

The Northfield granite is a light gray biotite granite with medium texture. It consists essentially of clear quartz, orthoclase somewhat kaolinized on the exterior, some oligoclase and biotite. The accessory minerals are apatite and zircon. The secondary minerals are kaolin and calcite.

This quarry presents the typical sheet structure, the sheets dipping 15 degrees east. The granite is orbicular. The orbules are not as abundantly scattered thru the granite mass as they are at Craftsbury, Vermont, where the orbicular granite was first discovered. The concentric arrangement of the biotite orbules is indicative of the slow segregation of the more basic portion of the magma from the molten mass. The orbules are largely in the flowage zone, or outer portions of the granite mass. These discoid aggregations vary in size from a fraction of an inch to about two inches in their longer diameter. Their presence renders the granite less valuable for monumental and decorative purposes, while it has been used for underpinnings, foundation work, culverts, and bridge guards. This granite was used in the construction of the Harlow bridge on the Central Vermont railroad. (Plate X.)

A few rods north of this abandoned quarry there is a dike-like mass of granite which has a strike of north 35 degrees east. It is a biotite granite, but no orbules were found in the flowage zone. If it is connected with the granite stock of the abandoned quarry the connection is covered by glacial till and probably with considerable depth of Cambrian quartzite.

On the Samuel Andrews farm, a mile or more to the north-east of the Moses King farm, there is an outcrop of granite several hundred feet in width. A few blocks have been quarried and used locally. It is a biotite granite. A part of the granite is of very fine grain with good rift. There are probably other outcrops of granite between these two farms in the wooded area. If such outcrops do not appear at the surface they may not be far below the surface. The intense crumpling of the Cambrian quartzite which surrounds these granite masses shows more disturbance of these sedimentaries than is otherwise common in the area.

APLITE DIKES

Several small aplite dikes are encountered in the vicinity of the Moses King farm. The strike of these dikes is nearly north and south. An aplite dike was found on the right hand side of the road leading down to the Harlow bridge on the Central Vermont railroad. It was four feet in width and had a strike of north five degrees east. These dikes consist essentially of quartz, orthoclase, and a little muscovite.

In the extreme northeastern part of the township of Northfield and on the western side of Berlin Mountain in Berlin there is a dike of granitic material ranging in width from 3 to 4 feet, and in length it is approximately one mile. The continuity of strike indicates that these numerous outcrops belong to the same dike, even tho in sections it is covered by glacial drift. The strike of this dike is north 30 degrees east, while the strike of the limestones cut by the dike is north 40 degrees east. Two smaller dikes were encountered in the same locality. (See Plate XI.)

About one mile northeast of the village of Northfield there are three pegmatite dikes with a strike of north 25 degrees east. The strike of the sericite schist which these dikes cut is north 40 degrees east. The first dike is 4 feet in width, the second 2 feet in width, and the third is 30 feet in width. They occur in the valley of Calvary Brook.

Basic Intrusives

DIABASE

Diabase dikes are not as numerous in Northfield as they are in many townships to the northeast. In fact the diabases are most abundant in the townships along the international boundary whose sedimentaries are Ordovician. A few dikes were discovered on Shaw Mountain in Northfield. One of these dikes had a strike of north 20 degrees east while the strike of the sedimentaries which it cuts was north 35 degrees east. The typical diabase jointing in some of the outcrops on the ridge to the west of the Vermont Black Slate Company's quarry suggests the presence of diabase dikes. This material is awaiting further study from new microscopic slides.

CHLORITE

About two miles east of the head waters of Stony Brook there are several dikes of chlorite or beds of chlorite schist. These chloritic rocks, whatever their origin may have been, cut the sericites and quartzites at angles varying from one to 45 degrees. There is evidence also in certain microscopic slides that a part of this chloritic material was derived from the metamorphism of diabases or amphibolites.

On the south slope of Dole Hill, near the Fair grounds, there is a dike, or bed of chlorite schist, that cuts the sericite schist at an angle of 5 degrees. Where the strike of the beds of chlorite schist conform to the strike of the enclosing sedimentaries the beds may result from the metamorphism of sediments. It is hoped that the petrographic study of these chlorites in Roxbury where they are much more abundant will throw additional light on this perplexing problem of origin.

PLATE XI

GRANITE DIKE IN LIMESTONE, WEST SIDE OF BERLIN MOUNTAIN

PERIDOTITE AND PYROXENITE

There are two relatively small peridotite areas in the western part of the township of Northfield. The larger of the two is situated near the head-waters of Rocky Brook on the eastern slope of the Northfield-Waitsfield range and near the Captain John Mosely camp. It is about 50 to 100 feet in width and some 500 feet in length. The strike is north 40 degrees east. The borders of this dike are well serpentinized while the presence of talc suggests an undifferentiated heterogeneous magma of peridotite and pyroxenite.

Another smaller peridotite area is located near Little Northfield Brook about one mile south of the area previously mentioned. This outcrop is about 500 feet in length and some 15 feet in width. The true peridotites consist essentially of the mineral olivine. The true pyroxenites of augite and other pyroxenes.

A small outcrop of altered pyroxenite was found near the Hutchins grove in the southwestern part of Northfield.

In the southern part of the township of Northfield, and not more than one mile west of the Dog River valley the peridotite belt again appears. It is several hundred feet in width and extends southward into Roxbury. It was not known to occupy this position in Northfield at the time the accompanying map was drawn and therefore it does not appear upon the map. Its northerly extension from Roxbury into Northfield will be indicated on the areal map of Roxbury. In this outcrop soft verd antique marble exists and very pure talc is encountered.

The granites of Northfield are regarded as having been introduced at the close of the Devonian. Their mineralogical character, their microscopic structure and their quarry structure give evidence that they have been subjected to severe crustal movement. Such a movement accompanied by uplift occurred at the close of the Carboniferous. Soon after the crystallization of the granites they were traversed by dikes of pegmatite and aplite. Some of the diabase dikes at least are younger than the granites, for at Barre and on Robeson Mountain, Woodbury, they cut the granite masses. They are regarded as having been introduced as late as the Carboniferous and possibly some of them as late as the Triassic.

PALEONTOLOGY

The sericite schists, hydromica schists, black pyritiferous mica schists and non-calcareous quartzites of the central and western portions of this area are continous in their northern extension into Canada, where in some of these terranes, Upper Cambrian fossils are obtained. In Vermont no fossil content has as yet been found in these terranes on the eastern side of the

Green Mountains. Their relative age is determined by continuity lithological characteristics, and stratigraphical position. They are unquestionably pre-Ordovician for they furnish pebbles for the basal conglomerate at Irasburg and Northfield which lies at the base of the Ordovician. In Irasburg and Albany where the Irasburg conglomerate is best developed the pebbles are pre Ordovican and the matrix is Ordovician limestone. In Northfield the pebbles are pre-Ordovician and the matrix is Ordovician slate. The frequent presence of a conglomerate in these Cambrian terranes would suggest that the sericite schist and associated quartzite were Upper Cambrian and the more western members like the hydromica schist Lower Cambrian. The Middle Cambrian is not known to exist east of the Green Mountains in Vermont.

Beds of graptolites have been discovered in Newport, Coventry, Brownington, Irasburg, Albany, Craftsbury, Barton, Glover, Greensboro, Hardwick, Woodbury, Calais, East Montpelier, Montpelier, Barre, Berlin, Northfield, Williamstown, Brookfield, Roxbury and Braintree. The numerous and widespread distribution of these graptolites places the age of the three phases of the Waits River limestones and their associated beds of quartzose marbles, the Memphremagog slates and their associated beds of phyllite schist, as Ordovician

The characteristics of many of these graptolites have been fully discussed in the earlier reports and need not be repeated here. Dr. Rudolf Ruedemann, State Paleontologist, Albany, N. Y., in his letter of July 19, 1917, writes, "Specimen marked number 1 is the best. It still shows in a certain light the characteristic structure of a Phyllograptus angustifolius. This indicates Deepkill shale (Beekmantown)." The peculiar significance attached to this statement is in the fact that the specimen submitted containing the graptolites was obtained from a a slate quarry on the south bank of a small brook about one mile southeast of Northfield village. The material was from the more quartzose layers within the slate. It thereby affords positive evidence as to the age of the Memphremagog slates in Northfield.

Dr. Ruedemann also writes concerning specimens marked numbers 4 and 5, "The branching graptolites are too much distorted to be clearly recognized. Nor could I make anything out of the nodules in the pyritiferous slate. As a matter of fact fossils other than graptolites are extremely rare in graptolitic shale. Occasionally minute brachiopods are found. There can be hardly any doubt that these fossils are remains of graptolites indicating very early Ordovician age."

In the same letter Dr. Ruedemann writes regarding the curved fossil. "I must admit that in outline it strongly suggests a coral or Cyrtoceras. A coral would hardly occur in graptolitic shales, and there is no species of that shape or size known in the early Ordovician. Nor would it be safe to refer it to the cephalopods because it shows no trace of the septa or of any structure whatsoever; nor have any such cephalopods been found in the New York graptolitic shales."

As this specimen with many others not as well preserved were found some five miles east of the beds of graptolites of very early Ordovician age and in limestone, containing graptolites of middle Ordovician age, it is not impossible that the species above referred to is a cephalopod. It does not necessarily follow that if cephalopods are absent from the Lower Ordovician in eastern New York that they must be absent from the Middle Ordovician of eastern Vermont. The specimen, however, is in the State museum at Montpelier as specimen No. 802 of the author's collection.

During the last four summers more than 50 beds of graptolitic limestone and slate have been discovered. Beds have been found even in the marbles that are well calcitized whose microscopic slides show all of the characteristics of calcite cleavage. Many more beds of graptolitic limestones and slates might have been located if all possible outcrops had been examined carefully for some graptolitic content. These fossils are generally found by breaking up and splitting open a considerable amount of the rock exposure. Even then it is difficult to secure them well preserved. In a few instances their presence is well marked upon the exposed surfaces.

In Northfield graptolitic beds occur on the southwestern side of Berlin Mountain, on the western slope of Paine Mountain, on Turkey Hill, in the Shaw Brook valley, in some of the abandoned slate quarries near Northfield, and along the Williamstown west town line. Therefore, paleontological as well as lithological and stratigraphical evidence places the age of these terranes as Lower and Middle Ordovician.

Economics

The sericite schists and Cambrian quartzites of Northfield are of little commercial significance. Slabs of this material find a local use for culverts, bridges, guards, underpinning and foundation work. It is also used somewhat in road construction.

The sericite schist in the ravine leading east from Calvary Street was at one time manufactured into whetstones. These stones had a very good grit and were free from objectionable impurities. Microscopic slides of this material show an abundance of fine grains of quartz with silvery muscovite (sericite). Good whetstones could still be manufactured from this schist.

The Northfield slate is black in color and of fine texture. The cleavage surfaces are smooth and lustrous. It is graphitic and contains a little magnetite. According to T. Nelson Dale the magnetic minerals are too numerous to make the slate best suited for electrical purposes. The sawn edges show minute lenses and crystals of pyrite. The slate is very fissile and does not discolor.

Under the microscope the slate is seen to possess a matrix of muscovite (sericite) and a very even texture. There are abundant minute grains of quartz and crystals of pyrite and magnetite whose axes are parallel to the grain. These iron minerals are usually surrounded by a rim of secondary quartz and muscovite, sometimes chlorite. There are a few lenses of interleaved muscovite and chlorite. Considerable dark, probably graphitic, matter in extremely fine particles could be observed. Some calcium carbonate was present together with minute prisms of rutile and tourmaline.

According to Dale the chief constitutents of this slate arranged in descending order of abundance appear to be muscovite (sericite), quartz, pyrite, graphite, magnetite, chlorite, calcium carbonate, and accessory rutile and tourmaline.

Hammer tests made on different samples at the quarries indicate that the slate is sufficiently strong to be nailed to roofs without splitting. The absence of ribbons in the bedding and the absence of horizontal joints crossing the cleavage renders it easy to quarry large slabs for mill stock.

There are thirteen or more abandoned slate quarries in Northfield. They lie along the western slope of the ridge just east of Northfield village and extend from a hill just northwest of Paine Mountain southward to South Northfield. In the following terse description they are numbered from north to south starting with the northernmost quarry visited.

1. This quarry is at an altitude of 1100 feet. The strike is north 35 degrees east and the dip 80-85 degrees both east and west. There is a sharp anticline near the center of the quarry.

2. This quarry is at an altitude of 1150 feet. The strike is north 30 degrees east and the dip 88 degrees west. The anticlinal structure in the slate is pronounced.

3. This quarry has an altitude of 925 feet. The quarry is flooded by two small streams flowing into the pit. The strike is north 30 degrees east and the dip is 80 degrees west. The anticlinal structure was also observed

4. A small quarry near number 3.

5. A small quarry near number 3.

6. This quarry has an altitude of 1210 feet. The strike is north 30 degrees east and the dip 75 degrees east.

7. This quarry has an altitude of 1010 feet. The strike is north 40 degrees east and the dip 85 degrees west. The sharp anticlines in this quarry are accompanied by faults and slickensides. This quarry is the largest.

8. This quarry has an altitude of 1025 feet. The strike is north 40 degrees east and the dip is 80 degrees west.

9. The altitude of this quarry is 975 feet. The strike is north 40 degrees east and the dip is 85 degrees west.

10. This quarry has an altitude of 990 feet. The strike is north 40 degrees east and the dip 85 degrees west.

11. This quarry is known as the Dole-Brill quarry. It has an altitude of 910 feet and is located on the left of the road from Northfield to South Northfield. At the center of the quarry a strike was recorded as north 40 degrees east while on the borders of the quarry it was north 30 degrees east. The dip is 80 degrees west. On one side of the quarry a small quartz vein showed a faulting of over two feet. The 4 foot quartz vein at the south end of the quarry has a strike of north 25 degrees west. The extensive equipment at the mill is fairly well sheltered and needs but little repair to put it in good working order.

12. This quarry has an altitude of 875 feet and is only a few rods south of the Dole-Brill quarry.

13. The quarry of the Vermont Black Slate Company has an altitude of 750 feet. The strike is north 35 degrees east and the dip is 85 degrees west. This quarry has the most extensive equipment of any quarry in Northfield. There are over 2000 pieces of slate in this mill ready for shipment or nearly ready. It is unfortunate that so much valuable machinery is lying idle and so many blocks and slabs of slate should have been left unmarketed. Some of these blocks or slabs are 6 feet in length, 4 feet in width, and two inches in thickness. The slate is of excellent quality. The slabs vary widely in their dimensions signifying a wide variety of uses for which the slate was originally intended.

The larger slate areas of Poultney and Castleton, Vermont, and their closer proximity to a large market with the lessened cost of transportation; the complex and expensive method of quarrying the slate with the consequent large amount of waste; together with the keen competition of the Pennsylvania slate, are some of the factors that caused the abandonment of the slate quarries in Northfield. However, with the close proximity of the Central Vermont railroad, the unfading black color of the slate, the fine quality of the slate, there is no known reason why these quarries can not be reopened with good financial returns for the money invested.

The limestones and quartzose marbles of Northfield have a local use in the construction of culverts, bridges, foundations and permanent roads. The limestones have good rift and grain and can be easily worked into rectangular blocks. The quartzose marbles are susceptible of a good polish and when freshly cut the contrast between the polished and hammered surface is strong. Beds of this quartzose marble can be found in the eastern part of the township near the Williamstown town line and in the valley of Mill Hill Brook.

As is common in nearly every township in this section of the state the limestone has been burned for the manufacture of lime.

The resulting lime was reported to be bluish white in color and of very good quality.

The granite industry in Northfield is confined to the manufacture of granite from material not obtained in Northfield. The stone worked is obtained mostly from Barre and in part from Bethel. The Cross Brothers are the largest dealers.

The granite on the Moses King and Samuel Andrews farms could be opened up and worked to a good advantage. Quite a little stone has been quarried on the former place and a few blocks split out for local use on the latter. Two miles from Northfield village up the Cox Brook toward Moretown there are thousands of granite boulders some of which have been worked in the past for local use. Many of them are with good rift and grain and could be worked to a good advantage. This material represents a granite area covered with boulders and glacial material of no great depth or else it is a part of a terminal moraine. If it is a moraine it is not known from what large granite area to the northeast the boulders came. They did not come from Barre and they are of different texture from the Robeson mountain granite in Woodbury.

The sand and gravel beds of Northfield yield good material for road and concrete work.

The streams of Northfield furnish good water powers. The powers at Northfield Falls, Northfield and South Northfield are utilized for woolen mills, saw mills, grist mills, manufacture of granite, and other industries. The power at Mill Hill Falls was formerly utilized. The falls along Rocky Brook could well be utilized for water power.

SUMMARY

The detailed study of the terranes of Northfield for this report was begun in 1916 and finished in the summer of 1918. The areal map is designed to show roughly the general distribution of the different terranes. Without topographic maps in a country as broken as Northfield this work is extremely difficult. The map must be regarded as an approximation. The protracted section shows the general dip of the cleavage planes and not necessarily the bedding planes because often the two do not coincide with each other. The nearest approach to the two planes coinciding with each other is found in some of the layers of the shaly graptolitic limestone, where the graptolites are well preserved. The erosional unconformity which was so pronounced in Irasburg and Albany has been proven continuous thru Northfield into Roxbury. The discovery of the slate conglomerate in Northfield lying at the base of the Ordovician series in Northfield is important. The siliceous limestones and calcareous quartzites are more or less interstratified with the slates and phyllites. The definition of the different terranes

has been effected by the study of many microscopic slides. The economic possibilities of these terranes have been carefully considered. The discovery of fossils in the Northfield slate quarries and in the limestones and quartzose marbles by which an authentic stratigraphic position has been assigned to these terranes is the most important feature of the entire work.

THE TERRANES OF ROXBURY, VERMONT

CHARLES H. RICHARDSON
Syracuse University

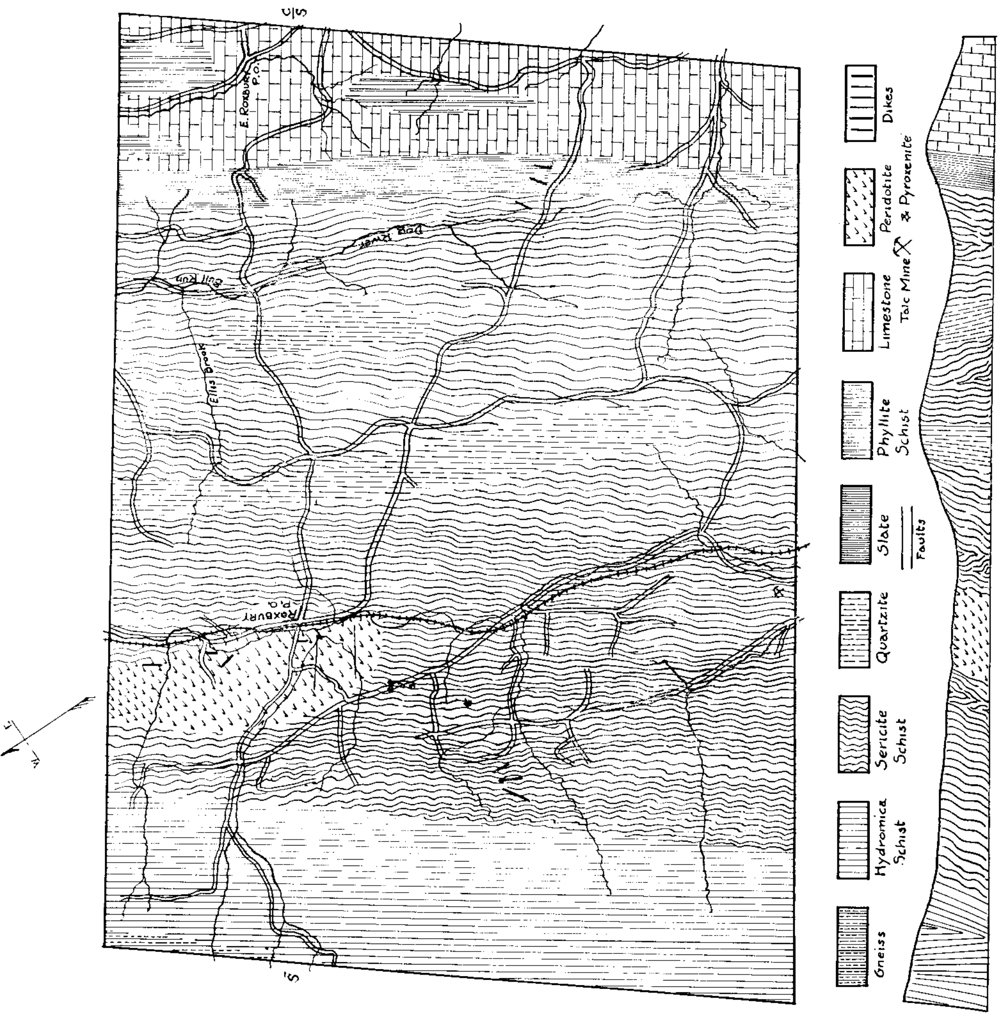
INTRODUCTION

The report upon The Terranes of Roxbury, Vermont, is of necessity very brief. It must be considered only as one of progress in the solution of the intricate geological problems of the eastern half of the State. The author traversed this area in reconnaissance work in 1895, and has visited the verd antique marble quarries of Roxbury nearly every summer since that date to watch their development and discover, if possible, new evidences as to the nature of the intrusive which has been metamorphosed into marble, and the origin of the chlorite schists with which the marble is associated. It was not, however, until the summer of 1918 that detailed study could be given to the field. The limited time available for field work has proven inadequate for a complete study of all of the field relations. The township is hilly, and much of it is densely wooded and difficult to work in an east and west direction across the strike of the different formations. Owing to war work which the author has been called upon to do the preparation of microscopic slides has been limited and chemical analyses have not been carried to completion from a quantitative standpoint, altho several qualitative analyses have been effected.

The area chosen lies just south of the geographic center of the State, and about 18 miles southwest of Montpelier. It is further situated in the southeastern corner of Washington County.

There are three reasons for the selection of this area. (1) It lies south 40 degrees west from the area covered in The Terranes of Northfield, Vermont, which appears with this article in the Biennial Report of the State Geologist for 1917-1918. (2) It falls in the line of the erosional unconformity between the Upper Cambrian and the Ordovician formations represented in the eastern half of the State. (3) The large economic possibilities of the verd antique marble of Roxbury, Vermont.

Some work was done this summer in Northfield on the north, in Brookfield on the east, in Braintree and Granville on the south, and in Warren on the west. The total number of rock specimens collected in the eastern half of the State and placed by the author in the State museum at Montpelier is eight hundred and thirty-three. A large number of samples were collected for microscopic slides for petrographic study, and many photographs were taken in the field. Some of the results of the petrographic



Scale 2000′ = 1″

PLATE XII
GEOLOGICAL MAP OF ROXBURY

study which is incomplete for want of time will have to go over for some subsequent report.

An areal map, showing the geographical distribution of the terranes in Roxbury, accompanies this report as Plate XII.

A cross-section is drawn practically thru the center of the township and at right angles to the strike of the different formations. This protracted section also accompanies this report.

The author recognizes herewith his great indebtedness to Prof. E. C. Jacobs, University of Vermont, for his work on "The Talc and Verd Antique Deposits of Vermont," also his paper on "Talc, and the Talc Deposits of Vermont"; to Prof. Edward Wigglesworth, Harvard University, for his paper on "The Serpentines of Vermont," and to T. Nelson Dale of the United States Geological Survey for his paper on "The Commercial Marbles of Western Vermont."

DRAINAGE

The drainage of the northern half of Roxbury is to the north and that of the southern half of the township is to the south. The line of division of this north and south drainage for the main valley is near the village of Roxbury, while towards the east the height of land is farther to the south.

In the northern half of the township there are three small streams that flow northward thru Northfield. The easternmost one is Shaw Brook. The central stream is cataloged upon the maps as Dog River which receives from the west, in Roxbury, Ellis Brook. The westernmost one flows thru the valley occupied by the Central Vermont railroad and is a tributary of the Dog River in Northfield. It receives two tributaries from the west which rise near the Roxbury west town line and one small tributary from the east which rises near the crest of the central north-south range of hills in the township.

In the western part of the southern half of the township the main stream empties into or becomes the Third Branch of the White River which empties into the Connecticut River at White River Junction. It receives from the west two tributaries that rise near the Roxbury west town line and one small tributary from the east. The combined waters flow out of Roxbury into the northeastern corner of Granville. The extreme southeastern part of Roxbury is drained by small streams which flow into the southwestern corner of Brookfield and empty into the Third Branch of the White River.

Altho these streams are all small in Roxbury nevertheless some good water powers are produced. Falls some 25 feet in height exist on the brook that flows east from Warren Mountain.

The larger streams flow in their old Pre-Glacial valleys. The smaller transverse streams have cut out deep V-shaped valleys in the morainal material down to the old, water-worn, pre-Glacial beds. In some instances they are out of the old valleys for short distances and falls are the result.

The only railroad traversing Roxbury is the Central Vermont which runs parallel with the major valley of the township.

TOPOGRAPHY

Roxbury lies between the parallels of 44 degrees 2 minutes and 44 degrees 9 minutes north latitude, and longitude 72 degrees 38 minutes and 72 degrees 50 minutes west of Greenwich.

The main valley is the one which the Central Vermont railroad traverses. It is a broad U-shaped valley and roughly parallel with the three ridges which traverse this area in a direction practically north 40 degrees east. The maximum elevation of the bed of the valley is at Roxbury station at an altitude of 1009 feet on the top of the railroad track in front of the station.

To the west of this valley the elevation rises gradually for about two miles and then rapidly to the crest of the Roxbury-Warren mountain. The town line is a few rods east of the crest of this ridge. The altitude of the crest of the hill in the road is approximately 2250 feet. This ridge is roughly parallel with the Roxbury west town line It is densely wooded and altitudes of the highest peaks were difficult to obtain.

The second major valley lies east of the central ridge passing in a direction of north 40 degrees east thru the township. It is known as the Bull Run valley. The altitude of the terrace at the home of R. C. Diemer at Bull Run Four Corners is 1100 feet. The highest altitude between these two valleys was approximately 2000 feet. The slopes are very precipitous on both sides of this central ridge.

The third longitudinal valley is found at East Roxbury. In its southern extension it passes into Brookfield where only a part of the western side of the valley is in Roxbury. This would hold especially true near the village of West Brookfield. The altitude at East Roxbury is approximately 1050 feet, and the highest altitude between these two valleys was 1850 feet. The lowest altitude recorded in the township was in the railroad valley near the Granville town line. The barometer reading here was 970 feet.

GLACIATION

Ths township of Roxbury is mantled with morainic material to such an extent that the geologist is seriously hampered in the study of the field relations of the different geological formations. The forested area some five miles in width which stretches in a southerly direction across the township to the east of the center of the township, together with the densely wooded area on the extreme western border, also impede geological progress in the interpretation of true stratigraphic positions.

Evidences of glaciation and the general direction of the ice movement are the striations still remaining on the more resistant rocks of the region. The well exposed outcrops of nearly pure white, secondary, vein quartz show striations upon their smoothed and polished surfaces. The resistant phyllites, slates, sericite schists, and Cambrian quartzites occasionally afford excellent illustrations of glacial grooves.

Three different sets of striations were recorded. They were south, southeast, and south 70 degrees east. A good locality for observing two of these directions is on the crest of the ridge just north of Roxbury-Warren road. The third set was here nearly obliterated.

The general trend of the ice is well known to have been in a southeasterly direction but there were many local variations. A south 30 degrees west direction was recorded in Northfield, and a south 20 degrees west in Roxbury.

Another evidence of glaciation is the boulder strewn fields, pastures, and woodlots. Boulders of a conglomerate were discovered in the wooded area along the four-mile wood road that closely resemble the Coventry conglomerate, and the boulders of the quartz conglomerate found in Northfield. These boulders may have come from a local phase of a quartz conglomerate whose true location is concealed in the densely wooded area.

About three miles west of Roxbury village and up the Warren Brook there are several boulders of augen gneiss whose size suggests that they came from the vicinity of the Northfield-Waitsfield town line. Some of these boulders several feet in diameter were found in Northfield. The presence of these boulders of augen gneiss from five to ten feet in diameter suggests the advisability of traversing this western ridge in Northfield and Roxbury to discover, if possible, the location of augen gneiss in place in Vermont.

The presence of terraces flanking the longitudinal and transverse streams is another evidence of glaciation. One of the best terraces is found in the Bull Run valley.

One of the most interesting evidences of glaciation of Roxbury is found in a section of a terminal moraine which traverses the main valley in an east and west direction about one mile north of Roxbury railroad station. The lower limit of the ice remained comparatively stationary for a time and caused the waters of this valley to flow southward into the Third Branch of the White River where formerly they flowed northward into the Dog River which is a branch of the Winooski. A similar moraine some thirty to forty feet high occurs in Warren which caused the head waters of the Mad River to flow in a southerly direction in to the Third Branch of the White River until the ice receded from the Mad River valley.

GEOLOGY

The geology of Roxbury is intricate and complex. The terranes consist of a series of highly folded and faulted metamorphic rocks, dipping always at a high angle, and cut by intrusives mostly of a basic character. The sediments as well as the intrusives differ widely in age, as well as in their mineral composition. A careful study of their field relations has been absolutely necessary to avoid the introduction of errors in their interpretation. Many microscopic slides have been prepared for study and still others are in the process of preparation. These later slides will be too late for translation into this report.

In the western part of the area involved the stratigraphy has been determined by apparent field relations and the study of microscopic slides. In the eastern part of the area covered by this report the stratigraphy is determined by the discovery of new beds of graptolites this summer in both the slates and the limestones. The graptolites are as abundant in the slates of Roxbury as they are in the limestones in Montpelier.

ALGONKIAN

It is not certain the Algonkian appears in place in Roxbury. Possibly the westernmost terrane in Roxbury is Algonkian. It would fall along the Roxbury-Warren mountain range. The gneiss encountered in Northfield probably extends southward into or thru Roxbury, but where the western town line was reached on the Roxbury-Warren road the rocks were sericite and hydromica schists. This area is either densely wooded, or burned over and now covered with a dense growth of underbrush. There are evidences in the number and size of the boulders that Algonkian gneiss and perhaps highly metamorphic schists of Algonkian age appear in the Roxbury-Warren mountain range.

CAMBRIAN

The term Cambrian as here used signifies a group of highly metamorphosed sedimentary rocks which lie between the eastern foothills of the Green Mountains and the erosional unconformity that separates the pre-Ordovician from the Ordovician formations. These formations consist of pyritiferous mica schists, hydromica schists, sericite schists, chlorite schists, and quartzites. The non-calcareous Cambrian quartzite is to be in no way confused with the Ordovician calcareous quartzite in the eastern part of the township.

These formations constitute by far the larger part of the terranes of Roxbury. All of the verd antique marble of Roxbury lies within these terranes.

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

HYDROMICA SCHISTS

The hydromica schists lie on the east side of the Roxbury-Warren range of mountains. They are markedly different from the sericite schists that flank them on the east. The hydromica schists are fine grained, greenish, micaceous rocks which are more or less associated with chlorite. If the prevailing mica of these schists was originally biotite it has been altered in many instances to chlorite.

BLACK PYRITIFEROUS MICA SCHIST

The black pyritiferous mica schist that traverses Northfield as a narrow band does not appear to extend any considerable distance into Roxbury. It does appear as a narrow belt in the northwestern part of the township. Its narrowness together with the large amount of glacial drift may explain why this phase of the sericite schist was not observed further to the south.

The typical pyritiferous mica schist carries an abundance of quartz, and a black to greenish black hydrated mica. In this formation there are many crystals of pyrite. In the northern part of the State these pyrites are sometimes an inch in diameter. In Roxbury they are only a fraction of an inch in diameter. Where the large pyrites are absent as in Middlesex the schist becomes splintery.

SERICITE SCHIST

This terrane has been continuous from the international boundary on the north southward for spproximately 100 miles into Braintree and Granville. Thruout the entire distance it flanks everywhere the Ordovician terranes on the west and becomes the easternmost member of the Cambrian group. It is the predominating formation in Roxbury as it is in Northfield. It probably occupies a greater area in Roxbury than all other formations combined. The sericites are interbedded with more or less quartzite, and perhaps much of the material mapped in as other formations of Cambrian age should have been mapped as sericite.

The sericite schists present a light colored appearance on their weathered surfaces. The schist is a fine grained rock containing quartz and silvery muscovite (sericite) as essential minerals, and garnet, magnetite, pyrite, and a plagioclase feldspar in some slides, as secondary constituents.

Where the muscovite mica (sericite) predominates the terrane is classified as a sericite schist. Where the quartz grains are in large excess over the mica it is cataloged as a quartzite. In some instances the sericite schist becomes decidedly talcose as in the southern part of Roxbury on the west side of the valley. Samples here collected should be cataloged as talc schist. In this same locality there is an abandoned talc mine.

The general strike of the sericite schists on the west side of the Roxbury valley is north 30 degrees east. There are some variations to a strike of north 40 degrees east. To the east of the Roxbury valley the strike of north 40 degrees east seems to prevail, but in the northeastern portion of the township a strike of north 50 degrees east was recorded. A strike of north 10 degrees east was recorded in the southern part of Roxbury and also in Granville.

The dip of these schists is always at a high angle and generally to the west. Dips from 80 to 85 degrees west are the most common but many easterly dips were observed. By carefully measuring a large number of dips across the valley at the village of Roxbury three closely folded synclines were found in the valley.

One of the lowest dips recorded in the sericite schist was just west of the village of Roxbury. Here the strike was north 30 degrees east and the dip 70 degrees west. This lower dip to the west is shown in Plate XIII.

The planes of bedding in the sericite schist in an outcrop along the small stream just west of Roxbury village are at a high angle to the east while the planes of foliation or cleavage in the schist are at an angle of 70 degrees to the west. The planes of bedding are brought out plainly when the surface of the exposed rocks are wet. This difference between bedding and cleavage is illustrated in figure 8.

QUARTZITE

The Cambrian quartzites have appeared in every township southward from the international boundary thru which the erosional unconformity between the Cambrian and Ordovician terranes extends southward for approximately 100 miles. In some instances these outcrops appear fairly uniform in width while in others they are more or less lens shaped. The quartzites are flanked both upon the east and the west by broad belts of sericite schist. It occurs on the ridge to the west of the Bull Run valley, in a belt to the west of the Roxbury, north-south road on the hill east of the village. However, it is just as likely to appear in the valleys as on the ridges. It occurs in the valleys in Berlin and Northfield where erosion has been carried to its lowest level in these townships.

In texture this quartzite is fine grained but it sometimes carries well rounded quartz pebbles of small dimensions, especially in the more northern part of the State. It consists of

PLATE XIII
LOW WESTERLY DIP IN SERICITE SCHIST, ROXBURY

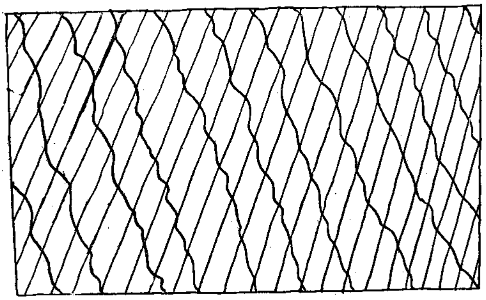


FIG. 8
DIFFERENCE BETWEEN PLANES OF BEDDING AND CLEAVAGE IN SERICITE SCHIST, ROXBURY, VT.
THE STRAIGHT, PARALLEL LINES REPRESENT CLEAVAGE

small, well rounded quartz grains and silvery muscovite (sericite). In some specimens biotite is present. It frequently carries a small amount of magnetite and pyrite. Garnets have been observed in this formation and small crystals of a plagioclase feldspar are occasionally present. The formation is generally marked by a multiplicity of narrow veins of secondary quartz traversing the outcrop at many different angles. A huge boulder showing this characteristic can be seen by the roadside some two miles west of the village of Roxbury.

The general strike of the quartzites in the western part of Roxbury is north 30 degrees east, in the central and eastern portion north 40 degrees east, and a strike north 50 degrees east was recorded in the northeastern part of the township.

The dip of the quartzites is usually from 80 to 85 degrees west but local dips from 80 to 85 degrees east are not infrequent.

CHLORITE SCHISTS

If any of the chlorite schists of Roxbury, Northfield, or Berlin are of sedimentary origin then these schists belong here. If they are of igneous origin then the proper place for their discussion is under the caption of intrusives. Under this caption evidence will be presented proving an igneous origin for many of these outcrops.

The chlorite schists occasionally conform in strike and dip with the enclosing sericite schists. Where this condition exists over a considerable area it suggests the possibility of such chloritic rocks being derived from highly altered sediments. A ferruginous clay by metamorphism could yield iron-alumina silicates which could be subsequently altered into chlorite. Secondary hornblende has been observed in these highly metamorphic rocks of Cambrian age. Biotite is not uncommon especially in the western part of these townships. Both hornblende and biotite alter to chlorite.

The chlorite schists have the mineral chlorite, or some related mineral of the chlorite group as their determinant constituent. More or less quartz is present. Magnetite and a plagioclase feldspar have been observed in microscopic slides. These rocks are decidedly schistose and in color some shade of green. In a few samples of these chloritic rocks the quartz content is comparable to the quartz grains in the associated sericite schists. Several microscopic slides of new material from these schists are in the process of preparation but the results of that study will be too late to embody in this report.

ORDOVICIAN

The term Ordovician as here used embraces a group of metamorphic sediments that lie to the east of the Cambrian terranes already described. These two groups are separated from each other by an erosional unconformity. This unconformity has been followed southward from the international boundary into Braintree, a distance of approximately 100 miles. How much farther to the south it can be traced is a matter of conjecture. From reconnaissance work of former years it is safe to say that this unconformity can be traced as far south as Barnard.

The Ordovician terranes consist of a basal conglomerate, limestones, marbles, calcareous quartzites, phyllite schists, and slates.

IRASBURG CONGLOMERATE

The Irasburg conglomerate as it exists in Irasburg is wanting in Roxbury, but its geological equivalent as discovered in Northfield last summer extends southward into Roxbury. In Northfield and Roxbury the matrix is Ordovician slate and the pebbles are all pre-Ordovician. It lies in the western limits of the slate in contact with the sericite schists. Its strike is north 35 degrees east and its dip 80 to 85 degrees west. Most of the area occupied by this conglomerate is densely wooded and consequently the exposures are few.

WAITS RIVER LIMESTONE

The Waits River limestone does not cover as extensive an area in Roxbury as it does in Northfield and in the townships northward therefrom. The formation in Roxbury includes a series of limestones, quartzose marbles, and calcareous quartzites. In the areal map no attempt has been made to distinguish one phase of these calcareous rocks from another.

The Washington phase of this limestone is a dark gray siliceous variety which in some instances yields a quatzose marble susceptible of a good polish. This marble weathers to a rusty brown on long continued exposure to the atmosphere and is best adapted for decorative interior work. This variety is abundantly distributed on the eastern side of the eastern north-south range of hills in Roxbury. These massive outcrops are perhaps best exposed in the ravines extending in a westerly direction from the east town line of Roxbury and to the north of East Roxbury. Distance from the railroad would make the marketing of this marble expensive However, some of these beds may be cataloged as marble reserves.

The true Waits River phase of these Ordovician limestones is light gray in color, banded, and siliceous. In these more western townships it often becomes shaly. The shaly graptolitic limestone of the eastern part of Roxbury belongs to this variety. It is often interstratified with phyllite schists. This phase of the limestone has been continuous from the international boundary southward to Braintree, a distance of approximately 100 miles. No beds of this variety in Roxbury are suitable for the manufacture of marble.

The Coventry phase of the Waits River limestone is very dark gray and well filled with pyrite. The belt is generally very narrow and lies near the slate. It is generally interstratified with phyllite schists with which it is intimately associated. However, a more easterly bed of this limestone than has been heretofore observed occurs in Roxbury near East Roxbury village.

Where the quartz grains predominate the rock is classified as a calcareous quartzite which is in no way to be confused with the Cambrian quartzite which is non-calcareous. The essential minerals of the calcareous quartzite are well rounded quartz grains and calcite showing in microscopic slides the characteristic calcite cleavage. As earlier noted the essential minerals of the Cambrian quartzite are quartz and muscovite (sericite). Scales or small plates of ordinary muscovite and biotite are secondary minerals in the calcareous quartzite. Small pyrites have been observed.

When the typical calcite cleavage prevails and the calcite grains are in excess over the quartz the rock is classified as a quartzose marble. Such a bed may be found about one mile west of West Brookfield, but several beds of this type have been found in the western part of Brookfield.

The general strike of these limestones is north 35 to 40 degrees east. A strike north 30 degrees east was recorded in the northeastern corner of Roxbury. Also a strike north 50 degrees east. The variations in Roxbury are far less pronounced than they are in Northfield and Berlin.

The dip of these limestones is at a high angle to the west.

MEMPHREMAGOG SLATES

The Memphremagog slates of Northfield are continuous thru Roxbury into Braintree. The belt in Roxbury is much narrower than it is in Northfield, especially in the southern part of Roxbury. In general it traverses a densely wooded area and good outcrops were somewhat difficult to find. In the eastern part of Roxbury the slate has the characteristic fissility of the slate in Northfield. This characteristic also holds true of the slate in the northeastern part of Roxbury. These beds are well suited for roofing purposes but their distance from the railroad would reduce possible profits in the industry.

The Memphremagog slates in the more northerly portion of the township occupy the crest of the easternmost north-south ridge in Roxbury. In the more southerly portions of the township they are confined to the eastern slope of this ridge. The slate begins about one-fourth mile east of Bull Run. It continues over the crest of the divide and down the eastern slope for a considerable distance. In the southeastern part of the township it does not reach within one-half mile the crest of Cram Hill, and is entirely confined to the eastern side. Beds of this slate in the brook on the east side of Cram Hill are filled with graptolites. The general strike of these slates is north 35 to 40 degrees east and the dip from 80 to 85 degrees west. No easterly dips were recorded in the slates in Roxbury.

PHYLLITE SCHISTS

In the northeastern part of Roxbury there are two belts of phyllite schists which are roughly parallel with the strike of the limestones and the slates. The phyllite schists are more resistant to erosion than the limestones and marbles and therefore they form the more prominent small ridges on the eastern slope of the easternmost north-south ridge in Roxbury. In general these schists are fine grained and consist of quartz with muscovite and biotite. Small scales of ottrelite are often set transverse to the planes of foliation. Magnetite, pyrite and garnet are not uncommon. In some cases they are graphitic. The strike of these schists is north 35 to 40 degrees east and the dip 80 to 85 degrees west. No easterly dip in these schists was recorded altho practically a 90 degree dip was encountered in the eastern part of the township.

ACID INTRUSIVES

GRANITES

It is not definitely known that there are any granite outcrops in Roxbury. There is evidence that such outcrops do exist to the north of the four mile wood road in a densely wooded area. The multiplicity of granite boulders strikingly suggests the presence of a granite stock not far from their present habitat.

APLITE DIKES

Small aplite dikes were found both north and south of the four mile wood road in the wooded area. One of these dikes crosses this abandoned road. Its width was about two feet, and its strike was north 30 degrees east. The wooded area both to the north and south of this road would be intensely interesting to work out purely from a scientific standpoint.

BASIC INTRUSIVES

DIABASE

Diabase dikes are not numerous in Roxbury. Where they do occur they are generally much altered. To be sure that all of these dikes are or were originally diabase would require a large number of microscopic slides for petrographic study. That they are dikes of some basic igneous rock there is no doubt. They are often very compact, tough, greenish in color, and cross the sedimentaries at many different angles.

About three miles southwest of Roxbury village there were several of these dikes. The strike of one was north and south. Of another north 10 degrees east. Of a third north 20 degrees east. The strike of the sericite schist which these dikes cut is north 30 degrees east.

Just above Lovers Lane a little to the west of the village of Roxbury there is a dike 15 feet wide with a strike of north 12 degrees east while the sericite schist at this locality has a strike of north 30 degrees east. The texture of this dike suggests a diorite. It is considerably altered and somewhat schistose, and until several microscopic slides can be studied its true classification may remain unknown. Until further evidence is at hand this dike is classified as a metadiorite.

A dike of apparent diabase cuts the talc deposit between quarries No. 1 and No. 2 of the verd antique marble. The strike of the talc lens is north 30 degrees east and this dike cuts across the talc lens. This dike was introduced later than the pyroxenite magma from which the talc has been derived. A far more pronounced outcrop proving absolutely that diabase dikes were introduced into the serpentine, or peridotite, belt in Vermont at a later period than the peridotite is found in North Troy where a diabase dike cut directly across an outcrop of talc. This outcrop was photographed and an illustration appears as a half-tone in Plate LIX, opposite page 280, in the Sixth Annual Report of the State Geologist.

CHLORITE SCHIST

The chlorite schists of Roxbury have chlorite as the determinant mineral. They vary from a decidedly schistose character to fairly massive and tough. The individual chlorite scales are sometimes too small to be seen by the eye, and sometimes they occur in foliated aggregates. The schist is of a bright green color. Its true color is better seen at a little distance from the outcrop than it is in hand specimens. Near the center of the verd antique ridge the rock is homogeneous and coarsely laminated. Both towards the east and the west it is more or less interlaminated with the sericite schist.

The strike of these schists is sometimes and perhaps most often north 30 degrees east but it varies from north 30 degrees east to almost east and west. This east and west strike can be found about one-half mile west of Roxbury station. The dip is usually at a high angle to the west but a dip of 80 degrees to the east was recorded in the northern part of Roxbury; also in the southern part of Roxbury.

Each of the verd antique marble lenses so far as is known is surrounded by chlorite schist. More or less talc is usually found next to the chlorite wall and then between these walls lies the massive verd antique marble. The east wall of quarry No. 1 becomes the west wall of quarry No. 2.

The variations in dip and the encircling character of the chlorite schist can be seen in Plate XIV.

In origin these schists are manifestly alteration products of some basic igneous rock rich in its ferromagnesian minerals. Their variation in strike from north 30 degrees east to practically east and west substantiates this theory. The strike of the adjacent sericite schist is north 30 degrees east. Quartz is generally if not always present in chlorite schists derived thru the alteration of sedimentary deposits, but many microscopic slides from these chlorite schists have shown quartz sporadically present or entirely wanting. The absence of uncombined silica in certain slides suggests an igneous origin for this rock in its association with the verd antique marble and talc deposits in Vermont. Many samples were collected this summer for additional petrographic study. The results of the study of slides now in the process of preparation will be too late for this report, but as these chloritic rocks are known to appear in the townships to the southward

PLATE XIV
SCHIST AND SERPENTINE
QUARRY OF VERMONT MARBLE COMPANY, ROXBURY

which the author of this paper expects to work next summer the evidence will be of much value at that time.

Peridotite and Pyroxenite

The peridotite and pyroxenite belt in Roxbury is three and one-half miles in length and one and one-half miles in width. In its northern extension it enters Northfield and its southern limit is about one-half mile south of Roxbury railroad station. The verd antique marble was discovered when the Central Vermont railroad was constructed thru the Roxbury valley in a railroad cut near the southern end of the outcrops. This belt is reported to extend across the swamp and to appear on the ridge to the east of the railroad. As none of these reported outcrops have been opened for the manufacture of marble or the mining of talc they were not visited.

The peridotite magma is regarded as having been introduced into the sericite schists and Cambrian quartzites at the close of the Cambrian. In Vermont at least this belt nowhere cuts terranes of Ordovician age.

Verd Antique Marble

The verd antique marble of Roxbury has been so fully and ably discussed by Prof. E. C. Jacobs, University of Vermont, in his report on "The Talc and Verd Antique Deposits of Vermont," and published in the Tenth Report of the State Geologist, pages 232-280, that the author of this report feels justified in the omission of an extensive discussion of these marble deposits.

The name serpentine is applied not only to the mineral itself but also to the rock masses consisting essentially of the mineral serpentine

Ophicalcite is the name applied to the spotted green and white varieties often appearing as crystalline marbles. It consists of a mixture of serpentine with calcite or dolomite.

Ophimagnesite is the name applied to a rock containing crystalline magnesite with disseminated serpentine.

The author of this report introduces into geological literature the term ophidolomite. Ophidolomite is the name applied to a rock containing crystalline dolomite with disseminated serpentine. Samples may be secured in Roxbury that meet this definition perfectly. Here it is of igneous origin, but ophidolomite like ophimagnesite might be of sedimentary origin. In keeping with the idea involved in the term ophidolomite, ophicalcite might be defined as a rock containing crystalline calcite with disseminated serpentine. The three terms would be correlative.

There are 11 verd antique marble quarries in Roxbury owned and operated by the Vermont Marble Company of Proctor, Vermont.

1. This quarry is situated about 80 rods south of the railroad station at Roxbury and a few rods west of the railroad track. It was opened approximately in 1850 and has been in operation much of the time since. Its east and west walls are chlorite.

2. This quarry is located a few rods south of No. 1. It was opened in 1910 and operated for two years. Its east and west walls are chlorite. The east wall of No. 1 is the west wall of No. 2.

3. This quarry is situated three-fourths of a mile northwest of the village of Roxbury on the farm of Hiram Ellis. It was opened in 1913. Its east and west walls are supposed to be chlorite.

4. This quarry is also located on the farm of Hiram Ellis. It was opened in 1913. Its east and west walls are supposed to be chlorite.

5. This quarry is located one-fourth of a mile west of the village of Roxbury on the farm of James Tierney, just north of the Warren road. It was opened in 1915. Its east and west walls are chlorite but a bed of talc schist 20 feet in width separates two beds of marble without being directly in contact with chlorite.

6. This quarry is situated 1000 feet southwest of No. 1. It was opened in 1913. There is a small tunnel in the north end of the quarry that quarrying in winter may be executed under cover. There is a wall of talc on both sides of the marble, and this talc is flanked by chlorite.

7. This quarry is known as the Scampini quarry. It is situated two and one-half miles north of No. 1. It was opened in 1914. It is a softer marble than that obtained from the other quarries. The marble is full of bird's eyes of talc that prevent a high polish to the stone. The west wall is chlorite but the east wall has never been encountered. Presumably it is chlorite.

8. This quarry is located 400 feet north of No. 6. 600 feet southwest of No. 1. Directly west of No. 2. It was opened in 1914. Its east and west walls are chlorite.

9. This quarry is north of No. 8. It was opened in 1915 and abandoned.

10. This quarry is situated on the high bluff 1000 feet south of No. 1 and 175 feet above the valley. It was opened in 1916. Its east and west walls are chlorite.

11. This quarry is situated one-fourth mile west of the railroad station at Roxbury. It was opened in 1917. Its east and west walls are chlorite. While it is the newest of the quarries it has produced some excellent marble and will produce much marble equal in beauty, if not superior, to any marble ever produced in Roxbury.

About 100 rods west of railroad station there are within a distance of 300 feet three separate beds of verd antique marble and four beds of chlorite schist which shows how intimately the marble beds are associated with the chlorite. In this same neighborhood the strike of the chlorite varies from north 20 degrees east to nearly east and west. This fact favors an igneous origin for the chlorites.

In the petrographic examination of both the serpentine and the verd antique marbles the primary minerals from which the serpentine and the verd antique marbles were derived are mainly wanting. Specimens showing olivine have been found. Samples have been obtained in the southwest corner of quarry No. 5 that are identical megascopically with samples obtained from the serpentine belt in Belvidere and Lowell, Vermont.

The serpentine occurs as the leafy variety, antigorite, associated with dolomite. In small samples the dolomite equals or even exceeds the serpentine. The dolomite at times includes both antigorite and magnetite. In some cases the magnetite includes small crystals of dolomite. The dolomite is later in formation than the serpentine. Some of the magnetite is earlier than the antigorite and some of it is later. Actinolite, picrolite and talc are common associates with the verd antique marble. The fibrous variety of serpentine, known as chrysotile, is present in some of the quarries.

The origin of the verd antique marble is from the alteration of a peridotite magma to serpentine, or else it was derived from the serpentine itself. The chrysotile fibers when present are set transverse to the fracture planes in the serpentine and have grown exogenously from a film of magnetite into the walls of the serpentine. The picrolite occurs where shearing of the serpentine has taken place. The talc occurs where the metamorphic processes have attacked the pyroxenic minerals of the parent rock, or else from the alterations of the serpentine. The absence of pyroxenic minerals in the talc is noteworthy. Perhaps they have been completely changed to talc. The verd antique marble has been influenced by carbonate solutions. The grit which is found in several of the talc mines in Vermont and which is a mixture of talc and dolomite have been formed under the influence of carbonate solutions. It is certain that a great deal of dolomite has come into the Roxbury serpentine from some source, and that it came after the serpentinization of the original magma and after the shearing which produced the chrysotile and the picrolite.

Along the new road leading up to quarry No. 11 there is an interesting mass of highly altered igneous rock whose original minerals are as yet undetermined. It appears to consist of smoky quartz and a ferriferous dolomite. It has been suggested by some scientists who have seen the samples that it is a highly altered calcareous sediment, but such a sedimentary deposit would not occur within the peridotite-pyroxenite lens where this outcrop is located. It will require several chemical analyses of different portions of this outcrop, and numerous microscopic slides for petrographic study before the exact composition and origin can be determined. The dolomitic content weathers brown upon exposure to the atmosphere and may prove to be breunnerite. The rock is called a metapyroxenite. It is regarded as a highly altered phase of the pyroxenite.

A transverse gravity fault traverses the verd antique marble belt just south of the high bluff on which quarry No. 10 is located, and another fault more or less parallel with this appears to the north of quarry No. 1.

In the southern part of the township of Roxbury, and on the west side of the Roxbury valley there is an abandoned talc mine. A considerable amount of gritty talc has been removed from this mine which is now nearly filled with water. It is flanked by the black walls containing chlorite like the other talc mines in the neighborhood. This deposit contains numerous crystals of breunnerite. Its origin appears to be from the alteration of pyroxenite.

The Eastern Talc Company owns and operates a talc mine at East Granville which is about one mile south of the abandoned mine in Roxbury. This mine, however, is located on the east side of the Roxbury valley on a chain of talc lenses that vary from 50 to 400 feet in length and from 15 to 50 feet in width. The mine is operated thru two adits and the talc is conveyed to the mill by an aerial tramway. The mill is situated by the side of the Central Vermont railroad. This mine has been quite extensively developed and is producing good talc which it can continue to do for many years.

USES OF SERPENTINE AND TALC

Serpentine has been used in many instances in the place of marble for structural purposes. The dressed stone does not weather uniformly and the white and yellowish white veins lose their luster and crumble. The entire face of a building may therefore become as unsightly as it once was beautiful. Its resistance to compression is too low for the more massive forms of architecture. It can be used to a good advantage in columns where only a moderate pressure is demanded. It has been used from time immemorial for monumental work in France and Italy. In later years it has been used somewhat for that purpose in America. It is sufficiently soft to be turned and polished on a lathe. Its beautiful colors when polished have made it a favorite with all civilized nations for decorative interior work and for small articles of ornamentation.

Ornamental fronts, pulpits, small shafts, pillars, pilasters, vases, tazzas, choir steps, ambulatories and inlaid work utilize serpentine. The finely fibrous variety known as chrysotile is now being manufactured into fireproof lumber which can be planed, sawed and finished like ordinary lumber, and yet possesses all the advantage of fireproof material.

While massive talc which is known as steatite occurs in Roxbury it is not apparently in commercial quantity. Steatite is most admirably adapted for table tops, sinks, stationary washtubs, refrigerators, fireplaces, furnaces, stoves, mantels, fire brick, hearthstones, warmers, grills, and griddles. The waste material when free from grit can be pulverized and used as a lubricant or a white earth. Large quantities of talc are consumed annually in the manufacture of soap. It increases the weight of the soap but not its power of solution. It is used extensively as a filler in the manufacture of paper by the sulphite process. Here also it needs to be free from grit. It is also used in the dressings for fine skins and leather. Shoe and glove dealers consume annually an appreciable amount of this commodity. The base of many toilet powders is talc. This is often mixed with borax. Talc has been used as the body of paint and in the manufacture of plaster. It has been used also in the sizing of cotton cloths. It is used in the manufacture of rubber goods, composition flooring, foundry facings, as a lubricant, and in the ceramic arts. As a foundry facing it has proved a very satisfactory substitute for graphite. As a lubricant deflocculated talc has proven equally serviceable with deflocculated graphite. Other uses for talc are for crayons, pencils, French chalk, grotesque images, and tips for gas burners. This last use illustrates the ease with which talc may be manufactured into small objects of considerable commercial value.

PALEONTOLOGY

The sericite schists, hydromica schists, and non-calcareous quartzites of the central and western portion of this area have been continuous in their northern extension into Canada, where, in the sericite schists and associated quartzites Upper Cambrian fossils have been obtained. In Vermont no fossil content has as yet been found in these terranes on the eastern side of the Green Mountains. Their relative age has been determined by continuity, lithological characteristics, and stratigraphical position. They are unquestionably pre-Ordovician for they furnish pebbles for the basal conglomerate in Irasburg, Albany, and Northfield, which lies at the base of the Ordovician series in eastern Vermont. The frequent occurrence of a conglomerate in these Cambrian terranes would suggest that the sericite schists and their associated quartzites were Upper Cambrian and the hydromica schists which flank these members on the west were Lower Cambrian. But little attention has been given to this westernmost member for it generally occurs in a densely wooded area and at high altitudes along the crest of the lower mountain ridges. It can be considered Lower Cambrian only tentatively.

No definite name has been applied hitherto to the sericite schists save describing them as sericite schists and quartz-sericite schists. The author of this paper proposes the name of Missisquoi schists for this terrane. It is the prevailing schist in the Missisquoi River valley in the northern part of the State from whence the name is derived. It is the schist which is associated with the two parallel serpentine beds which occur to the north of Belvidere Mountain. In fact it is the schist in which most if not all of the serpentine and talc beds occur on the eastern side of the Green Mountains. The term is not pre-occupied. The Cambrian quartzite is only a sericite schist in which there is a great preponderance of quartz grains over the scaly or fibrous muscovite (sericite) and therefore it belongs with the Missisquoi schists.

The discovery of many new beds of graptolites this summer in Roxbury, Brookfield and Braintree is significant. They have been discovered now in more than 20 townships along the line of the erosional unconformity for a distance of approximately 100 miles and in a breadth of nearly 10 miles. Their discovery this summer in the slates on the east side of Cram Hill in a densely wooded area in Roxbury proves the southern extension of the Memphremagog slates as early Ordovician. Graptolites were not found in the interstratified phyllite schists but they were found in both the Waits River and the Washington phase of the Waits River limestones and quartzose marbles, which still leave these calcareous formations as Ordovician. Numerous beds of these graptolites may be found in the shaly limestones near the west town line in Brookfield, and in the slates on the east side of the easternmost north-south ridge in Roxbury. They are also abundant in the limestones which flank these slates on the east in Roxbury. It is interesting to note that they are as numerous in the slates in Roxbury as they are in the slates in Woodbury some 50 miles to the north of Roxbury.

Economics

The Missisquoi schists in Roxbury are of little commercial value. Slabs of this material find a local use for culverts, bridges, guards, underpinning and foundation work. It is also used somewhat in road construction. In the southern part of Roxbury the sericite schist appears suitable for flagging purposes.

The more quartzose phase, styled the Cambrian quartzite, has a fine grit, does not gum, and could be easily manufactured into whetstones of a good grade. Such an outcrop can be found on the north of the road leading from the village of Roxbury over Roxbury Mountain to Bull Run and to the west of the north-south road near the crest of the divide.

There are beds of slate in the Memphremagog slates in Roxbury that are quite fissile so that they can be easily split into

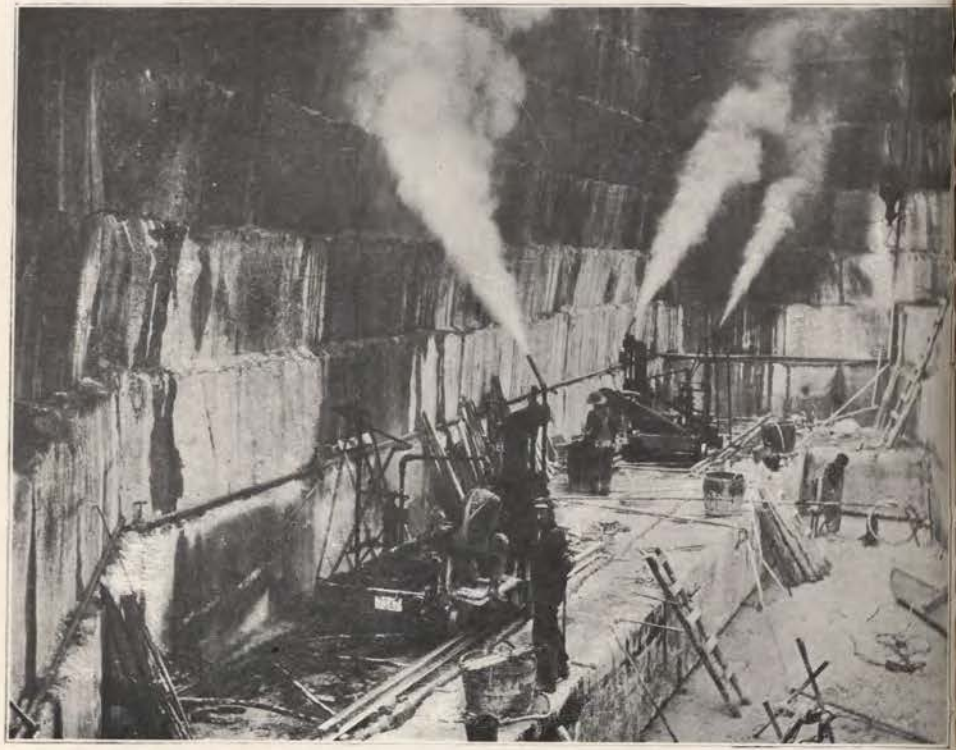


PLATE XV
QUARRY OF VERDE ANTIQUE, ROXBURY
VERMONT MARBLE COMPANY

slates for roofing purposes. These deposits are located in the northern and eastern part of the township.

The limestones and the quartzose marbles of Roxbury may have a local use in the construction of culverts, bridges, foundations and permanent roads. The limestones in places have a good rift and grain and can be easily worked into rectangular blocks. The quartzose marbles are susceptible of a good polish and when freshly cut the contrast between the polished and hammered surfaces would be strong. Beds of this marble can be found to the west of West Brookfield and east of Cram Hill.

By far the most important economic product in Roxbury is the verd antique marble where there are 11 used or unused marble quarries owned and operated by the Vermont Marble Company of Proctor, Vermont. While this marble is quarried in Roxbury there is no mill in Roxbury for the manufacture of the marble into its numerous commercial forms. The blocks are all shipped elsewhere for this purpose. Explosives are not used in the quarrying of the marble. The vertical cutting is done by channelling machines and the under cutting by gadding machines. The work of the channelling machine is shown in Plate XV. The blocks weighing from 15 to 30 tons each are raised from the floor of the quarry and loaded by derricks.

According to Mr. J. B. Kidder, Superintendent of the Vermont Marble Company's plant at Roxbury, only about 30 men are now employed at the quarries while before the outbreak of the war the number was approximately 100 men.

SUMMARY

The areal map is designed to show roughly the general distribution of the different terranes in Roxbury. Without topographic maps in a country as rugged, broken, and densely wooded as Roxbury accurate mapping would be extremely difficult. The map must be regarded as an approximation.

The protracted section shows the general dip of the cleavage planes which does not always coincide with the bedding planes. In fact a wide difference in these planes can be seen just west of the northern end of Lovers Lane a little to the west of the village of Roxbury. The nearest approach to these two planes coinciding with each other is found in the graptolitic limestones and slates in the eastern part of the township.

The erosional unconformity which was so pronounced in Irasburg, Albany, and Northfield has been proven to extend southward thru Roxbury into Braintree. The definition of the different terranes has been effected by the study of microscopic slides. The origin of the verd antique marble has been carefully studied together with its mineral composition. Some of the chlorite schists or chloritic dikes at least have been proven of igneous origin. The discovery of several new beds of graptolites in the slates and limestones thereby proving the stratigraphical position of these terranes by fossil content is important. Several problems remain unsolved for lack of time to complete the work before this Report must go to press.

PROGRESS IN COPPER MINING AND MILLING

E. C. JACOBS

UNIVERSITY OF VERMONT

In the last report, under the caption Copper Mining in Vermont, the writer showed that there had been a revival of copper mining in the State. He gave a brief account of the geological formations at the three old centers of the copper industry, South Strafford, Vershire, and Corinth, and an historical sketch of their mining and metallurgical activities.

The ore was shown to consist of chalcopyrite ($CuFeS_2$) disseminated in pyrrhotite (Fe_7S_8) and carrying a very small amount of silver. The minerals were seen to occur in great lenses or pods, lying concordantly with the foliations of the country schists and striking generally north and south.

It was seen that, at South Strafford, the Vermont Copper Co. was experimenting to determine the practicability of smelting its ores pyritically; while at Corinth, the Pike Hill Mines Co. was investigating the Wood system of flotation as a means of separating the valuable chalcopyrite from the worthless pyrrhotite.

At South Strafford it was found that, while probably practicable, pyritic smelting would be attended with many difficulties. The mine was remote from the coke producing districts, fluxing material would have to be brought from the west side of the State and would carry no mineral values with which to help defray haulage costs, while the deleterious effect of smelter fumes on the vegetation would always subject the company to suits for damages by neighboring farmers.

At Corinth the Pike Hill Co. found that the Wood system of flotation was not reliable enough (was too much "hit or miss") in its working to justify its installation on a large scale.

THE PRESENT SITUATION

THE VERMONT COPPER CO. OF DELAWARE

President, August Heckscher.
Mining Engineer and Gen'l Manager, N O. Lawton.
Mine and mill at South Strafford, Vermont.

MINING

As the last Report showed, the ore body here consists of one or more great lenses of chalcopyrite disseminated in pyrrhotite.

These lenses strike north 20 degrees east, dip about 60 degrees easterly, and pitch 12 to 14 degrees downward to the north. The southern workings, which outcrop on the surface, have been practically exhausted, but the northern workings, which plunge deeply below the surface, are now being mined.

The ore bodies are reached by an adit, driven westward from the surface, at the mill, 1350 feet into the hill in which the ore bodies lie. The northern ore body is cut by the adit level, driven on the strike of the deposit for its entire length (about a thousand feet) and by an inclined shaft 810 ft. long, having a slope of 20 to 27 degrees. From this incline, levels have been driven at 96 feet, 227 feet, and 311 feet, respectively, below the adit level. The lower end of the lens is some 600 feet below the surface, at the mill, but only 30 feet above the Pompanoosuc River. The ore is mined mostly by underhand stoping. The ore body varies from 12 feet to 100 feet in thickness. Tramming and lighting are done by electricity, hydro-electric power being furnished by the Sharon Power Co.

Conservative estimates show 540,000 tons of mineral "in sight," while exploratory drilling is being carried on to locate other possible lenses.

Labor shortage, accentuated by the war, is greatly handicapping mining operations.

Milling

The flotation mill, designed by the General Engineering Co., of New York and Salt Lake City, was erected in the summer of 1917 and was ready for work in the following October. The mill has a capacity of 100 tons per 24 hours and is producing concentrates running from 16 to 25% in copper. Coal tar creosote, coal tar, and pine oil are the flotation agents.

Flow Sheet

The ore is brought from the mine, through the adit, by electric tramcars to the crude ore bin. It is then crushed by a Blake jawcrusher and a Telsmith gyratory crusher to about one inch cubes and passes to the crude ore bin. The ore is next elevated to a Hardinge ball mill (6 ft. by 22″) which crushes it to a variable sized product. This product is then separated into "sands" and "slimes" by a Dorr classifier, the former passing back to the ball mill for further grinding, while the latter goes to the Callow flotation cells. The proper amount of oil for the flotation is fed into the ball mill and so becomes thoroughly mixed with the slimes by the time they reach the Callow cells. There are two units of these cells, each unit comprising two cells placed in tandem. The slime passes across the first cell and is divided into "heads" and "tails." The tails are then air lifted

and pass across the second cell, also forming heads and tails. The second tails are then rejected while the heads pass to a "cleaner cell," arranged with a return flow. The first tails go back to the "rougher cells" while the clean heads go either to thickening tanks, where the excess of water is decanted off, or else directly to an Oliver filter, in which the water is removed by a rotating vacuum cylinder and the dried product (chalcopyrite, containing 16 to 25% copper and $1\frac{1}{4}$ oz. of silver) is stored in bins. This product is hauled by motor trucks to Sharon and shipped to the American Smelting and Refining Co. at Perth Amboy, N. J.

The plant is operated by electricity, is compact, easy to operate, and is giving excellent satisfaction. It is run on the "three shift" plan, with five men to a shift.

Production

The new mill was in operation, although not continuously, during the last three months of 1917, during which time 1,035,960 lbs. of concentrates were recovered.

For the first six months of 1918, 1,980,320 lbs. of concentrates were produced, which contained 312,678 lbs. of copper, or 15.78%.

It is estimated that the cost of producing the copper will vary from 12c to 18c per pound.

VERSHIRE

In the prosperous days of the Ely Mine the ore was brought to the surface and hand picked (cobbed), the rich material going to the roasting beds and the poor to the dumps. The richest ore contained about 20% of copper, the average ore roasted carried about 16%, while the discarded material probably averaged 1½% copper. It is estimated that there are 300,000 tons of available ore on these dumps. This material has awaited the application of a cheap method of extraction, which has now been apparently found in the oil flotation process.

The old Ely Mine, dumps, and rights (all machinery, houses and other movable property were sold and removed after Mr. George Westinghouse's unfortunate experience of 1900-1901), were acquired by the Ely-Copperfield Associates of New York.

Mr. Hogge, President.

Mr. H. W. Bennett, of New York City, principal owner.

Mr. K. A. Schleifer, resident superintendent.

Mr. A. P. Watt, New York City, consulting engineer.

The purpose of the company is to recover the copper from the dumps, and later, perhaps, to rehabilitate the mine, in the lower workings of which much ore is said still to exist.

The flotation plant was erected just below the largest dump in 1917-18 and milling operations began in April 1918.

FLOW SHEET

Dump.
↓
tramcars
↓
crusher (30″ x 12″)
↓
storage bins (400 tons)
↓
Hardinge Ball Mill (8′ x 30″)
(capacity 250 T. per 24 hours, crushes to 65#)
↓
Dorr Classifier (5′6″ x 18′)

sands
↓
back to Hardinge Mill
for regrinding

slimes
↓
elevated by Frenier pump
↓
Mineral Separation Co-12 Compartment
Flotation Cell
(250 T. capacity per 24 hours)
↙ ↓

heads
↓
Dorr Thickener
↓
Oliver Continuous Filter
(6′ x 4′) ↓
Chalcopyrite concentrates
↓
shipped

middlings
↓
to head cells

tails
↓
waste

The cells use a mixture of 50% pine oil and 50% coal tar, of which 1½ lbs. per ton of concentrates are used.

The mill is designed to treat 200 tons of ore per 24 hours and is extracting 90 to 95% of the copper and silver values. The raw ore carries about 1½% copper. The concentrates carry from 15 to 23% copper, while the tailings run from .17 to .25% copper. The concentrates also contain slightly less than 1 oz. of silver per ton and 5 to 6% of moisture.

The concentrates are hauled nine miles to Ely Station, Passumpsic Division of the Boston and Maine Railroad, at a cost of $2.00 per ton, and shipped to the Norfolk Smelting Co

The plant is at present operated by steam power, but plans are on foot to develop a hydro-electric plant on the Ompompanoosuc River. Such a plant should result in large economies as well as in continuity of operation.

The company employs about forty men but finds much difficulty in maintaining this force.

It is estimated that three years will be required for reworking the dumps.

PRODUCTION

The Company reports that it began production in April, 1918. Concentrates recovered up to July 1, 1918, amounted to 437 tons, which averaged 16.1% copper. The average per cent of running time was 81.

THE PIKE HILL MINES CO.

President, John H. Allen.
Mining Engineer and Manager, Harry G. Hunter.
Mine and Mill at Corinth, Vermont.

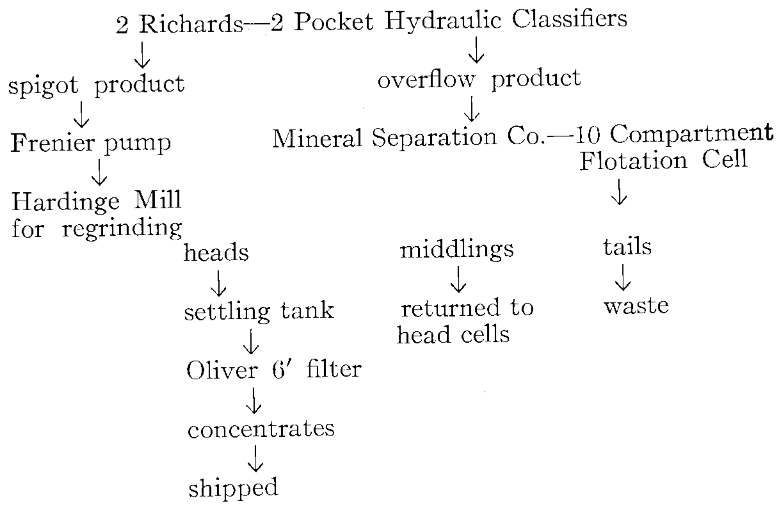
This company was incorporated in 1905 and has been working the old Cuprum and Eureka Lodes intermittently.

These old ore bodies have been developed and at least 90,000 tons of ore are known to be available for milling. Besides this, there are some 45,000 tons of low grade ore on the dumps, which will average 1¾% copper. The company estimates that it will take at least five years to mine and mill the ore "in sight," while of course further development may reveal other ore bodies.

The Wood Water Flotation Process having been abandoned, the company undertook experimentation in oil flotation in the summer of 1916. The proper method of treatment having been determined, building operations on the new mill were begun in April, 1917, and completed in the following September, when production of concentrates began.

The mill differs somewhat in its design from the other copper concentrators above described. Its flow sheet is as follows:

Mined ore or ore from dumps
↓
rough ore bin (800 T. capacity)
↓
Sturtevant crusher (9″ x 15″)
↓
belt elevator to crushed ore bin (100 T. capacity)
↓
Hardinge Ball Mill (6′ x 22″)
(crushes to 60#)



The flotation cell is being run with pine oil alone, .18 lb per ton of ore being used. The oil is introduced at the head cell. The flotation cell has been somewhat modified in some of its details and is giving excellent results. The mill is designed to treat 100 tons of ore per 24 hours. The ore will average 2½% copper, while the maximum content is 3¾%. About 90% of the values is being recovered. The concentrates average 18 to 20% copper, while the richest have shown 24.28%. The concentrates also carry 1½ oz. of silver per ton and a trace of gold. The insoluble matter in the concentrates amounts to 5 or 6% and the moisture is also 5 or 6%. The mill runs very smoothly and requires the services of only one man per shift below the crusher floor.

The concentrates are hauled to Bradford, 14 miles away, at a cost of $3.50 per ton, and shipped to the Nicols Copper Co., at Laurel Hill, N. Y.

Electric power for both mine and mill is obtained from Groton, 15 miles away, being furnished by the Eastern Vermont Public Utilities Corporation. It is transmitted at 13,200 volts to the mine where it is stepped down to 440 volts.

About forty men are employed in mine and mill and labor shortage is painfully felt.

The total cost of producing a pound of refined copper is at present probably 21 cents.

PRODUCTION

The Company's production in 1916 was 281,271 pounds of copper and 1,675 ounces of silver, this being obtained with the old magnetic separator plant and in experimenting with flotation.

In 1917, 51,090 pounds of copper and 216 ounces of silver were recovered.

The production for the first half of 1918 was 185,206 pounds of copper and 776 ounces of silver.

The maximum production was attained in August, 1918, when 412,111 pounds of concentrates were recovered, which contained 69,810 pounds of copper.

OTHER COPPER DEPOSITS

On the Gove farm, just northwest of Strafford Upper Village, there is a copper deposit, called the Orange Mine, on which some work has been done intermittently during the last 25 years. There is said to be an inclined shaft, 107 feet long, and several pits dug along the strike of the lode. The property is owned by Messrs. Reynolds and Fraser.

Near the Orange deposit is the old Green Mountain Mine, from which ore was shipped, years ago, to the smelter at Vershire.

About a mile northwest of the Orange Mine there is said to be a promising deposit of copper on the Walker property. About 70 feet of development work has been done here.

PROGRESS IN TALC PRODUCTION

E. C. Jacobs

UNIVERSITY OF VERMONT

Vermont became the first state in talc production in 1917, with an output of 94,000 tons, passing New York, which had hitherto held first place.

The bulk of Vermont's talc is of low grade and cannot compete with the agalite of New York, the best products of Georgia, North Carolina and California, or the high grade imported material; but there is a constantly increasing demand for this low grade mineral for use in the paper, rubber, bleachery, and other industries. In the paper pulp industry this increased demand has been due very largely to the decreased importation of English kaolin (China clay)—in fact Vermont's increase, in 1917, of 20,600 tons, over 1916, largely offsets the decrease of kaolin importations, of 22,900 tons, in the same period.

For some grades of stock, as roofing papers, foundry facings, etc., of course the color of the talc is of no importance and this permits the grinding of a good deal of "black wall," whose magnesian content gives it the requisite "slip" and infusibility.

The labor situation has been acute and is growing more so. That Vermont has been able to increase her output in these trying times is remarkable and speaks well for the efficient management displayed by the companies in improving their milling arrangements. Talc production has been recognized by the Federal Government as an "essential industry" and ample transportation facilities have been furnished.

Considerably higher prices have been obtained for talc products during the war, the present average for the State of $8.05 per short ton being some 18% higher than the average for 1917; but this increase has by no means kept pace with increasing costs and still higher prices must be expected.

In the list of talc producing companies there is one new comer, the Vermont Talc Products Company, incorporated in July 1918, which plans to work the deposit in the towns of Waitsfield, Fayston, and Moretown.

Several important deposits of talc have been prospected and opened up since the last report, and the known reserves are probably larger now than ever before.

THE PRODUCING COMPANIES

JOHNSON

The American Mineral Company is making a new record for production and is planning important improvements to its equipment.

South of its old deposit, near the mill, there has been discovered a new talc lens which will, it is hoped, add materially to the mineral reserves of the company. This lens is some 200 to 300 feet from the old mine and will be opened by a tunnel from it.

On the large deposit at East Johnson the old shaft on the east wall of the deposits has been sunk to the third level, 120 feet from the surface. Cross cutting has been carried 200 feet westward and is still in good grit. A new shaft is being sunk in the middle of the deposit, dipping seventy degrees easterly, and has reached a depth of 100 feet. It is to be equipped with electrical hoisting machinery, the power to come from the Morrisville plant. The East Johnson deposit is an enormous one and should furnish ample supplies of talc for many years to come. The deposit is three and one half miles from the mill, in an "air line," and the company is planning to install an aerial tramway which will greatly increase the mill production while decreasing transportation costs. This tramway will probably be built by The American Steel and Wire Company and it is estimated that haulage costs can be reduced from $1.10 per short ton (the present price) to forty cents. Meantime Garford two-ton trucks are being used.

The American Mineral Company has been reorganized and now provides for $100,000, seven percent cumulative preferred stock (par value $100) and $60,000 common stock. The company owns 368 acres of mining lands and has mining rights on 369 acres more. It finds an extensive market for its products all over the country, the talc being used for talcum powder, soap, wire insulation, and as a filler for paper, cotton cloth, window shades, leather and paint. The coarser grades are in demand for roofing paper, rubber goods, composition flooring, grease, plaster, insect powder, foundry facings, etc. The sales of the company have increased from $23,608, in 1912, to $90,351, in 1917, while current demands cannot be met with present equipment. The company therefore proposes, with the increased capitalization, to install the tramway above referred to, to increase the mill buildings and machinery, and to provide sufficient capital for growing needs. It is proposed to build the new mill in sixty ton units, the first unit to be constructed as soon as possible. This will give a total daily production of 100 tons, while additional units will provide for growing needs. The company has paid dividends since 1917.

MORETOWN

The Magnesia Talc Company is the second largest talc producing corporation in the State and, like its competitors, is enjoying a period of great growth and prosperity. Its products are in demand for paper and rubber filling and in bleacheries, roller mills, etc. Fifty to seventy-five per cent of its present output is needed for filling war contracts.

The company is continuing mining operations on its large deposits just south of the mill and has now extended its adits over 1,900 feet into the talc lens. Five "raises" have been driven from the lower adit and 22 "stopes" are being worked. Mining operations have shown the deposit to consist of one enormous lens of mineral, widening in some places and pinching in others. The maximum width of the lens is probably sixty to eighty feet, while the average width is forty feet. There are talc outcrops on the hill 1,500 feet south of the present workings, so that ample reserves of mineral are assured.

The company has acquired this year a large new talc deposit in Waterbury Center, on the lands of Frank C. Hayes and John H. Parker. Like the Moretown deposits, the talc here has been derived from serpentine, as it forms a part of a great ridge of that mineral over 1000 feet long and probably 250 feet wide at the surface. This ridge lies 400 feet east of and parallel to the road from Waterbury Center to Stowe Hollow and has a strike of N. 25 degrees E. (magnetic). The serpentine is ash colored and much fissured. A twenty-five foot prospect pit on the east side of the ridge has disclosed a good grade of talc and grit, and there seems every reason for believing that an enormous deposit of talc here awaits development. The topography is such that the deposit can be advantageously opened by adits, while proximity to the Stowe Electric Railway suggests an efficient and economical means of transportation to Waterbury.

The Company's mill at Moretown has been rearranged during the last few months, and this has resulted in increased ease of handling the mineral and in much labor saving.

FAYSTON—MORETOWN—WAITSFIELD

The talc deposit here, which has been worked at various times by the Vermont Talc and Asbestos Company, The International Mineral Company, and The American Quarries Company, has now passed under the control of the Vermont Talc Products Company. This company was incorporated in July, this year, the incorporators being G. E. Moody, F. C. Luce, E. E. Grant and J. S. Wilkins, of Waterbury, and George Almon, of Montpelier. The old mine on the talc lens, which is said to be 100 feet wide, is being cleaned out and it is hoped that production may start by September 15, with an output of 35 to 40 tons per day. The company will make ground talc and crayons.

EAST GRANVILLE

The Eastern Talc Company is continuing work upon its talc deposits here. A large amount of mineral is still available, and is being steadily mined and milled, the product being used in the paper industry.

ROCHESTER

The Eastern Talc Company, which is by far the largest producer in the State, is still obtaining the bulk of its talc products from the old Williams Mine, and at the same time is developing the numerous prospects which have been located in the immediate vicinity of this enormous lens. The Williams deposit is said to be the largest in the world, and that it is only one, although probably the largest, of a group of lenses has been proved by the systematic diamond drill explorations which the company has carried on for several years.

In the last report of the writer*, a diagram was presented showing that the Williams Mine consisted of a great talc lens or pod, some three hundred feet long and sixty feet maximum width, lying in the foliations of the country schist and dipping generally seventy-five degrees easterly. The mine was shown to have a maximum vertical depth of over 450 feet. Diamond drilling driven eastward from the fourth level, through the black wall, discovered a new lens, lying sixteen feet from the old one and parallel to it. The new lens was opened up on this level to a length of 160 feet and a maximum width of 30 feet.

From the observed relationship of the lenses, the writer expressed the opinion that the deposit had resulted from an injection of the country schists by a basic magma, which had been forced upwards by hydrostatic pressure into preexisting cavities—that it was, to use Daly's term, a "chonolith." Since the last report this side lens has been developed in all directions. On the fourth level it is now over 300 feet in length and 70 feet wide. The lens appears to be pitching southward. At the south end the walls have come together. Stoping has been carried upward to the first level. But at the fifth level, which is 65 feet below the fourth, cross cutting from the old mine has revealed only a trace of the new lens. This seems to prove the chonolithic nature of the new lens, that it has resulted probably from an overflow of the magma from the old lens into a preexisting cavity, at the location of the fourth level.

This new lens is furnishing an excellent quality of talc and grit.

A drill hole bored easterly from the south end of the new lens, for 80 feet, struck talc for a distance of 90 feet, while more talc has been encountered 93 feet north of the northern end of the new lens.

At No. 5 Mine, about 700 feet southeast of the Williams, mining operations have extended to the third level and the lens has been opened up for a distance of over 300 feet on its long axis

---

* Tenth Report of the Vermont State Geologist.

and 150 feet in width. Furthermore, drill holes bored north and south of the present workings, through the country rock, have proved the existence of talc at considerable distances from the No. 5 lens.

Earlier reports of the writer have noted the presence of a small dome shaped hill of serpentine (Cushman's Hill) about 700 yards north of the Williams Mine, and the development of talc to some extent thereon. The Eastern Talc Company has acquired this property and conducted systematic prospecting operations by diamond drilling. This has resulted in the location of a large body of talc 1,500 feet from the Williams Mine. The drills have encountered talc and serpentine and seem to show that Cushman's Hill is an enormous dome shaped intrusion, on the flanks of which a large amount of talc has been developed. It will be recalled that practically no signs of serpentine have been found in the Williams Mine, but that analyses pointed to the mineral enstatite as the probable progenitor of the talc. Here, however, the talc has been derived from serpentine, as is also the case at Moretown. It was shown in the last Report that probably at least two injections of the Vermont sericite schists have taken place, at different times, the one giving rise to the serpentine hillocks, which in some cases have developed talc; the other, probably to enstatite from which talc has also been derived. The former existence of enstatite is entirely hypothetical and is based on chemical analysis. The derivation of talc from serpentine (or rather antigorite) is plain and unmistakable.

To return to the newly discovered lens (which has been called the No. 8 Mine), talc has been proven for a distance of over 600 feet in length, from 150 to 275 feet in breadth, and from 80 to 120 feet in depth. The estimated tonnage is 600,000 tons. A shaft has been sunk in the deposit to a depth of 135 feet, on a forty-five degree incline, and is ready for hoisting equipment.

It is more and more apparent that this region contains an almost inexhaustible supply of talc and grit. The value of the diamond drill as an exploratory agent is apparent.

The Eastern Talc Company's Rochester mill remains substantially as it was two years ago, with a productive capacity of about 100 tons a day, but it is now planned to electrify it with power from the Hortonia Power Company. An office building has been added to the equipment and a moving picture theater has been provided for the amusement of employees and their families.

CHESTER DEPOT

The Vermont Talc Company continues to mine talc at its Windham property and mill it at Chester Depot. The company also has other prospects under option. The Windham Mine still contains a very large tonnage of talc, which will last the company for many years to come. The mine is being equipped with additional machinery and the company is making every effort to increase its output, although here, as everywhere else, labor shortage is a serious handicap. Motor trucks as a substitute for team haulage have been found advantageous. The mill is at present producing about 20 tons per day, but is easily capable of a much greater output. The product finds its chief use in paper and rubber manufacture.

THE AMERICAN SOAPSTONE FINISH COMPANY

This company is still working the old Carlton Quarry but has another large deposit at Smokeshire, about five miles from Gassett's Station. The product is used in the manufacture of several preparations: soapstone finish, plaster board, dusting powder, roofing paper, etc.

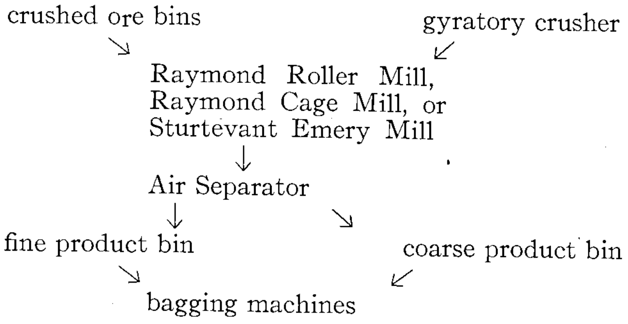
MILLING PRACTICE

In talc milling fine grinding is a prime requisite. For the better grades of product color is, of course, essential. In the poorer grades, however, such as are used for rubber filling, roofing papers, foundry facings, etc., color is of secondary importance, but fine grinding is indispensable.

The milling practice in Vermont has, to a large degree, become standardized. The old burr stones, as grinding agents, and silk bolting cloth, for screening, have become nearly obsolete; while the Raymond Mills or the Sturtevant Vertical Rock Emery Mill, for grinding, and the Air Separator, for sizing, have very largely taken their places. With these agents there can be produced a talc powder over 95% of which will pass a 300 mesh screen.

A typical "flow sheet" for talc milling is as follows:

Rough ore bin
↓
belt conveyor
↓
jaw crusher (12″ x 15″)
↓
elevator
↓
trommels
↙ ↘
fines oversize
↓
rotary kiln dryer



Different sized products can be made by suitably adjusting the air separator.

TALC IMPORTATIONS AND DOMESTIC PRODUCTION

Importations

The talc importations, ground or manufactured, in short tons, have been as follows:*

	1915 Quantity	1915 Average price	1916 Quantity	1916 Average price	1917 Quantity	1917 Average price.
Austria Hungary......	138	$ 21.88	......	......	......	......
British S. Africa......	......	......	10	$ 21.88	......	......
Canada..............	4797	12.08	5964	12.58	10,287	$ 14.13
England.............	......	......	1	38.00	55	15.80
France..............	3734	5.16	3570	5.82	1,512	7.29
French Africa........	......	......	......	......	33	20.55
Germany............	8	236.00	......	......	......	......
Italy................	7268	14.36	7105	17.07	4167	23.53
Jamaica.............	......	......	......	......	66	18.40
Japan...............	......	......	......	......	10	18.40
Spain...............	......	......	11	36.36	1	11.00
Sweden	......	......	22	24.73	......	......
	15,945	$ 11.70	16,683	$ 13.08	16,131	$ 15.96

These figures may be compared with the total imports of former years:

	Short tons	Average price
1908......................	7,429	$ 13.07
1909......................	4,417	12.74
1910......................	8,378	12.71
1911......................	7,113	12.38
1912......................	10,989	11.19
1913......................	13,744	10.04
1914......................	15,644	11.29

From these data it it seen that the importations of talc have steadily increased since 1911, the maximum being reached in 1916—this in spite of the great war. Importations in 1916 were 21% greater than in 1913, the year before the war. On the other hand, imports in 1917 shows a 3.3% falling off from 1916, but a 22% increase in average price. It is noteworthy that importations from France in 1917 showed a decrease of 72% from the figures for 1913, while those from Italy showed only a 7% decrease in the same period.

But the most notable increase in importations has come from Canada, which in 1917 increased her shipments 300% over 1913 and now furnishes 64% of the entire imports. The Madoc deposit, in the County of Hastings, Province of Ontario, is the chief source of Canadian talc, and the average price per ton of $14.13 shows the high quality of the product.

The Mineral Industry states that the Italian talc is the chief source of the high grade mineral used in toilet powders, while the material used for cutting comes from Sweden, Spain and India (via England).

Japan evidently possesses very high grade material, while talc is also reported as existing in the ancient crystalline rocks of Brazil.

Talc production in the different states has been as follows:*

TALC PRODUCTION IN THE UNITED STATES†

	1916 Short tons.	1916 Valuc.	1917 Short tons	1917 Value	1917 Average price per ton.
California...............	630	$ 10,694	4,152	$ 74,000	$17.82
Gcorgia.................	3,080	88,364	3,819	94,314	24.70
New York...............	93,236	961,510	74,671	881,462	11.80
North Carolina..........	1,787	41,824	2,175	41,766	19.20
Vermont................	73,215	501,175	93,960	625,150	6.65
Virginia.................	8,798	73,622	6,432	85,856	13.35
Md. Miss. N. J. Pa.......	12,563	85,653	13,404	87,124	6.50
	193,309	$1,762,842	198,613	1,889,672	$ 9.51

CLASSIFICATION OF TALC SOLD IN THE UNITED STATES†

	1916 Short tons.	1916 Value.	1917 Short tons	1917 Value	1917 Average price per ton.
Rough (crude)...........	11,299	$ 106,928	12,269	$ 68,440	$ 5.58
Pencils and blanks—slate pencils—metal workers crayons, acetylene burners—etc..........	828	102,674	5,781	$ 176,404	30.51
Ground, foundry facings, filler for paper, paints, rubber goods, toilet powder, foot ease, lubricants, dressing skins, leather, etc...........	181,182	$1,553,240	180,563	1,644,828	9.11
	193,309	$1,762,842	198,613	$1,889,672	$ 9.51

In the matter of tonnage, Vermont and New York are the largest producers but have changed places in the last two years.

---

*Mineral resources of the United States.

*Mineral Resources of the United States.

†Mineral Resources of the United States.

New York furnished 48% of the whole domestic production, to Vermont's 38%, in 1916; Vermont produced 47% to New York's 38% in 1917.

The best grades of talc are furnished by Georgia, North Carolina and California, the increased production of the last named being especially noteworthy. This higher grade material is used for gas tips, pencil crayons, and talcum powder. Production is far behind the demand. The Mineral Industry states that only 25 tons of the highest grade of talc (presumably comparable with the best imported material) were mined in the United States in 1917 and that this material sold at over $300 per ton.

The great bulk of domestic talc is ground and is used as a filler for paper, rubber, etc.

The total amount of talc produced in the United States and imported may be noted.

1913	163,045	short tons
1914	166,732	" "
1915	182,281	" "
1916	212,992	" "
1917	214,744	" "

TALC PRODUCTION IN VERMONT

The talc producing companies of the State continue to be The Eastern Talc Company at Rochester and East Granville, The Magnesia Talc Company at Moretown, The American Mineral Company at Johnson, The Vermont Talc Company and The American Soap stone Finish Company at Chester Depot. The present year is expected to see production started by the Vermont Talc Products Company, at the Fayston-Moretown-Waitsfield deposit.

The following statistics are taken from "Mineral Resources of the United States," save those for 1915, 1916, and 1917, which have been compiled from returns made to the writer by the above companies.

1.	Short tons.	Value.	Average per ton.
1905	8,987	$ 65,525	$7.29
1906	10,413	101,057	9.70
1907	16,200	82,500	5.09
1908	10,755	99,741	9.27
1909	23,626	120,329	5.09
1910	25,975	136,674	5.26
1911	29,488	200,015	6.78
1912	42,413	275,679	6.49
1913	45,547	327,375	7.18
1914	50,123	358,465	7.15
1915	61,977	443,494	7.15
1916	73,575	488,617	6.64
1917	94,183	642,379	6.82
First half 1918	46,880	377,605	8.05

Vermont, in 1917, is seen to have increased her production 28% over that of 1916. Prices have advanced 18% in the same period.

It is confidently expected that with greater and better arranged milling facilities, production will be still further increased in the future.

THE LIME INDUSTRY IN VERMONT

E. C. Jacobs

UNIVERSITY OF VERMONT

Geological

West of the metamorphics which make up the Green Mountain Range lie the great terranes of limestone and shale which constitute the Ordovician Formation in Vermont. The chronological order of the members of this formation, which normally should rest on the Cambrian sandstone and quartzite, is: Beekmantown, Chazy, Black river, Trenton, and Utica. Of these the first four are limestones and the fifth is a shale. But the great overthrust has, in places, brought the Cambrian sandstones and quartzites on top of the Ordovician members, producing the condition so beautifully shown at Rock Point, where the Cambrian is seen resting disconformably on the Utica; at Highgate, where the Cambrian overlies the Chazy and Utica; and in other place, such as Mt. Philo and Snake Mountain, where the relationships are not so evident to the casual observer.

The Ordovician series extends, interruptedly, from Highgate, on the north, to Orwell, on the south, and reaches as far east as Highgate Center, East Colchester, Monkton, New Haven, Bristol, Weybridge, Middlebury, Salisbury, Leicester, and Rutland.

These Ordovician terranes were quite fully described by Professor Perkins in his article entitled, The Geology of Western Vermont.*

Economic

The limestone is in places highly silicious; in others, magnesian; and in still others, nearly pure calcium carbonate. The last named is of special importance industrially, for from the large outcrops an enormous amount of limestone has been quarried and burned for chemical purposes, while the smaller outcrops are coming more and more into use by the farmers for neutralizing the vegetable acidity of their soils.

The lime industry in the State dates back at least to 1830 and for many years Vermont lime has been held in high esteem and has been used for many purposes. Among these may be mentioned precipitated lime, tanning, bleaching powder for various purposes, gelatine and glue making, in photographic plate manufacture, in fiber for shoes, in mordants, paint, oil, and varnishes, and for building lime, plaster, etc.

In the following account, the companies engaged in lime burning, their quarries and kilns will be considered, together with such points of geological interest as have come to the writer's notice.

---

*Tenth Report Vermont State Geologist.

HIGHGATE SPRINGS

The Missisquoi Lime Works Incorporated

President, F. B. Wright.
Vice-president, C. H. Schoff.
Treasurer, E. Deschenes.
Superintendent, O. H. Parker.
Offices at St. Albans.

The company's plant is located at Highgate Springs, thirteen miles from St. Albans, and is connected by a spur track to the Central Vermont Railroad. Limestone quarrying and lime burning were started by Mr. L. H. Felton, in 1888, and were continued by him to his death, in 1914. The present company was incorporated in 1916.

The limestone consists of a great series of upturned strata, dipping about 25 degrees easterly, and extending from the lake shore eastward for about two miles, when they disappear beneath the overthrust Lower Cambrian sandstone and quartzite, which form a ridge trending roughly north and south. The limestone is of Chazy age. Some portions of it are silicious and some are dolomitic, rendering them unfit for burning; but other portions are nearly pure calcium carbonate and it is on these portions that the quarries are opened. The quarries are located about eight-tenths of a mile east of Highgate Springs Station.

The company owns eighty acres of limestone lands. The large quarry is located about 1200 feet east of the kilns. The stone, which is a compact, dove-colored rock, is broken to suitable size at the quarry and brought by a horse railroad to the works. These consist, at present, of five wood burning kilns, which produce about forty-five tons of lime per day.

The company is building a large, modern plant which it hopes to have in operation in the fall of 1918.

Production

The company produced over 100,000 barrels of lime in 1917 (one barrel contains 180 lbs), while the 1918 output will probably exceed 130,000 barrels. The price of the lime varies from $6.00 to $11.00 per ton, in bulk, and from $1.10 to $1.60 per barrel. The lime runs from 95% to 99% calcium oxide and has a high reputation in the lime industries.

FONDA JUNCTION

The Fonda Lime Kilns

Manager, Leo F. Willson,
Offices at St. Albans.

The works are located just west of Fonda Junction. Lime burning was begun in 1846 by Chas. W. Rich, following the building of the Vermont Central Railway. It was continued in 1850 by Lawrence Brainerd and Edward A. Smith. The works were acquired in 1872 by W. B. Fonda. The present management took control in 1917.

The property consists of seventeen or eighteen acres of limestone, which is a dove-colored, compact rock, showing but little jointing. Professor Perkins states that the rock is of Chazy age. The quarry is perhaps 1,000 by 600 feet in area and 90 to 100 feet deep. On the west side the excavations have disclosed the underlying (Utica?) shale, dipping easterly twenty-five or thirty degrees, with which the limestone makes a sharp, clean contact. If the limestone is Chazy, the intermediate numbers, Black River and Trenton, are evidently missing.

The quarried rock is hoisted up an inclined railroad and trammed to the works, where it is burned in five vertical kilns fired by soft coal.

Production

The capacity of the works is 18,000 tons per year, but labor shortage has materially reduced the output.

SWANTON

The Swanton Lime Works

Owner and manager, John P. Rich.

The works and office are in the outskirts of the town. The plant was started by A. B. and E. W. Jewett, and C. W. Rich in 1877, on the completion of the Portland and Ogdensburg Railroad (later known as the Lamoile Valley Railroad and now called the St. Johnsbury and Lake Champlain). The present owner assumed control in 1888.

The quarry now being operated lies just south of the kiln house. The limestone is the typical dove-colored rock of this region, but is more jointed and somewhat more crystalline than the rock at Highgate Springs and Fonda Junction. The limestone is said to be of Chazy age, but fossils are vanishingly few On the south side of the quarry the contact with the underlying (Utica?) shales has been disclosed, and it is interesting to note that this contact is not sharp, but that there is a considerable interfingering of the limestone and shale. The floor of the quarry is on the shale, so that a vertical limit of quarrying has been reached. On the south wall of the quarry there is seen a distinct bedding plane between the underlying, dove-colored limestone and the overlying whiter and more crystalline rock. The old quarry east of the present workings is no longer being operated.

The blasted rock is carried from the quarry to the kiln house by an aerial tramway. The kiln house contains five gas burning and nine wood burning kilns of which only the former are now in use. The gas is furnished by a Bradley Gas Producer. Both kilns and gas producer are fed by the aerial tram. The whole plant is one of the most modern and best equipped in the State.

Production

The gas kilns have a daily productive capacity of 10 tons each. The yearly capacity is 15,000 tons, but the present output, on account of labor shortage, is much less.

The lime is advertised with the following analysis:

Lime (CaO)	99.29%
Magnesia (MgO)	.46%
Iron oxide (FeO)	.12%
Manganese & Alumina	trace.
	99.87

The average price in 1916 was $5.00 per ton; in 1917, $8.00; while the current price is $11.00.

Other Localities

Mr. Rich states that there were formerly many small lime pot kilns, operated by farmers who did their own burning, all through this region. The kiln at Lime Kiln Point, owned by Boston interests, was in operation until 1888.

WINOOSKI

The Champlain Valley Lime Corporation, of Mass.

Pres and Supt., A. J. Crandall.
Treasurer, C. E. Ralph.
Post Office address, Winooski.
Quarries at High Bridge, South Burlington.

Limestone has been quarried here since 1829. The quarries were operated for years by Messrs. Tobey and Catlin, who preceded the present company.

The limestone has been shown by Professor Perkins to be of

Beekmantown age. It is dove-colored and very pure. The property contains eighty-six acres, and the quarry is about 300 x 400 feet in area. The blasted rock is hauled by teams to the kiln building where it is fed to three wood-burning kilns.

The burned lime is used by chemical and paper manufacturers. The company also crushes a part of its rock for agricultural purposes. A Jaffray crusher is used which delivers a product, 75% of which will pass a 100 mesh sieve. Lime ashes are also sold for fertilizer.

Production

The company produces about 100 barrels of lime a day. The wholesale price is $11.00 per ton, in bulk; $1.80 per barrel, wholesale; $2.25 retail.

NEW HAVEN JUNCTION

The Green Mountain Lime Company.

Owner, The Brewer Company, of Worcester, Mass.
Superintendent, W. J. Dandrow.
Offices, Worcester, Mass.

The old company, of the same name, was operated by Middlebury owners for twelve years, when it failed and was in a receiver's hands for two years. The present management took control in December, 1916.

The quarries are about two miles from New Haven Junction and are connected by a spur track to the Rutland Railroad. They comprise sixty-four acres of limestone. This rock is of Beekmantown age and is characterized by its unevenness. The west side of the quarry consists of a very fine granular limestone which has been metamorphosed almost to a marble. This material is hard to burn but gives the best quality of lime. The east face yields the characteristic Ordovician gray limestone but contains enormous clay nodules, called locally "nigger heads." The stone here has to be hand picked, since the nodules spoil the color of the burned product. The quarry is some 200 x 400 feet in area and is connected with the kiln plant by a horse tramway.

The lime burning is done in five wood and coal burning kilns, which use the Eldred Process. In this the kilns are closed at the top and "down-comers" bring the carbonic acid to the hearths, where it partially checks the combustion and, it is claimed, gives a more uniform heat. This process has been described by W. E. Emley, in Technical Paper No. 16, U. S. Dep't of Commerce.

Production

The kilns have a productive capacity of 12 tons each per day, but labor shortage is at present greatly reducing the output. Analysis of the lime shows:

Lime (CaO)	98.4%
Magnesia (MgO)	.71%
Silicia (SiO_2)	.62%
Ferric oxide	.24%
	99.97

LEICESTER JUNCTION

The Brandon Lime and Marble Company.

Owner, Harry B. Huntley.
Office, Leicester Junction.

The quarries here have been in operation for fifty years, under various ownerships. They consist of ten acres of limestone, which is of Beekmantown or Chazy age. The deposit is a long, narrow one much crushed and contorted. As at New Haven, there is a good deal of included, argillaceous material, which renders hand picking of the blasted rock necessary. The quarry is some 450 feet long, 125 feet maximum width, and seventy-five feet maximum depth.

The rock is burned in two kilns, which are fired by wood and have a daily capacity of 10 tons each. The burned lime is used mainly for chemical purposes, but the fines are sold for fertilizer. The lime brings $11.00 per ton in bulk and $2.00 per barrel.

RUTLAND

The Vermont Marble Company of Proctor, Vt.

In dressing its marble the Vermont Marble Co. of necessity produces a large amount of waste material. Some of this is shipped to the iron smelter at Port Henry, but a very large amount remains. Attempts to burn this highly crystalline limestone in the vertical kilns used for non-crystalline rock have proved futile. since the effect of heat is to granulate the material, with consequent choking of the kilns.

Two years ago the Company installed a large rotary kiln for converting its waste products into burned lime and hydrated lime and now produces "Vermarco Quick and Hydrated Lime" on a large scale. A full account of the plant and its working, by Harold Ladd Smith, appeared in the last Report of the Vermont State Geologist.

Beekmantown age. It is dove-colored and very pure. The property contains eighty-six acres, and the quarry is about 300 x 400 feet in area. The blasted rock is hauled by teams to the kiln building where it is fed to three wood-burning kilns.

The burned lime is used by chemical and paper manufacturers. The company also crushes a part of its rock for agricultural purposes. A Jaffray crusher is used which delivers a product, 75% of which will pass a 100 mesh sieve. Lime ashes are also sold for fertilizer.

PRODUCTION

The company produces about 100 barrels of lime a day. The wholesale price is $11.00 per ton, in bulk; $1.80 per barrel, wholesale; $2.25 retail.

NEW HAVEN JUNCTION

The Green Mountain Lime Company.

Owner, The Brewer Company, of Worcester, Mass.
Superintendent, W. J. Dandrow.
Offices, Worcester, Mass.

The old company, of the same name, was operated by Middlebury owners for twelve years, when it failed and was in a receiver's hands for two years. The present management took control in December, 1916.

The quarries are about two miles from New Haven Junction and are connected by a spur track to the Rutland Railroad. They comprise sixty-four acres of limestone. This rock is of Beekmantown age and is characterized by its unevenness. The west side of the quarry consists of a very fine granular limestone which has been metamorphosed almost to a marble. This material is hard to burn but gives the best quality of lime. The east face yields the characteristic Ordovician gray limestone but contains enormous clay nodules, called locally "nigger heads." The stone here has to be hand picked, since the nodules spoil the color of the burned product. The quarry is some 200 x 400 feet in area and is connected with the kiln plant by a horse tramway.

The lime burning is done in five wood and coal burning kilns, which use the Eldred Process. In this the kilns are closed at the top and "down-comers" bring the carbonic acid to the hearths, where it partially checks the combustion and, it is claimed, gives a more uniform heat. This process has been described by W. E. Emley, in Technical Paper No. 16, U. S. Dep't of Commerce.

PRODUCTION

The kilns have a productive capacity of 12 tons each per day, but labor shortage is at present greatly reducing the output.

Analysis of the lime shows:

Lime (CaO)	98.4%
Magnesia (MgO)	.71%
Silicia (SiO_2)	.62%
Ferric oxide	.24%
	99.97

LEICESTER JUNCTION

The Brandon Lime and Marble Company.

Owner, Harry B. Huntley.
Office, Leicester Junction.

The quarries here have been in operation for fifty years, under various ownerships. They consist of ten acres of limestone, which is of Beekmantown or Chazy age. The deposit is a long, narrow one much crushed and contorted. As at New Haven, there is a good deal of included, argillaceous material, which renders hand picking of the blasted rock necessary. The quarry is some 450 feet long, 125 feet maximum width, and seventy-five feet maximum depth.

The rock is burned in two kilns, which are fired by wood and have a daily capacity of 10 tons each. The burned lime is used mainly for chemical purposes, but the fines are sold for fertilizer. The lime brings $11.00 per ton in bulk and $2.00 per barrel.

RUTLAND

The Vermont Marble Company of Proctor, Vt.

In dressing its marble the Vermont Marble Co. of necessity produces a large amount of waste material. Some of this is shipped to the iron smelter at Port Henry, but a very large amount remains. Attempts to burn this highly crystalline limestone in the vertical kilns used for non-crystalline rock have proved futile. since the effect of heat is to granulate the material, with consequent choking of the kilns.

Two years ago the Company installed a large rotary kiln for converting its waste products into burned lime and hydrated lime and now produces "Vermarco Quick and Hydrated Lime" on a large scale. A full account of the plant and its working, by Harold Ladd Smith, appeared in the last Report of the Vermont State Geologist.

Production

The present production is 60 tons of oxide, or 75 tons of hydrated lime, per day, while the plant is so designed that this production can be doubled when the demand warrants the installation of another unit.

The Company claims for its hydrated lime: that the product is more uniform than ordinary burned lime: that it obviates the curing process in plaster making, that its addition to concrete results in marked advantages in increasing the plasticity and covering capacity of the product, in decreasing the tendency toward segregation, in increasing its strength, etc. It is also claimed that hydrated lime is much better for chemical purposes.

POWNAL

The Pownal Lime Company, Boston, Mass.
Sales Department 92 State St., Boston.

This company advertises ground limestone for liming purposes. The writer has not visited the plant.

Inactive Quarries and Kilns

In the past, limestone has been quarried and burned at many places in the State, not only in the Champlain Valley but also in and east of the mountains. Thus, lime kilns were formerly in operation at Amsden (near Cavendish), at Plymouth, Ludlow, Readsboro, etc., etc.

T. N. Dale, in his Lime Deposits and Kilns in Eastern Vermont*, has enumerated these deposits and kilns and reference is made to his article.

Finally, the Vermont Agricultural Experiment Station has, during the last few years, analysed several hundred samples of limestones and dolomites, representing outcrops on Vermont farms. With simple crushing machinery like the Jaffray Crusher available, such outcrops should furnish an adequate supply of material for liming purposes for many years to come.

---

*Ninth Report Vermont State Geologist.

ADDITIONS AND CORRECTIONS TO LIST OF ALTITUDES IN VERMONT

On page 150 of the previous Report there is a List of Vermont Altitudes. Since this list was printed there have been few surveys, but some changes should be made in the List as more accurate measurements have come to hand.

Those who use the List are asked to make the following corrections.

Barnet	B. & M. R. R.	461.
Barton	B. & M. R. R.	463.968
	B. & M. R. R.	949.
	H. L. F.	950.112
Boltonville	H. L. F.	669.
Centervale	B. & M. R. R.	590.15
Central Park, Vernon	H. L. F.	295.
Conicut, Station	B. & M. R. R.	407.1
Coventry, Station	B. & M. R. R.	695.025
Deweys Mills	U. S. G. S.	627.
Deweys Mills, Station	W. R. R.	617.5
Ely, Station	B. & M. R. R.	430.6
Fairlee, Station	B. & M. R. R.	435.6
Fairmount	H. L. F.	766.
Groton, Station	H. L. F.	816.
Hartford, Deweys Mills, Station	W. R. R.	617.5
Hartland, Station	U. S. G. S.	420.
Inwood, Station	B. & M. R. R.	504.239
Lanesboro	H. L. F.	1,380.8
Lower Waterford, Church	H. L. F.	810.
Lyndon, Station	B. & M. R. R.	705.
Lyndonville, Station	B. & M. R. R.	715.5
McIndoes, Station	B. & M. R. R.	488.
Marshfield, Station	M. & W. R. R. R.	1,181.86
Newport, Station	C. P. R. R.	691.
Newport, Station	B. & M. R. R.	692.23
Northboro, Station	B. & M. R. R.	396.2
Norwich, Station	B. & M. R. R.	402.6
Orleans, Station	B. & M. R. R.	741.11
Ottaquechee Bridge	W. R. R.	617.5
Plainfield, Station	M. & W. R. R. R.	799.
Pompanoosuc, Station	B. & M. R. R.	392.25
Quechee, Station	W. R. R.	640.
St. Johnsbury, Station	B. & M. R. R.	577.75
Shallies Hill, Summit	B. & M. R. R.	782.
South Ryegate, Station	M. & W. R. R. R.	744.
Summit Groton	M. & W. R. R. R.	1,430.13

Summit Siding................	B. & M. R. R.	1,235.
Sutton, Station..............	B. & M. R. R.	1,061.
Taftsville, Station.............	W. R. R.	650.
Upper Waterford, Four Corners	H. L. F.	730.
Waterford, Toll Bridge.........	H. L. F.	675.
Wells River, Station...........	M. & W. R. R. R.	462.
West Burke, Station...........	B. & M. R. R.	932.41
White River Junction, Station..	B. & M. R. R.	365.124
White River Junction, track....	W. R. R.	363.7
Willoughby, Station...........	B. & M. R. R.	1,155.4
Windsor, Station..............	C. V. R. R.	322.
Woodstock....................	U. S. G. S.	705.
Woodstock, Station............	W. R. R.	690.

For most of the above changes I am indebted to Professor H. L. Fairchild who for several seasons has investigated the surface geology of certain parts of the State. I am also indebted to Mr. F. E. Samson, division Engineer, B. & M. R. R.

In nearly all cases when the authority given is that of a railroad the altitude was taken in front of the station on top of the rail.

The following account of "Eruptive Rocks at Cuttingsville, Vermont," by Mr. Julius Wooster Eggleston, was first published in the American Journal of Science, Vol. XLV, May, 1918, pp. 377-410.

Since writing this account for the Journal, Mr. Eggleston has done additional field work in the region involved, and the changes in the maps and some paragraphs of the text are made because of more extended study.

Mr. Eggleston's paper was published as a Harvard University "Shaler Memorial Investigation."

ERUPTIVE ROCKS AT CUTTINGSVILLE, VERMONT

J. W. Eggleston

INTRODUCTION

Under the name "granite" the eruptive body at Cuttingsville, on the west slope of the Green Mountains and 10 miles southeast of Rutland, Vermont, was noted in E. Hitchcock's geological report on Vermont (map and vol. 2, p 742, 1861). In 1892 and 1894 Mr. C. L. Whittle, with an assistant, studied the Cuttingsville area for the U. S. Geological Survey, but the results of this work have not been published.

In the years 1906 to 1909 the writer carried on intermittent detailed work in the area. A summary of results was given before the Geological Society of America, at Cambridge, Mass., in December, 1909. An abstract appears in the Bulletin of the Society, Vol XXI, p 785, 1910.

In connection with the present paper, acknowledgments are due to Professor Charles Palache, who first called the writer's attention to the Cuttingsville rocks; to Professor John E. Wolff, under whose direction the study was undertaken; to Mr. C. L. Whittle for the use of his reconnaisance map and collections; to Professor R. A. Daly, who has assisted in the preparation of the manuscript.

Special thanks are due to Dr. H. E. Merwin, now of the Carnegie Geophysical Laboratory, Washington, D. C., and to Professor C. D. Test of the Department of Chemistry of the Colorado School of Mines, who made the excellent chemical analyses accompanying this paper.

TOPOGRAPHY

Cuttingsville lies in the valley of Mill River on the Rutland railroad, about a thousand feet above the sea.

Plate XVI is a map of the area considered*

The main eruptive body, 1.7 square miles (4 sq. km.) in area, is largely confined to Granite Hill (2,007 feet Plate XVII) so named from its quarries of syenite, popularly called "granite." This hill is crescentic in form, with a knob towards either end of the crescent, the south knob rising about 250 feet higher than the north knob (Plate XVI). The shape of the hill is very suggestive of a low glacial cirque tributary to the glaciated valley of Mill River.

---

*Plate XVI, Geological map of Cuttingsville area. Scale 1:28,000. Standard orientation.

Stock Rocks—1, Essexite; 2, hornblende-biotite syenite; 3, pulaskite; 4, sodalite-nephelite syenite; 5, nordmarkite

Dike Rocks—Dotted line, essexite porphyry. Heavy broken line, syenite porphyry. Heavy full line, tinguaite. Double line, camptonite.

Country Rocks—except limestone (L), not distinguished.

A-B, line of section D, dike of type tinguaite (shown on the map an eighth of a mile too far south). M, open cut for molybdenite, P, pit. Q, quarry, T, tunnel.

(Other changes should be made in reading the map—essexite of northern area too extensive; should not be shown south of stream.

The branch of Mill River, south of Copperas Hill, joins Mill River north, not south, of the highway bridge in Cuttingsville center.)

Two smaller eruptive bodies lie on the northeast side of Mill River (Plate XVI), and, still farther north, a mass of breccia and two related areas of eruptive rock, occur north of, and along the upper west slope of, a 1,400-foot hill north of Mill River (fig10) Including the breccia, the bodies extend along a line nearly 3½ miles long.

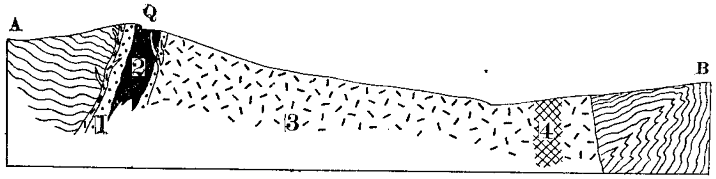


Fig. 9. Section along line A-B in Plate XVI. Natural scale 1:28,000.

The accompanying geological maps are based upon an enlargement of adjoining parts of the Wallingford and Rutland, Vt., sheets of the topographic map of the United States.

CONDITIONS OF EXPOSURE

Much of Granite Hill, particularly the north and east slopes of the two knobs, is thickly wooded. The bowl, crest, and west slope are fairly free from trees, but the bowl is heavily drift-covered. Along the crest, on the slopes of the north knob, and also at the east foot of each knob, where Mill River is actively eroding, exposures are especially numerous; those on the south knob are much fewer. Three small abandoned quarries, several test pits, a prospect cut, a tunnel, and a railroad cut south of Cuttingsville (Plate XVI) furnish fresh rock. Ledges and open cuts along a pyrrhotite deposit on the lower southwest slope of Copperas Hill expose a group of dikes presumably connected with the main eruptive body (Plate XVII).

Excepting along the crest of the middle part of Granite Hill and for a short stretch along the crest of the south knob, contacts are rarely exposed. As mapped they are accordingly for the most part only approximate.

OUTLINE OF FIELD RELATIONS

COUNTRY ROCKS

The country rocks are all metamorphic—chiefly hornblende-pyroxene and mica gneisses, with considerable limestone, and quite subordinate chloritic schists and quartzite. In a zone a score or two feet wide along the only visible contact, on the west side of the main eruptive body, they show some contact metamorphism besides moderate brecciation, diking and impregnation by eruptive rocks.

Strikes and dips of the country rocks are indicated upon the map (Plate XVI). The strikes are commonly northeasterly, in accord with the usual Appalachian trend, and run at high angles to the axis of the eruptive bodies.

Structural relations among the members of the country-rock series are obscure. The hornblendic gneisses commonly strike at an angle to the other members and are probably intrusive into them. The structural complexity makes it difficult to state the nature of the rocks beneath those actually visible. Quartzite and less certain dolomite xenoliths in the essexite of one of the northern eruptive bodies may have been derived wholly from beds formerly overlying the visible country rocks, although some may have come from beneath. Whittle* refers the country rocks to the Algonkian, and places them in a series named by him, the Mount Holly from a neighboring hill and village.

ERUPTIVE ROCKS

The eruptive rocks include essexite, hornblende-biotite syenite, pulaskite, nephelite syenite, sodalite-nephelite syenite, nordmarkite, essexite porphyry, syenite porphyry, aplite, tinguaite, camptonite, and an eruptive breccia. Some of the eruptives have locally suffered slight faulting and possibly very limited crushing and shearing along certain contacts, as a result of successive intrusions and later movements, but all these rocks are entirely free from anything at all comparable to the effects of regional metamorphism displayed by the country rocks.

Composite stock—Cross-cutting relations to the country rocks, combined with high outward dips of the contact where observable, nearly vertical flow lines, and small areal extent of the intrusive mass, indicate that the main body is a stock. In any case a laccolithic origin cannot be assumed. The composite character of the body is revealed by the distribution and structural relations of its rocks. The chief types are arranged in a roughly concentric manner (see Plate XVI), essexite partly encircling pulaskite and both being probably cut by peripheral nordmarkite.

Essexite composes nearly one-quarter of the total area of the eruptives. In practically all of its occurrences it is cut by syenite or syenite porphyry, the smaller masses apparently being completely inclosed. Evidently the essexite represents an older body, probably a stock, which has been invaded and largely engulfed by the later intrusions. Nearly vertical contacts and occasional nearly vertical flow lines, in the essexite and some of the syenite, suggest that the whole forms a composite stock.

Pulaskite, especially well shown on the north slopes of the bowl, constitutes about two-thirds of the main eruptive body. It clearly penetrates the essexite and gneisses. In places it extends west of the crest of the middle part of Granite Hill (Plate XVI,) forming, where essexite is present, a band of no great width between the essexite and gneisses.

Between flanking lenses of essexite and occupying the crest of the middle part of Granite Hill, is an area of ***hornblende-biotite syenite*** upwards of 1,000 feet long and half as wide. It appears again, in a much narrower band, near the crest of the north knob. Its total areal extent is believed to be least of all the chief types of rock exposed on Granite Hill. Its structural relations to both the essexite and the pulaskite are somewhat obscure, due to the failure of sharp contacts. A point bearing upon this question, however, is the very common development of a biotite-hornblende phase of the pulaskite on the side towards the essexite. These border phases frequently resemble very closely the type hornblende-biotite syenite in the quarry near the crest of the middle part of Granite Hill.

These facts might be explained on the assumption that the hornblende-biotite syenite is a sort of hybrid, having resulted from the assimilation of essexite by pulaskite. This view accords with the usual absence of sharp contacts between pulaskite and essexite, the one gradually passing into the other, as illustrated in a narrow band near the crest of the north knob.

However, in the quarry the hornblende-biotite syenite itself is cut by an apophysis or irregular dike of syenite porphyry merging into porphyritic syenite. If it is a tongue from the main mass of pulaskite, the view that the hornblende syenite is a hybrid of essexite and pulaskite must be relinquished in favor of early differentiation and intrusion coincidently with or immediately succeeding the essexite, but preceding the pulaskite.

Nordmarkite is clearly intrusive into the essexite, cutting it freely and inclosing fragments, as well shown in the contact zone of essexite and nordmarkite on the north knob. Its relations to the other syenites are obscure. On the lower southeast slope of the north knob, the path to the quarry has been cut in bedrock which shows quartz-syenite dikes penetrating a pulaskitic type. A similar combination, with gneiss fragments also included, is shown in excavated blocks at the edge of Mill River just below. This is the only observed evidence that nordmarkite intrudes eruptives other than essexite, and it is not conclusive.

The nordmarkite along Mill River, at the east foot of the north knob of Granite Hill, is cut by several large dikes of syenite porphyry. These may possibly be apophyses from the pulaskite, though there are certain field, lithological, and chemical reasons for believing these syenite-porphyry dikes to be intrusions later than both nordmarkite and pulaskite, and connected with the sodalite-nephelite syenite.

Sodalite-nephelite syenite in the railroad cut, is probably considerably less extensive than any type on Granite Hill. Very

---

*C. L. Whittle, The Occurrence of Algonkian Rocks in Vermont and the Evidence for their Subdivision, Journal of Geology, Vol. II, p 396, 1894.

similar rock exposed on the lower east slope of the south knob, on the west shore of Mill River, may indicate that the area extends into Granite Hill. The structural relations are completely hidden. The rock is either a sodalite-bearing phase of the pulaskite and contemporaneous with it or, as just suggested, a distinctly later intrusion.

Smaller igneous-rock areas.—The two smaller areas north of Granite Hill appear to be parts of one irregular composite intrusion, fed from the same magma reservoir as the main body. It is quite possible that the northern areas are continuous with the Granite Hill mass, beneath the cover of drift and alluvium in Mill River Valley. If so, this would increase the length of the area of the Granite Hill stock by about three-quarters of a mile, and give it a pronounced northward elongation.

The northern eruptives, where exposed, are much more involved with the country rocks than is the case on Granite Hill. Contorted and brecciated gneisses frequently alternate with eruptives along the railroad, and flank them on the northwest. The geological map, owing to the limitations of its scale, gives a quite inadequate impression of the intricate relations between eruptives and country rock, especially in the case of the more northern area.

The rocks of the northern areas resemble those on Granite Hill, but nordmarkite and the basic phases of essexite are absent. Thick dikes, or borders of camptonitic rock are impressive features in the more northern area.

Although not so well shown as on Granite Hill, the syenite of the northern areas is nevertheless clearly intrusive into the essexite, probably vertically, judging from limited contacts and nearly vertical flow lines in some of the syenite. The essexite, less basic than on Granite Hill, carries occasional xenoliths of quartzite, hornblende gneiss, and possibly of dolomite, and is probably a quite irregular intrusion. The syenite, although not chemically, or microscopically studied, is regarded as partly pulaskite and partly biotite syenite (with some hornblende). The latter has been mapped under the same symbol (2, Plate XVI) as the hornblende-biotite syenite of Granite Hill, which rock it most resembles.

Breccia mass.—About a mile north of the small areas of eruptive rock just described, there is a body of breccia, shown in figure 10. Though not closely studied, it appears to be related to those areas. The constituent fragments, usually not more than a few centimeters in diameter, are composed of quartzite with subordinate schist, gneiss, and limestone. The breccia is intimately injected by a trappean rock, possibly an essexite porphyry.

The exposures indicate three areas in a distance of about half a mile. Of these areas the northern is most extensive and most truly a breccia. The other two, especially the middle, because of fewer and smaller included fragments, are better classed as essexitic or camptonitic eruptives. All are flanked by gneisses and lie *en axe* with the eruptive bodies already described. The eruptive rocks of the small areas farther south are bordered by, and alternate with, brecciated country rock. This fact suggests that all the breccias are the result of intrusion along a line of shattering, some being not so much injected by igneous rock because of greater distance from eruptive centers.

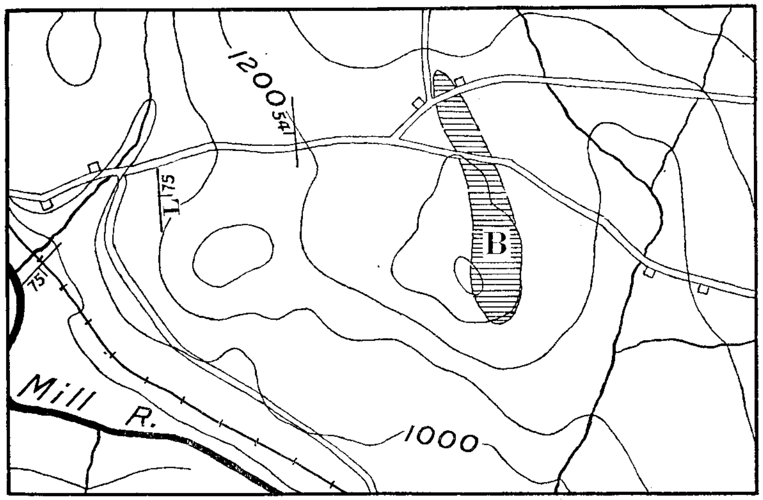


Figure 10. Area of breccia, two miles northwest of Cuttingsville. Standard orientation.

Scale 1:21,000. Area shown is nearly continuous with that of Plate XVI. B, breccia L, limestone. Other rocks not distinguished.

(B should not be a single band, but three small detached areas west of crest of hill, and flanked by gneisses.)

Dikes.—Associated with the plutonic rocks are numerous dikes, both aschistic and diaschistic. They comprise in the inferred order of intrusion, essexite porphyry, nephelite syenite, syenite porphyry, aplite, tinguaite, and camptonite. As a whole the dikes have not been thoroughly diagnosed. Two, a syenite-porphyry dike and a tinguaite dike, mapped respectively at T and D, Plate XVI have been chemically studied. Classification of the other dikes is tentative. Some mapped as tinguaite may, upon further study, prove to be fine-textured phases of syenite porphyry, or possibly bostonite. Others mapped as camptonite may prove to be fine-textured essexite porphyries.

The dikes range in thickness from a fraction of an inch to 25 feet, with an average of about one foot. The dikes are most mumerous in or near eruptive areas. They rarely occur more than half a mile distant. In the eruptive areas they are not confined to any particular kind of plutonic rock, though they seem to be more numerous near contacts of the syenites with essexite.

Date of Eruptivity

There is little direct evidence bearing upon the exact geological age of the eruptives. They are clearly of later date than the gneisses and limestone of supposed Algonkian age. Their freedom from marked crushing and shearing suggests that the intrusions did not consolidate until after the strong deformations of the country rocks had been accomplished. Assuming that the last of these could not have been earlier than late Carboniferous times, when the whole Appalachian province was greatly disturbed, it may be inferred that the Cuttingsville eruptives do not antedate the close of the Carboniferous period. Similar intrusions, at Ascutney Mountain, not more than 25 miles distant, are regarded as probably of post-Carboniferous and pre-Cretaceous age.*

Petrography

COUNTRY ROCKS

Gneisses.—The gneisses are of two kinds a basic hornblende-pyroxene gneiss and mica gneiss which is more or less granitic. The former is the more abundant in the immediate neighborhood of the eruptives, and more study has been devoted to it on that account. It is typically a heavy, rather dense, fine- to medium-grained, black rock weathering a streaked or speckled brownish gray. The thin section shows about equal amounts of olive-brown to green hornblende and pale greenish pyroxene. In addition there is subordinate brown biotite and plagioclase with some orthoclase and doubtful quartz. Magnetite and apatite are accessory. The rock is inferred to be a metamorphosed eruptive of gabbroid, diabasic, or basaltic character.

Limestone.—The limestone (L, Plate XVI and fig 10) varies considerably in texture, mineral content, and degree of metamorphism. It is quite subordinate to the gneisses as a member of the country-rock series. It crops out at four localities about the main eruptive body and also about one-half mile west of the area of breccia shown in fig. 10. An outcrop of limestone one-half mile south of the area of breccia is not indicated in fig 10.

The limestone on the southwest slope of Granite Hill and on Mill River varies in color from bluish gray through cream to white. It is fine grained although the sparkle of the calcite cleavage is distinctly visible. It effervesces freely with dilute hydrochloric acid. Under a hand lens grains of quartz and particles which are probably graphite are noticeable.

On the southwest slope of Copperas Hill (Plate XVI), one or more bands of crystalline limestone follow the easterly to northeasterly strike and high dips of the enclosing gneisses. One of the bands has an exposed width of 20 feet. In working the pyrrhotite bodies, which replace limestone along the belt of tinguaite dikes on this slope of Copperas Hill (Plate XVI), cuts have been made in masses of limestone, 5 to 15 feet thick, associated with hornblende gneiss. This limestone is light bluish gray to white in color, fairly coarse grained, and distinctly metamorphic. The metamorphism is presumably due to regional rather than igneous contact action. Hand specimens show, besides calcite, generally considerable muscovite or sericite, and more locally, abundant flakes of graphite. Some bands carry much tremolite or wollastonite developed in short prisms and fibers along the planes of schistosity. All samples effervesce freely with dilute hydrochloric acid.

One-half mile southeast of the Granite Hill eruptive body, a bed of coarsely crystalline tremolitic limestone about 15 feet thick is associated with quartzite and hornblende and mica gneisses, and is cut by a dike of camptonite or essexite porphyry.

The limestone indicated in fig 10 varies from light gray and medium grained with occasional graphite flakes, to cream white and decidedly coarse grained, with quartz veins and considerable muscovite. There is a notable amount of limestone altogether, although it soon passes into sericitic schist.

Quartzite.—Micaceous quartzite forms a few thin beds or lenses in gneiss and limestone. Granular quartzite is relatively abundant as fragments in the breccia, and as xenoliths in the essexite of the northern eruptive area.

Schists.—Sericitic, chloritic, and tremolitic schists occur only as thin bands between much thicker beds of quartzose gneiss, hornblende gneiss, and crystalline limestone.

STOCK ROCKS

The rocks of the stocks will be described in the order from oldest to youngest, which is also the order from basic to acid.

Essexite.—(Plate XVI and fig 9). Fresh essexite is exposed in cuts on both sides of the crest of the central part of Granite Hill and along the path to the quarry, near the top of the hill. It varies from a nearly black, fairly uniform, medium- or coarse-grained gabbroid rock, to a gray, more or less porphyritic phase.

The *type phase* was taken for study from an open cut or pit (P, Plate XVI) on the southwest side of the crest of the middle part of Granite Hill, less than 1000 feet south of the hornblende-biotite syenite quarry, (Q 2, Plate XVI). The same phase has been freshly cut on the other side of the crest along the path, near the quarry, and rock much like it is exposed by Mill River at the east foot of the south knob. It is dark colored, sometimes almost black, and usually coarse grained. Barkevikitic hornblende, showing luster-mottling, is generally prominent in the hand specimen.

Thin sections show coarse grain and hypidiomorphic-granular texture. About sixty per cent of the rock is feldspar, mostly plagioclase, ranging from $Ab_7 An_3$ to $Ab_3 An_7$. From five to ten

---

*R. A. Daly, U. S. Geol. Surv., Bull. 209, p. 21, 1903 per cent of the rock is orthoclase, which appears in small- and medium-sized grains and irregular areas sometimes intergrown with, enclosing, or embaying the plagioclase. The other essentials are hornblende, pyroxene, and biotite, in nearly equal amounts.

Of the dark-colored minerals, barkevkitic hornblende is most notable. Its optical properties are sensibly identical with those of hornblende in the hornblende-biotite syenite, and will be stated at length in the description of that rock. The pleochroism of the hornblende of the essexite shows, however, more reddish or chestnut tints in the darker colors. Poikilitic inclusions of pyroxene and, in less amount, biotite and olivine give rise to the luster-mottling visible in the hand specimen.

Pyroxene is represented by augite of two colors, pale green and pale brown. The colors appear separately or sometimes together in the same grain. A pale brown center may be bordered by pale green, with a zone of inclusions of magnetite and hornblende between the two colors. The differently colored parts are optically continuous and extinguish together. When occurring separately, a maximum extinction angle of 44° for the green and 37° for the brown was observed. The augite and hornblende are remarkably intergrown, the latter surrounding augite which in turn incloses grains of hornblende.

Biotite is in thick tables, besides forming striking intergrowths with hornblende. Its pleochroism ranges from pale yellow to chestnut and deep brown or nearly black. Olivine in occasional large grains, partly serpentinized, enters the list of accessory minerals, which also includes magnetite, titanite, apatite, pyrite, and probably pyrrhotite. One of the sections includes an irregular area of what is possibly cancrinite derived from original nephelite. This is the only suggestion of the presence of nephelite, indicating that it is seldom, if at all, a constituent.

Texture and mineralogical composition place the rock among the alkali-gabbros under the head of essexite. Chemical analysis supports this conclusion.

	I	II	III	IV	V	VI	VII
SiO_2	46.47	46.99	48.85	44.00	49.96	47.90	48.64
TiO_2	2.86	2.92	2.47	1.90	2.40	1.91	1.86
Al_2O_3	16.86	17.94	19.38	27.73	18.83	16.55	17.96
Fe_2O_3	3.21	2.56	4.29	2.36	2.52	5.67	4.31
FeO	7.72	7.56	4.94	3.90	6.64	7.50	5.58
MnO	0.23	Trace	0.19	0.08	0.20	0.60	0.19
MgO	5.16	3.22	2.00	2.30	3.52	4.44	4.00
CaO	9.45	7.85	7.98	13.94	7.42	9.35	8.89
Na_2O	4.20	6.35	5.44	2.36	5.26	3.23	4.30
K_2O	1.35	2.62	1.91	0.45	2.58	2.08	2.28
H_2O+	0.45	0.65	0.68	0.80	0.07	0.20	1.34
H_2O-	0.04				0.53		
P_2O_5	1.15	0.94	1.23	0.20	0.25	0.32	0.65
CO_2	Trace						
ZrO_2	None						
SO_3	None		not det.				
Cl	0.06						
F	0.10						
Cr_2O_3	None						
BaO	Trace						
SrO	0.04						
FeS_2	0.21						
Fe_7S_8	0.08						
Li_2O	None						
Sum	99.64	99.60	99.36	100.01	100.18	99.75	100.00
Specific gravity		2.919					

I = Essexite, type phase (andose), Cuttingsville, Vt., H. E. Merwin, analyst.
II = Essexite (essexose), Salem Neck, Essex Co., Mass.
III = Normal essexite (andose), Mt. Johnson, Quebec.
IV = Essexite (hessose), Brome Mt., Quebec.
V = Essexite (salemose), St. Hilaire Mt., Quebec.
VI = Essexite (camptonose), Toftcholmen, Norway.
VII = Essexite (average of 20 analyses, R. A. Daly, in "Igneous Rocks and Their origin," 1914, p. 30).

The rock is an andose, allied to camptonose, with the following norm:

Orthoclase	7.78	Olivine	9.93
Albite	27.25	Magnetite	4.64
Anorthite	23.35	Ilmenite	5.47
Nephelite	4.54	Apatite	2.48
Diopside	13.07	Water, etc.	.98
			99.49

Comparison of the Cuttingsville essexite shows its close similarity to the type from Essex County, Massachusetts, and to the varieties of essexite from the Monteregian Hills, Quebec. The likeness in chemical composition to the essexite from Tofteholmen, Norway, is but one example of a striking chemical similarity between the Cuttingsville rocks and some of those of southern Norway.* The table facilitates comparison with the average essexite as computed by Daly from twenty analyses.

One of the variations from the type phase apparently results from the local impregnation and partial assimilation of essexite by pulaskite. Hand specimens usually show dikelets and streamers of this syenite, traversing essexite. The color resulting from the combination of pulaskite with essexite is lighter and the grain less uniform than in simple essexite. Idiomorphic hornblende and more or less definitely bounded feldspar are sometimes noticeable. A characteristic feature is an abundance of titanite. Sections show a greater proportion of feldspars than simple essexite. About seventy per cent is feldspar, of which approximately one-third is orthoclase and two-thirds plagioclase, of a composition intermediate between basic orthoclase and andesine. There is some microperthite, and possibly altered nephelite and cancrinite. The remaining chief constituents are

*Brögger, W. C. "Die Eruptivgesteine des Kristianiagebietes" Vidensk. Skrifter I, No. 4, 1894; No. 7, 1895; No. 6, 1897.

hornblende, sometimes surrounded by, and intergrown with, olive-brown biotite, and augite poikilitically inclosed in hornblende. The rock may be regarded as a more acid essexite which, with the hornblende-biotite syenite itself, occurs in the series between essexite and pulaskite.

On the north knob of Granite Hill, an *extremely coarse-grained phase* of essexite is developed. It is largely composed of prisms of hornblende, some upwards of two inches in length. A little biotite is visible in hand specimens. The amount of feldspar varies. Towards pulaskite contacts the proportion of feldspar increases, and the rock grades into a very coarse hornblende-biotite syenite. This gradation is quite clearly shown near the crest of Granite Hill, from the north knob to the molybdenite prospect, (M, Plate XVI.)

Porphyritic phases form important parts of the more extensive essexite areas. They are also exposed as smaller masses which appear to be apophyses and detached portions of the main bodies. The groundmass varies from coarse to almost aphanitic. The phenocrysts are usually hornblende, commonly an inch or two in length, frequently much less, and sometimes very much greater. In one case the measured dimensions of a hornblende phenocryst were fifteen by eight inches. Biotite appears, with or without hornblende, usually in the groundmass. The porphyritic phases quite generally carry large and small inclusions, apparently of the coarse phases of essexite and hornblende-biotite syenite. These inclusions are not always so sharply defined as accompanying inclusions of the country rocks, but they seem to demonstrate an intrusion of porphyritic essexite into an earlier intrusions of more uniformly coarse-grained essexite and possibly syenite. The blurred outlines of the inclusions suggest that the interval between the earlier and the later intrusion was comparatively short.

Hornblende-biotite syenite (2, Plate XVI and fig 9).—Hornblende-biotite syenite is of smaller total area than most of the other plutonic types. Its principal exposures are near the crest of the central part of Granite Hill, where a small quarry was opened about 25 years ago.

The *type phase* taken from the quarry (Q 2, Plate XVI), is moderately coarse-grained, almost white in ground color, and abundantly specked with black amphibole and mica. Occasionally a slightly darker-colored, finer-grained, indistinct patch or schlier, a few centimeters in dimensions, appears in the hand specimen.

In thin section, the hornblende-biotite syenite shows a hypidiomorphic, medium to coarse, granular texture. Eighty per cent or more is feldspar, of which the bulk is plagioclase, in composition intermediate between basic oligoclase and andesine. About one-third of the feldspar is orthoclase, some of which is intergrown with plagioclase.

After the feldspar, amphibole is most notable. It appears

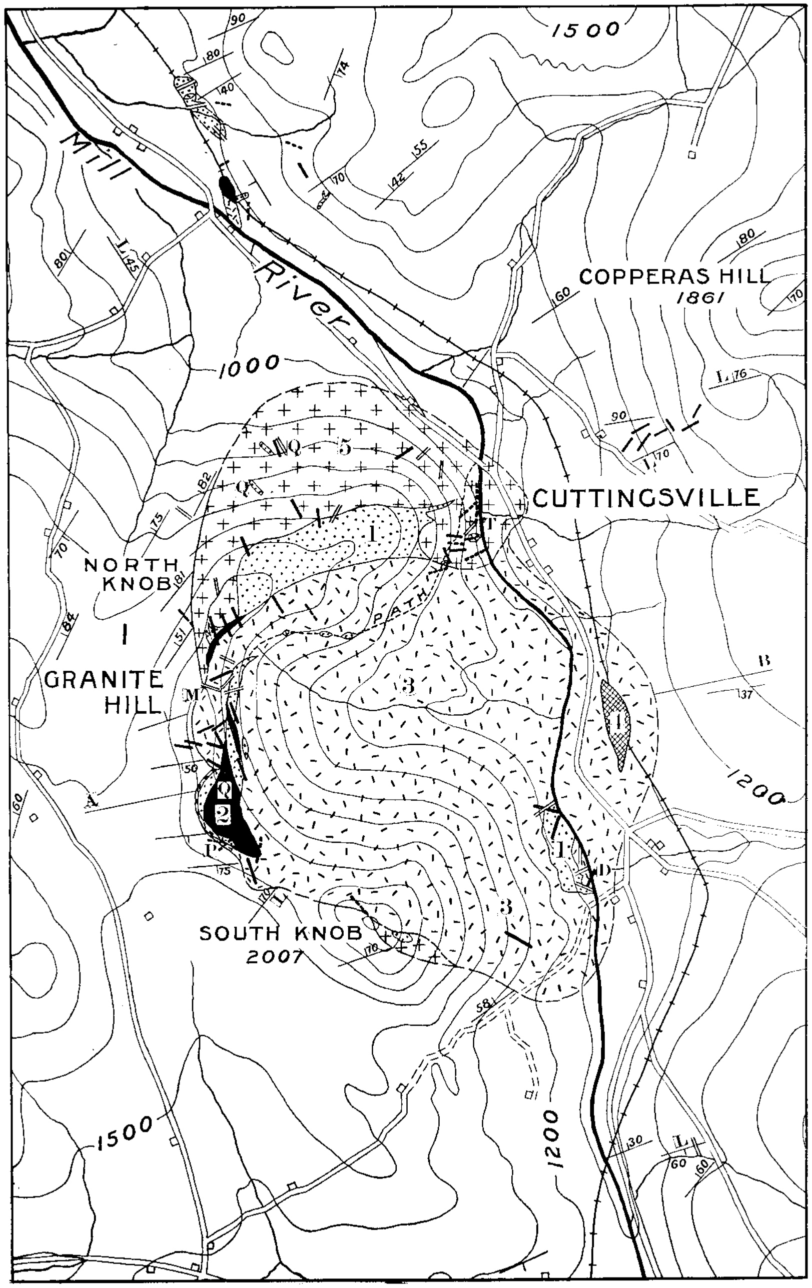


PLATE XVI
MAP OF CUTTINGSVILLE AREA

in well-defined prisms, commonly twinned. The pleochroism is distinctive, green to greenish brown in the direction of the *c* axis; dark greenish brown to almost black parallel to the *b* axis; and pale yellow parallel to the *a* axis. The absorption scheme is $b >$ (nearly =) $c > a$. The extinction angle on (110) cleavage pieces is 12°. 2E = 70°—80° or less. A calculation of the angle of extinction on (010) gave 8°. The specific gravity, by pycnometer, at 20° C., is 3.518. These characteristics taken together indicate a soda-amphibole near barkevikite.

In order to check the optical determination of the amphibole a chemical analysis of the amphibole was made by Professor C. D. Test of the Department of Chemistry of the Colorado School of Mines. Good material was obtained by the usual modes of separation from the rock powder. The analysis resulted in the values given in column I of the following table, in which those for related amphiboles are also entered:

	I	II	III	IV	V	VI
SiO_2	38.04	38.633	40.10	42.46	42.27	38.41
TiO_2	1.06	5.035	4.35	(In SiO_2)	1.01	1.26
Al_2O_3	13.50	11.974	10.88	11.45	6.31	16.39
Fe_2O_3	6.21	3.903	7.81	6.18	6.62	3.75
FeO	15.85	11.523	9.66	19.93	21.72	21.75
MnO	1.21	0.729	0.15	0.75	1.13	0.15
MgO	7.26	10.200	9.74	1.11	3.62	2.54
CaO	12.42	12.807	12.60	10.24	9.68	10.52
Na_2O	3.21	3.139	3.18	6.08	3.14	2.95
K_2O	1.68	1.489	1.60	1.44	2.65	1.95
H_2O(by ignition)	0.48	0.330	0.00		0.48	0.24
F			0.31			
P_2O_5			0.63			
Sum	100.92	99.762	100.01	99.64	98.63	99.96

I = Hornblende from Cuttingsville hornblende-biotite syenite, C. D. Test, analyst.
II = Hornblende from Mt. Johnson, Quebec, essexite, F. D. Adams, Jour. Geology, vol. 11, p. 260, 1903.
III = Hornblende from Heum, Norway, heumite, J. P. Idings, "Rock Minerals," 1906, p. 338.
V = Barkevikite from Barkevik, Norway, nephelite syenite, ibid, p. 339.
IV = Barkevikite from Barkevik, Norway, syenite, ibid, p. 339.
VI = Barkevikitic hornblende from Square Butte, Montana, sodalite syenite, L. V. Pirsson, U. S. Geol. Survey, Bulletin 237, p. 67, 1905.

Chemically as well as optically, this Cuttingsville amphibole is seen to be a barkevikitic hornblende.

Chief among the remaining minerals, in thin sections of the type phase of the Cuttingsville hornblende-biotite syenite, is brown biotite which is present in amount nearly equal to hornblende. There are occasional triangular and irregular areas, filled with alteration products probably derived from nephelite, which is not otherwise represented in the type phase of the syenite, though visible to the naked eye in coarser-grained segregations to be described hereafter. Apatite, titanite, magnetite, zircon, and pyrite are accessory.

The abundant plagioclase allies it to monzonite, but the ratio of dark silicates to feldspar warrants the designation of the rock as a hornblende-biotite syenite. Its analysis is given in the following table (column I), which introduces relevant analyses from similar rock bodies and also the average analysis of laurvikite:—

	I	II	III	IV	V	VI	VII
SiO_2	57.44	57.44	59.96	59.01	56.85	57.12	57.45
TiO_2	0.69	1.97	0.66	0.81			
Al_2O_3	21.60	19.43	19.12	18.18	21.56	21.69	21.11
Fe_2O_3	0.20	1.69	1.85	1.63	3.44	1.63	2.89
FeO	2.62	2.70	1.73	3.65	1.14	3.65	2.39
MnO	0.14	0.25	0.49	0.03			
MgO	1.09	1.16	0.65	1.05	0.85	1.55	1.06
CaO	2.90	2.66	2.24	2.40	5.26	4.03	4.10
Na_2O	7.36	6.48	6.98	7.03	6.07	5.93	5.89
K_2O	4.12	4.28	4.91	5.34	3.66	3.48	3.87
H_2O+	0.58	1.03	1.10	0.50	0.52	0.58	0.70
H_2O-	0.03			0.15			
P_2O_5	0.38	0.60	0.14	Trace			0.54
CO_2	0.39						
ZrO_2	0.02						
SO_3	None	not det.	0.08				
Cl	0.07	Trace	0.14	0.12			
F	0.05						
Cr_2O_3	None						
BaO	0.26	not det.	0.12	0.08			
SrO	0.04						
FeS_2	0.15						
Fe_7S_8	0.14						
Li_2O	None						
Sum	100.27	99.69	100.17	99.98	99.35	99.66	100.00

I = Hornblende-biotite syenite, type phase (laurvikose), Cuttingsville, Vt., H. E. Merwin, analyst.
II = Pulaskite (laurvikose), Mt. Johnson, Quebec.
III = Pulaskite (laurvikose), Shefford Mt., Quebec.
IV = Umptekite (umptekose), Red Hill, Moultonboro, N. H.
V = Laurvikite (laurvikose), Nottcrö, Norway.
VI = Laurvikite (laurvikose), Frederiksvärn, Norway.
VII = Laurvikite (average of 3 analyses, R. A. Daly).

II, III Quoted from F. D. Adams, Jour. Geology, vol. 11, p. 271, 1903.
IV, V, VI " " Washington, H. S., "Chemical Analyses of Igneous Rocks": U. S. Geol. Surv., Prof. Paper 14, pp. 253, 203, 1903.
VII " " Daly, R. A., "Igneous Rocks and Their Origin", p 23.

The norm (laurvikose) was calculated to be:

Orthoclase	24.46	Ilmenite	1.36
Albite	44.01	Magnetite	0.23
Nephelite	9.94	Corundum	0.31
Anorthite	12.81	Apatite	0.93
Olivine	4.75	Water, etc.	1.47
			100.27

PLATE XVII
GRANITE HILL, LOOKING SOUTHWEST

PLATE XVII
COPPERAS HILL, LOOKING NORTHEAST. DUMPS FROM OPEN CUTS IN PYRRHOTITE DEPOSIT AT RIGHT CENTER

A coarse-grained phase of this syenite is best shown in a narrow belt between essexite and pulaskite, extending for a part of the distance between the summit of the north knob and the molybdenite prospect (M, Plate XVI) near the crest of Granite Hill. Hornblende in prisms, occasionally upwards of two inches in length, is the most prominent constituent. Flakes of biotite, sometimes half an inch across, are sparsely scattered through the rock. Titanite and pyrite are visible without a lens. As the proportion of feldspar, much of which is plagioclase, diminishes, the rock becomes dark colored and gabbroid, and grades into coarse-grained essexite.

A strongly *biotitic phase* of medium grain, and with a somewhat greater proportion of dark silicates than in the type phase, is exposed along the railroad in the first eruptive area north of the Granite Hill area (Plate XVI).

In the hornblende-biotite syenite of the quarry on Granite Hill (Q 2, Plate XVI), *foyaitic schliers* are not uncommon. Some appear to be segregations. Others are more sharply defined, elongate, and dike-like. They are usually small, but may attain a width of several inches and a length of two or three feet. The larger are coarse grained, with gray nephelite, sometimes an inch or more in diameter, white or pearl gray feldspars, and an occasional biotite flake or hornblende prism. Thin sections of these schliers show microperthite, some plagioclase, nephelite, colorless sodalite, hornblende, titanite, and magnetite. In the finer-grained rock there also appear olive-brown biotite, pyrite, and possibly cancrinite and zircon as subordinate accessories.

Pulaskite (3, Plate XVI and fig. 9)—This rock is usually coarse grained and much weathered. The *type phase* is essentially a coarse-grained aggregate of hypidiomophic, gray-white feldspars which weather cream-white, yellowish, or brownish. Biotite is generally present, becoming abundant in some varieties.

A thin section of comparatively fresh rock from the exposure along Mill River, at the east foot of the south knob of Granite Hill, shows the rock to be composed chiefly of microperthitic feldspar with a little orthoclase. One area probably represents cancrinite derived from original nephelite. A little nephelite is almost certainly present in some other hand specimens. Titanite, magnetite, pyrrhotite, apatite, and zircon are accessory; the sulphides and titanite are sometimes macroscopically visible.

Some of the weathered rock from the upper southward slope of the north knob of Granite Hill appears to carry a little augite, as well as some biotite. If so, it approaches augite syenite in composition, but is decidedly more feldspathic and coarser grained than the typical augite syenite or nordmarkite (5, Plate XVI) of the northward slope of the north knob. It has been a difficult matter to draw a line between the two in mapping their respective areas. It is possible that there is no such line, and that the pulaskite and nordmarkite are really one body, more augitic and nordmarkitic on the north and more feldspathic and pulaskitic on the south.

Coarse-grained phases of pulaskite are very strikingly developed near the crest of the middle part of Granite Hill, as ill-defined, apparently northward-trending streaks or schliers, about a foot wide, in syenite not quite so coarse. The rock is practically all feldspar, in chunks or rough crystals, some upwards of two inches in length. A noteworthy point about some of the coarse-grained phases of the Cuttingsville eruptives is their proximity to eruptive contacts suggesting that their coarseness of grain is partly due to the action of gases emanating at contacts.

Biotitic phases of the pulaskite develop near contacts with essexite. This is notably the case on the north knob of Granite Hill, and in the exposures along Mill River at the east foot of the south knob. A peculiar coarse biotitic phase is developed in small amount between essexite and normal pulaskite in the pit (P, Plate XVI), south of the quarry. Similar rock with the same association of essexite and normal pulaskite and in limited amounts is exposed beside the path near the quarry. Penetrating the usual coarse, hypidiomorphic, gray-white feldspars are skeleton flakes of biotite up to one inch in diameter. The flakes are quite numerous and lie in various attitudes. Consequently, a broken surface of the rock shows a number of roughly radiating black lines, which are the traces of wide flakes broken across. Besides these, some flakes, luster-mottled as a result of their skeletal structure, appear full face.

Fine-grained and porphyritic phases of pulaskite appear frequently along contacts. The pulaskite of the two small eruptive areas, (PlateXVI), north of the Granite Hill area is mostly medium grained.

Sodalite-nephelite syenite (4, Plate XVI and figure 9)—The sodalite-nephelite syenite at the railroad cut is a holocrystalline, moderately coarse-grained aggregate of light gray feldspar of tabular habit, rather frequently in Carlsbad twins, with interstitial black pyroxene and brownish nephelite. Minute grains and small masses of pyrite are disseminated through the rock. Blue sodalite is rarely discernible in a hand specimen.

Thin sections show about ninety per cent of feldspar, of which upwards of one-half is microperthite, orthoclase, and microcline. Both the orthoclase and microcline are somewhat microperthitic. Some form of microperthite is thus the chief feldspar. A part is possibly anorthoclase. The plagioclase is near albite in composition. Colorless sodalite forms angular and veinlike areas between and penetrating the feldspars. The chemical analysis indicates its amount as about three per cent.

The nephelite, in nearly equal abundance, is in various stages of alteration to cancrinite, zeolites, and muscovite. Pyroxene is next to the feldspars in abundance. It is a pleochroic variety, the color ranging from pale yellowish green through olive-green to green. Extinction angles indicate an aegirite-augite somewhat nearer aegirite than augite. There is some biotite bordering, penetrating, and included in the aegirite-augite. The order of crystallization is given in the following list which also shows the nature of the accessories: (1) apatite; (2) magnetite, titanite, and possibly pyrite; (3) biotite; (4) aegirite-augite; (5) plagioclase; (6) sodalite, nephelite, and most of the feldspars.

The chemical analysis (column I of the following table) agrees with the mineralogical composition in referring the rock to the sodalite-nephelite syenites. For convenience the analyses of other types are also entered:

	I	II	III	IV	V	VI
SiO_2	60.88	56.45	60.20	60.13	58.61	61.86
TiO_2	0.35	0.29	0.14	1.15	1.10	0.15
Al_2O_3	20.75	20.08	20.40	20.03	21.12	19.07
Fe_2O_3	0.63	1.31	1.74	2.36	2.62	2.65
FeO	1.13	4.39	1.88	1.33	1.14	1.49
MnO	0.22	0.09	Trace	Trace	Trace	0.01
MgO	0.17	0.63	1.04	0.76	0.79	0.55
CaO	1.08	2.14	2.00	0.87	0.62	1.47
Na_2O	6.35	5.61	6.30	6.30	7.85	6.45
K_2O	5.57	7.13	6.07	5.97	5.93	5.75
H_2O+	0.88	1.51	0.23	1.41	1.01	0.47
H_2O-	0.03	0.26	0.10	0.16		
P_2O_5	Trace	0.13	0.15	0.06	Trace	0.08
CO_2	0.61		None	None		
ZrO_2	Trace		Trace	0.05		
SO_3	None		0.13	0.14		
Cl	0.18	0.43	0.09			
F	0.05					
Cr_2O_3	None					
BaO	0.02					
SrO	Trace					
FeS_2	0.61					
Fe_7S_8	0.13					
Li_2O	None					
Sum	99.64	100.45	100.47	100.72	100.79	100.00

I = Sodalite-nephelite syenite, type phase (nordmarkose), Cuttingsville, Vt., H. E. Merwin, analyst.
II = Sodalite syenite (pulaskose), Square Butte, Mont.
III = Pulaskite (pulaskose), Fourche Mts., Ark.
IV = Foyaite (phlegrose), Fourche Mts., Ark.
V = Aegirite—kataforite foyaite (miaskose), Heum, Norway.
VI = Pulaskite (average of 5 analyses, R. A. Daly).

II, III, IV, V Quoted from Washington, H. S., U. S. Geol. Surv., Prof., Paper 14, pp. 201, 199, 195, 211, 1903.
VI " " Daly, R. A., "Igneous Rocks and Their Origin", p. 22.

The rock is a nordmarkose, near phlegrose, with the following norm:

Orthoclase	32.80	Magnetite	.93
Albite	53.45	Ilmenite	.61
Anorthite	5.28	Corundum	2.35
Hypersthene	1.72	Water, etc.	2.51
			99.65

A comparison of columns I, III, and VI tends to support the view that the sodalite-nephelite syenite is a phase of the Cuttingsville pulaskite.

Augite syenite (*nordmarkite*) (5, Plate XVI).—In the middle of the last century, during the construction of the railroad, openings were made in the north end of Granite Hill and a considerable amount of stone quarried for bridge foundations. This stone is popularly known as green granite from its light olive-green color. The grain is usually medium, but there are fine-grained and decidedly coarse-grained phases. In total areal extent it is probably second only to the pulaskite. The *type phase* is a medium-grained aggregate largely of hypidiomorphic feldspar. Grains of black augite and occasional small grains of quartz are usually discernible. The rock, on the fresh fracture, is bluish gray to gray-green in color. This color changes in a few weeks indoors to olive or brownish green.* The change is presumably due to the oxidation of iron sulphide or some other substance disseminated through the feldspar. The rock yields a strong sulphurous odor while being broken. Outdoor weathering rusts the rock surface, finally changing the color to pale buff or very light brown.

In thin section, the texture is holocrystalline, hypidiomorphic granular. Seventy-five per cent or more is feldspar, of which microperthite is most notable and is accompanied by microcline, probably anorthoclase, orthoclase, and a little albite. Green augite, locally rimmed with green hornblende, is chief of the remaining minerals. With it there is some aegirite-augite whose extinction angle approaches that of aegirite. An occasional large grain of olivine (fayalite?), more or less serpentinized, and a little primary quartz, in distinct grains, are usually present. Magnetite, possibly some ilmenite, zircon, and apatite are accessory. A single large crystal, possibly allanite, was noted in one section.

The mineralogical composition indicates that the rock is an augite syenite of the nordmarkite group, a conclusion borne out by a comparison of its chemical analysis (column I of the following table) with other nordmarkitic types and with average nordmarkite (column VII.)

	I	II	III	IV	V	VI	VII
SiO_2	67.30	65.43	65.43	60.45	66.13	67.99	64.36
TiO_2	0.17	0.16	0.50		0.74		0.45
Al_2O_3	17.44	16.96	16.11	20.14	17.40	17.54	16.81
Fe_2O_3	1.56	1.55	1.15	3.80	2.19	1.17	1.08
FeO	1.76	1.53	2.85	not det.	not det.	0.82	2.71
MnO	0.16	0.40	0.23		0.13		0.15
MgO	0.14	0.22	0.40	1.27	0.04	0.13	0.72
CaO	1.00	1.36	1.49	1.68	0.81	1.44	1.55
Na_2O	7.08	5.95	5.00	7.23	5.28	4.92	5.76
K_2O	4.78	5.36	5.97	5.12	5.60	5.78	5.62
H_2O+	0.05	0.82	0.39	0.71	1.22	0.05	0.70
H_2O-	0.05		0.19				
P_2O_5	0.04	0.02	0 13				0.09
CO_2		None	Trace				
ZrO_2	0.08		0.11				
SO_3	None	0.06	None				
Cl		0.04	0.05				
F			0.08				
BaO		None	0.03				
SrO			Trace				
FeS_2			0.07				
Li_2O			Strong trace				
Sum	101.61	99.86	100.18	100.40	99.54	99.84	100.00
Specific gravity			2.659				

---

*This remarkable behavior is paralleled in the case of the nordmarkite of Ascutney Mountain. (See R. A. Daly, U. S. Geol Survey, Bulletin 209, p. 51, 1903).

I = Augite syenite, nordmarkite, type phase (nordmarkose), Cuttingsville, Vt., C. D. Test, analyst.
II = Nordmarkite (nordmarkose), Shefford Mountain, Quebec.
III = Hornblende-biotite nordmarkite (phlegrose), Ascutney Mountain, Vt.
IV = Nordmarkite (laurvikose), Anneröd, Norway.
V = Akerite (phlegrose), between Thinghoud and Fjelebua, Norway.
VI = Quartz nordmarkite (toscanose), Halasag, Ditro, Siebenbürgen, Hungary.
VII = Nordmarkite (average of 7 analyses, R. A. Daly).

II Quoted from Dresser, J. A., Amer. Geologist, vol. 28, p. 209, 1901.
III " " Daly, R. A., U. S. Geol. Surv., Bull. 209, p. 59, 1903.
IV, V, VI " " Washington, H. S., U. S. Geol. Surv. Prof. Paper 14, pp. 171, 195, 203, 1903.
VII " " Daly, R. A., "Igneous Rocks and Their Origin", p. 22.

The rock is nordmarkose, with the following norm:

Quartz	5.40
Orthoclase	28.36
Albite	59.74
Anorthite	1.67
Diopside	2.85
Hypersthene	.76
Magnetite	2.32
Ilmenite	.30
Water, etc.	.22
	101.65

Hand specimens of the Cuttingsville augite syenite and the Ascutney Mountain nordmarkite very closely resemble each other and the Shefford Mountain nordmarkite. The resemblance is so close that hand specimens of the three are practically indistinguishable. Although the Cuttingsville rock contains the highest per cent of silica, thin sections of the Ascutney rock seem to show the most quartz, and thin sections of the Cuttingsville rock the most augite. The Shefford Mountain rock, judged in this manner appears to be intermediate between the other two.

The Cuttingsville augite syenite has a *quartz-bearing phase.* It is apparently quite subordinate to the type phase, and occupies no well-defined area. Generally it is developed as a selvage a a few feet in width, along the contact of the augite syenite and the country rocks. It is usually finer grained than the type phase, but the quartz is always distinctly visible, sometimes forming a considerable part of the rock. With diminution of the proportion of dark silicates, the finer-grained rock becomes quite aplitic. Some of it of aplitic or paisanitic habit, occurs in narrow dikelets and streamers cutting the type and coarser phases. Green hornblende, with accessory quartz, is notable in certain thin sections. Part of the hornblende is probably secondary. The presence of hornblende and quartz allies this phase to the Ascutney Mountain nordmarkite, and less closely to the Shefford Mountain nordmarkite.

Near the summit of the south knob of Granite Hill, a *porphyritic syenite*, tentatively mapped as nordmarkite (5, Plate XVI) is closely associated with essexite not far from the country-rock contact. Apparently it is a border development of the eruptive body, and of small extent.

In the zone between nordmarkite and essexite, on the upper north slope of the north knob of Granite Hill, the nordmarkite becomes increasingly *biotitic*. Some of it also carries roughly idiomorphic hornblende and plagioclase, which are sometimes arranged in flow lines. The rock grades from medium grained to fairly fine, and from granitic to porphyritic. It becomes so much like the adjoining essexite that the actual contact is somewhat indistinct. The contact rock is perhaps best classified as an essexite-nordmarkite hybrid.

DIKE ROCKS

Essexite porphyry.—The apophyses from the essexite are generally porphyritic. Petrographically this essexite porphyry has no special peculiarities worthy of detailed statement. Hornblende and biotite, alone or together, are the chief phenocrysts.

Nephelite syenite.—As already noted, nephelite syenite forms dike-like bodies in the hornblende-biotite syenite of the quarry (Q 2, Plate XVI).

Syenite porphyry.—Pulaskite porphyry and nordmarkite porphyry are developed at the borders of both the pulaskite and nordmarkite masses. Reference has already been made to porphyritic phases of pulaskite and nordmarkite. These phases pass into pulaskite porphyry and nordmarkite porphyry at contacts and in apophyses, by increase of groundmass. Some of the pulaskite porphyry is apophysal from the main pulaskite body, but other masses form dikes which seem to be distinctly later intrusions. Two or more of these later dikes are exposed in the pit (P, in Plate XVI) south of the quarry (Q 2, Plate XVI). They appear to cut essexite and probably also biotitic pulaskite.

Zircon-rich pulaskite porphyry.—At the foot of the eastern slope of the north end of Granite Hill, about 200 feet downstream from a short tunnel (T, Plate XVI), a dike of coarse trachytic rock is exposed from the bank of Mill River 40 feet up the steep slope. The dike cuts green, quartz-bearing, augite syenite, which is brecciated at the lower contact and receives branch dikelets. The main dike has a thickness of approximately 12 feet, and dips about 50° S. E. About 125 feet upstream, an irregular dike of similar rock, with a maximum width of 15 feet, extends 10 feet up the slope. Downstream from the main dike, near a dam, similar rock is again exposed. All three of these exposures may belong to the same dike.

The rock of the main dike shows strong contact chilling. The sections studied are of the coarse-grained, middle phase. Specimens of this phase show broad, half-inch tablets of gray feldspar, slender prisms and small grains of black pyroxene, and less frequent, small, hexagonal, and irregular flakes of black mica, in a fine to medium-grained mass of feldspar, black pyroxene, and black mica. Feldspar greatly predominates, giving the rock its light gray color.

Thin sections show roughly idiomorphic feldspar and pyroxene in a granular mass including feldspars, pyroxene, biotite, magnetite, acicular zircon, titanite, apatite, little hornblende, and possibly nephelite (or sodalite), corundum, and fluorite. About 90 per cent of the rock is feldspar, chiefly anorthoclase, with orthoclase, microperthite, and subordinate oligoclase ($Ab_6 An_1$). Between and penetrating the feldspar are irregular areas of zeolites, or other secondary minerals, which may have been derived from nephelite or sodalite. Augite, occasionally with outer zones of aegirite-augite, or aegirite, is the principal colored mineral.

Mineralogically the rock is a zircon-rich pulaskite porphyry. Its complete chemical analysis was not attempted. Dr. H. E. Merwin, however, tested it for zirconia in order to check the microscopic evidence of abundant zircon. He found sufficient zircona for at least 1 per cent of zircon. He also determined the percentages of soda and potash as, respectively, 7.32 and 4.81.

Aplite.—Narrow aplitic dikes of paisanitic quality cut the coarse and medium phases of the augite syenite. They also penetrate, for short distances, the country gneisses to the west.

Tinguaite.—The locations of tinguaite dikes are shown in Plate XVI. At the foot of the eastern slope of the south knob of Granite Hill, along the bank of Mill River, a complex of syenitic and essexitic rock-phases is cut by numerous dikes of syenite porphyry, tinguaite, and camptonite. A tinguaite dike (D, Plate XVI), towards the downstream end of the exposure, carries remarkably fresh rock, selected for chemical analysis. The dike, about one foot wide, dips 80° W.N.W.

The hand specimen has a medium-gray color, a dense fine-grained texture, and a superficial resemblance to blue quartzite, though of duller luster. A few, small, phenocrystic laths of feldspar are discernible. In the groundmass, nephelite is sufficiently abundant to yield much gelatinous silica when the powdered rock is treated with hydrochloric acid.

The thin section shows well-formed phenocrysts of anorthoclase and microperthite in a fine granular groundmass. The groundmass carries some fairly distinct laths of feldspar and prisms of pyroxene. The remaining feldspar, pyroxene, and most of the other minerals are allotriomorphic. Orthoclase and nephelite appear in roughly equal amounts, with plagioclase, (albite) apparently somewhat less than either.

Reckoning groundmass and phenocrysts together, ninety per cent or more of the rock is feldspar and nephelite. The nephelite is seen to enclose minute orthoclase crystals. There are occasional grains of cancrinite. A colorless mineral in irregular and vein-like patches is probably sodalite; a little chlorine reported in the analysis may thus be accounted for. Pyroxene is represented by two varieties. One is pleochroic, in colors from yellowish or brownish to green. Extinction angles run up to 20°. These characters, together with the proper elongation, indicate an aegirite-augite. The other, less abundant, is a very pale or colorless variety, apparently diopside. The accessories are magnetite, titanite, zircon, and rare apatite.

The chemical analysis of this tinguaite (miaskose) and its parallels are stated in the accompanying table:

	I	II	III	IV	V	VI	VII
SiO_2	57.64	55.68	54.22	55.06	55.46	56.58	55.02
TiO_2	0.15	0.60	0.38		0.20		0.36
Al_2O_3	23.31	20.39	20.20	23.29	24.49	19.89	20.42
Fe_2O_3	1.22	2.10	2.35	3.29	2.63	3.18	3.06
FeO	0.55	1.95	1.02	not det.	1.06	0.56	1.82
MnO	0.10	0.31	0.19		Trace	0.47	0.22
MgO	0.22	0.80	0.29	Trace	0.05	0.13	0.59
CaO	0.67	1.92	0.70	1.46	0.92	1.10	1.67
Na_2O	10.48	9.18	9.44	6.76	9.78	10.72	8.63
K_2O	5.09	5.34	4.85	8.86	5.16	5.43	5.38
H_2O+	0.24	1.50	5.57	1.08	0.07	1.77	2.77
H_2O-	0.02		0.42				
P_2O_5	Trace	0.06	0.11		Trace		0.06
Co_2	None		Trace				
ZrO_2	0.12						
SO_3	Trace		None				
Cl	0.02		Trace				
F	0.06		Trace				
Cr_2O_3	None						
BaO	None		Trace				
SrO	Trace						
FeS_2	0.08						
Fe_7S_8	0.05						
Li_2O	None						
Sum	100.02	99.83	99.74	99.80	99.82	99.83	100.00

I = Tinguaite, type phase (miaskose), Cuttingsville, Vt., H. E. Merwin, analyst.
II = Tinguaite (laurdalose), Brome Mt., Quebec.
III = Aegirite tinguaite (miaskose), Southboro, Mass.
IV = Leucite tinguaite (beemerose), Serra de Tingua, Brazil.
V = Tinguaite (miaskose), Gy. Szt. Miklos, Czanod, Siebenbürgen.
VI = Tinguaite (laurdalose), Hedrum, Norway.
VII = Tinguaite (average of 15 analyses, R. A. Daly).

II Quoted from Dresser, J. A., Amer. Journal Science, vol. 17, p. 355, 1904.
III " " Clarke, F. W. U. S. Geol. Surv., Bull. 591, p. 35, 1915.

IV, V, VI " " Washington, H. S.. U. S. Geol. Surv., Prof. Paper 14, pp. 207, 213, 295, 1903.
VII " " Daly, R. A., "Igneous Rocks and Their Origin", p. 35.

The rock is a miaskose, with the following norm:

Orthoclase	30.02	Diopside	1.08
Albite	36.68	Magnetite	1.86
Anorthite	1.96	Ilmenite	.30
Nephelite	27.55	Water, etc.	.59
			100.04

Comparison with the Brome Mountain tinguaite shows one more proof of general chemical similarity between the Monteregian eruptives and those at Cuttingsville. The Southboro, Mass., tinguaite (also miaskose) contains aegirite, while the Cuttingsville rock carries aegirite-augite. The Brazilian tinguaite is the classic example from Serra de Tingua, the type locality. It differs from the Cuttingsville rock in bearing leucite.

Camptonite.—Camptonite dikes, not quite as numerous as the tinguaite dikes (Plate XVI), are associated most closely with essexite and nordmarkite.

Perhaps the most typical camptonite occurs in a dike a foot thick, exposed in the wall of a small, abandoned nordmarkite quarry (Q5, Plate XVI) on the lower north slope of Granite Hill. The rock is black and porphyritic, with a few scattered, flashing crystals of black hornblende, and more numerous, smaller tablets and masses of gray-white feldspar. One of the hornblendes is 2 centimeters long. An occasional grain of olivine also contrasts with the black, fine-grained groundmass. The thin section shows phenocrysts of augite, moderately basic plagioclase, brown hornblende, and serpentinized olivine. The groundmass is an aggregate of brown hornblende, plagioclase, augite, magnetite, and some pyrite.

In the more northerly of the two small eruptive areas north of Granite Hill (Plate XVI), two or more camptonite dikes cut essexite or the country gneisses. One of the dikes, about 25 feet wide, carries many inclusions of gneiss, quartzite, syenite, and probably essexite. They are generally angular in shape and not more than 1 cm. in diameter. The camptonite is porphyritic. The phenocrysts are brilliant black hornblendes. They are usually under 2 cm. in length, though some reach 8 or 10 cm. A single large grain of serpentinized olivine appears in one specimen. The groundmass is dark gray, fine grained, and dense.

Thin sections show the phenocrysts to be brown hornblende and, in smaller amount, zoned plagioclase, andesine to basic labradorite. There is some kaolinized orthoclase or microperthite, probably xenolithic. Green pyroxene, more or less altered to actinolite and chlorite, also appears among the phenocrysts.

The groundmass is chiefly composed of plagioclase laths, small prisms of hornblende and actinolite, and chlorite. Brown biotite, magnetite, apatite, titanite, ilmenite, and pyrite are accessory.

Mineral Deposits

On Copperas Hill (Plates XVI and XVII), large bodies of pyrrhotite, once mined as a source of copperas, have replaced limestone cut by tinguaitic dikes which appear to have played a determining part in the ore deposition. In this connection, the presence of pyrrhotite, as an accessory mineral in several of the rocks which have been described, is worth noting. Molybdenite (M, Plate XVI) occurs in syenite at its contact with gneiss on the crest of Granite Hill, a quarter of a mile north of the hornblende-syenite quarry. The molybdenite scales are of small size, often thickly powdered, like the enclosing syenite, with yellow molybdite. Apparently the deposit is too limited to warrant development. Some pyritic mineralization appears at T, Plate XVI, and near the middle area of B, figure 10. In the former case, the deposit has been explored by means of a sixty-foot tunnel.

General Conclusions

Emplacement of eruptives.—Composite character, cross-cutting relations to the country rocks, the oval surface plan, and high contact dips indicate that the main eruptive body is a composite stock. It is certainly not a laccolith and probably not a chonolith. The two small eruptive areas north of the main body seem to be parts of a single small, satellitic stock or chonolith, if not simply a northward prolongation of the main body, now separated in outcrop by fluviatile and glacial deposits.

Comparison with other areas.—The general structure is comparable to that of Ascutney Mountain, 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.

Though the main Cuttingsville body has a rough concentric structure, its relations to country rock recall those of at least four stocks of the Monteregian Hills, Quebec, namely: St. Hilaire, Rougemont, Johnson (a neck?), and Yamaska mountains. Of the other Monteregian masses, Shefford, Brome, and St. Bruno (Montarville) are composite, and have been described as laccoliths without compelling evidence. In all of these hills essexite is represented. In six, perhaps all, the essexite is associated with syenite. This association, combined with close mineralogical and chemical similarity to the Ascutney and Cuttingsville eruptives, renders the comparison doubly impressive.

Red Hill, N. H., a neighboring New England locality, furnishes another example of a small, composite syenite stock, described by Pirsson.* The country rock is a granitic gneiss, and the eruptives include, in the order of eruption, nephelite syenite (umptekite, foyaite,) aplite, paisanite, bostonite, syenite porphyry, and camptonite. Chemical similarity of the Red Hill umptekite and the Cuttingsville hornblende-biotite syenite has been noted.

Essex County, Mass., the type locality for essexite, and Southboro, Mass., a tinguaite locality, are other examples of New England areas containing eruptives chemically related to certain of the Cuttingsville rocks.

The Cuttingsville area thus takes its place as one more of the known number of small, alkaline, intrusive bodies in the New England-Quebec region. Most of the Monteregian Hills lie west of the limit of Appalachian deformation, their intrusions penetrating practically undisturbed beds. The Cuttingsville and other New England examples are located in disturbed rocks, although themselves not notably affected by deformation.

Reference has also been made to the similarity of the Cuttingsville rocks to certain eruptive rocks of southern Norway.

Order of eruption.—Field observation indicates that eruption of the plutonic types proceeded in the order usual with alkaline intrusions, namely from basic to acidic. Essexite was plainly the earliest intrusion. The syenites followed essexite in a succession not entirely clear. Nordmarkite was apparently the last. Hornblende-biotite syenite, with pulaskite, nephelite syenite (foyaite) and sodalite-nephelite syenite, probably came between essexite and nordmarkite in about the order given.

On the other hand, the syenites possibly constitute a single eruption, rather than a succession of intrusions. If the hornblende-biotite syenite is a simple differentiate, rather than a hybrid, it was the first of the syenites to separate.

The apophysal dikes conform, in a general way, to the same order of basic to acidic intrusions. Essexite porphyries were the earliest, some of them apparently truly apophysal from the essexite body, and others intrusive into it. Aplite was later than the nordmarkite. The syenite porphyries presumably came between essexite porphyry and aplite. Some of the pulaskite-porphyry dikes, however, cut nordmarkite, and may be even younger than aplite.

With the "complementary" dikes the order was reversed, the tinguaite dikes, which are relatively acidic, preceding the relatively basic camptonite dikes. Some of the tinguaite dikes are probably younger than all the plutonic types and the truly apophysal dikes. Others are possibly only tinguaitic phases of pulaskite porphyry and nordmarkite porphyry. The camptonite dikes may not all be of the same age. Some of them are the latest of all the intrusions.

---

*L. V. Pirsson, Am. Journal Science, vol. XXIII, p. 257, 1907.

Origin of the magmas.—The Cuttingsville eruptives are clearly consanguineous; it may be reasonably inferred that all have come from a single parent magma. No subalkaline rocks have been noted in association with the Cuttingsville eruptives. Yet that fact does not necessarily invalidate the hypothesis that the alkaline rocks are differentiates from modified subalkaline magmas. It might be assumed that an originally subalkaline magma was modified by desilication to produce the alkaline parent magma. The desilication may have resulted from the assimilation of limestone which outcrops in at least four different localities about the main eruptive body. More limestone may have been stoped from overlying beds since removed by erosion. Assimilation of hornblende gneiss, so abundant in the country-rock series, may have increased the desilicating effect.

That syntexis of country rock has played a part in magmatic changes is to some extent supported by the frequent development of a quartzose selvage of syenite in contact with quartzose country rock, and by the occurrence of apparently primary calcite in certain of the dike rocks.

A highly important factor in the problem of the origin of the magma is the stock structure of the eruptive body. This structure implies a body of magma very much greater than that corresponding to the rocks directly visible at the present erosion surface. Stocks are generally assumed to be small projections from greater batholithic bodies. In any case, the exposed part of a stock is only a transverse section high up in the magma chamber. This condition renders assumptions regarding the nature of the original magma, before assimilation and gravitative differentiation had set in, highly speculative.

The exposed rocks of the stock have an average composition not far from that of a typical laurvikose. It is not unlikely that, owing to gravitative differentiation, the deeper rocks are more basic and maffic. This, of course, would increase the basicity of the stock as a whole and necessitate the assumption of a parent magma more basic than laurvikose. The essexite may represent nearly the chemical nature of the parent magma, suggesting, further, that the original, unmodified subalkaline magma was truly basaltic.

This view has much in its favor. It explains the eruption of essexite first, as an extravasation of parent magma before very marked differentiation had set in. The succeeding, increasingly feldspathic eruptions mark stages in the advance of differentiation, possibly interrupted, and again renewed, by further assimilation of country rock.

LIST OF CHEMICAL ANALYSES.

	I	II	III	IV	V	VI	VII
SiO_2	57.44	46.47	60.88	57.64		67.30	38.04
Al_2O_3	21.60	16.86	20.75	23.31		17.44	13.50
Fe_2O_3	.20	3.21	.63	1.22		1.56	6.21
FeO	2.62	7.72	1.13	.55		1.76	15.85
MgO	1.09	5.16	.17	.22		0.14	7.26
CaO	2.90	9.45	1.08	.67		1.00	12.42
Na_2O	7.36	4.20	6.35	10.48	7.32	7.08	3.21
K_2O	4.12	1.35	5.57	5.09	4.81	4.78	1.68
H_2O+	.58	.45	.88	.24		0.05	0.48
H_2O-	.03	.04	.03	.02		0.05	
CO_2	.39	Trace	.61	None			
TiO_2	.69	2.86	.35	.15		0.17	1.06
ZrO_2	.02	None	Trace	.12		0.08	
P_2O_5	.38	1.15	Trace	Trace		0.04	
SO_3	None	None	None	Trace		None	
Cl	.07	.06	.18	.02			
F	.05	.10	.05	.06			
Cr_2O_3	None	None	None	None			
MnO	.14	.23	.22	.10		0.16	1.21
BaO	.26	Trace	.02	None			
SrO	.04	.04	Trace	Trace			
FeS_2	.15	.21	.61	.08			
Fe_7S_8	.14	.08	.13	.05			
Li_2O	None	None	None	None			
Sum	100.27	99.64	99.64	100.02		101.61	100.92
Specific gravity——							3.518

I = Hornblende-biotite syenite (laurvikose), H. E. Merwin, analyst.
II = Essexite (andose), H. E. Merwin, analyst.
III = Sodalite-nephelite syenite (nordmarkose), H. E. Merwin, analyst.
IV = Tinguaite (miaskose), H. E. Merwin, analyst.
V (partial) = Zircon-rich pulaskite porphyry, H. E. Merwin, analyst.
VI = Augite syenite (nordmarkite, nordmarkose), C. D. Test, analyst.
VII = Barkevikitic hornblende from hornblende-biotite syenite of analysis I, C. D. Test, analyst.

PROVISIONAL REPORT

of the Areal and Structural Geology of the Western Flank of the Green Mt. Range

N. C. DALE

HAMILTON COLLEGE

INTRODUCTION

Through the courtesy of Dr. G. H. Perkins, the State geologist of Vermont, the writer undertook an investigation of the areal geology with special emphasis upon the structural details of a portion of the western flank of the northern part of the Green Mountain range, during the summer of 1915. At this time only a provisional report can be made as there still remains some unfinished field work vital to the solution of the problems presented, as well as certain petrologic considerations, together with all the illustrative material necessary for a more lucid presentation of the structural details.

In the final report the following subjects will be presented:
Geography.
Physiography.
Areal Geology.
Stratigraphic Geology.
Structural Geology.
Metamorphism.
General history of the region.

In this report only the most general consideration will be presented. Areal, outcrop and structure maps accompany this report.

GEOGRAPHY

The western flank of the Green Mountain range includes a north-south strip of mountainous land, 26 miles long and 5 miles wide, approximately 130 square miles in area and situated in parts of the following townships: Middlebury, Ripton, Bristol, Lincoln, Monkton, Starksboro, Hinesburg and Huntington. The northern end of this strip is about 15 miles south-east of Burlington while the southern end is between 4 and 5 miles east of Middlebury.

AREAL GEOLOGY

The accompanying areal geological map shows that the above area is wholly a metamorphic one and largely of Cambrian and Ordovician age with the small area of granite gneiss near the southern extremity of the region undoubtedly belonging to the pre-Cambrian.

With the exception of some sheared quartzose conglomerates, in all probability a member of the quartzite beds, the Cambrian period is represented by quartzites and dolomites, the same forming the outermost western fringe of the range. From the northern end of Hogback Mountains, however, the quartzite pitches northward under the dolomite, not appearing again to the north in such massive beds as seen in the south. East of the quartzite dolomite area are found various schists and gneiss, a large part of which are of sedimentary origin. In addition to micaceous, chloritic and quartzose schists there are some with a high content of calcite, dolomite and feldspar. The feldspathic schists and gneisses are found in a pretty well defined north-south strip of about one half to one mile in width and not more than a half of a mile east of the Cambrian quartzite area. For these rocks the name of metamorphic arkoses has been given because they apparently contain most of the essential minerals of the granitic rocks without the granitic texture of an igneous rock.

The extreme eastern section of the region is largely taken up by rocks of gneissic structure but only at one locality could a definite igneous origin be assigned and this is probably of pre-Cambrian age. More field work in the township of Ripton will be necessary before the limits of this formation can be drawn.

Several basaltic (diabase) dikes were found, one in the north slope of South Mountain about 12 ft wide and traceable for 50 ft. At the outcropping where the brook has helped cause a waterfall the intrusion was conformable with the schistosity. Another dike was formed in the west slope of Lincoln Hill but it was only one foot wide and not traceable for any great distance. It was cutting a chlorite mica schist. A third dike of the same nature, 2 ft wide and traceable for 10 ft was found cutting a dolomite. Loose blocks of another dike were seen near the top of Lincoln hill in the west slope.

STRATIGRAPHIC GEOLOGY

The age, superposition and rock variation is given below.

GEOLOGIC AGE	VARIETIES OF ROCK	
Ordovician	Sedimentary Gneisses	
	Schists	Silicious Chloritic Micaceous Calcareous Dolomitic
Cambrian	Arkoses	Schists Gneisses
	Dolomite	Cream Blue
	Quartzite	Massive Sheared Congloses.
Pre-Cambrian	Granite Gneiss.	

The metamorphics lying east of the dolomite quartzite area are so entirely different from the rocks of the western section that it was thought best to classify them according to the above table for the present.

PRE-CAMBRIAN

Though no contact of the Canadian quartzite with an older formation was discovered in this region yet it seemed best to classify the only true granite gneiss in the pre-Cambrian age. More investigation in the southern end of the sheet will be necessary before one can write finally upon this occurrence found in the western tributary of the north branch of the Middlebury River. Its swirl like structure consisting of biotite and feldspar bands as well as an undoubted original granitoid texture all seem to signify its igneous origin.

CAMBRIAN

The Canadian quartzite of this region is the typical maple sugar colored and textural variety found south of this region in Southern Vermont but included in the formation are sheared beds producing a pseudo conglomeratic structure and real beds of conglomerate, the pebbles of which are quartzite. The greatest thickness of this formation is about 1,800 ft., found in the Hogback and South Mountain vicinity.

The dolomite of this same period is a brown weathering cream colored crystalline rock that is sometimes blue.

At the road cutting just a mile south of Starksboro is an excellent contact exposure of vertically bedded dolomite and quartzite beds. The main dolomite beds of Lewis Creek are succeeded in the east by the following strata:

Dolomite	
Dolomite Shale (schist)	
Quartzite dolomite	5′
Road	25′
Dolomite shale (schist)	3′
Quartzite	5′
Dolomite shale (schist)	30′ with quartzose dolomite boulders
Quartzite	15′
Dolomite shale (schist)	
Quartzite	75′
Dolomite shale schist	50′ +
Quartzite	20′ +
Quartzite schist	125′
Argillaceous quarzite schists	

The dolomite shale referred to in this series is in all probability a sheared dolomite and resembles a shale in structure only.

The repetition of beds by alternations would strongly suggest isoclinal folding. With the exception of the lowest bed this series has much in common with the main Cambrian quartzite and dolomite.

METAMORPHIC ARKOSES

Following upon this series toward the east is one of indurated arkosic schists and gneisses with blue quartz and orthoclase feldspar grains as the essential minerals. This series occurs in a zone, ½ to 1 mile wide, extending nearly to the northern end of the sheet, N. E. of Hinesburg and some distance to the south as far as Abbey Pond. The pervading characteristics of this series are the presence of grains of orthoclase feldspar and blue quartz, though pink quartz grains do exist as well as a general schistose structure. Where quartz predominates the arkose exhibits a very massive structure which disappears when feldspar and mica predominate causing the rock to assume a plicated and corrugated structure. Where the foliations are coarse the rock has been called an arkosic gneiss and where fine, an arkosic schist. Both schist and gneiss may be pyritiferous or magnetiferous.

OTHER SCHISTS AND GNEISSES

Other than the metamorphics just described and east is a series of schists and gneisses distinguished largely by the predominating mineral such as chlorite, mica, quartz, calcite and dolomite, or by the degree of foliation. The coarsely foliated metamorphics are included under the gneisses and the more finely under the schists. No attempt has been made to differentiate between these varieties on the areal map as the time at the disposal of the writer was much too limited. These rocks presumably belong to the sedimentary series as they not only frequently show bedded relationship but also a clastic composition, some of the beds being distinctly conglomeratic.

Just where the boundary between the Cambrian and Ordovician should be drawn in the western flank of the Green Mountain range is not altogether clear but with the exception of the Arkosic metamorphics the prevailing mica, chlorite and quartzose schists have much in common with the typical Berkshire Schist formation of Southern Vermont.

STRUCTURAL GEOLOGY

Three north-south structural provinces characterize this region. The westernmost one, physiographically known as the Champlain valley from west to east is a progressively less folded area consisting of rocks of Cambrian and Ordovician age, that part nearest the lake consisting of nearly horizontal strata while the rocks nearest the Green Mountain range are more folded. The intermediate structural province is in great contrast to the valley region as is seen by the highly elevated and folded mountains east of Middlebury and Bristol, rising as an abrupt wall. Hogback Mountain is more typical of this region because its folded character resembles the Appalachian mountain structure more than the region either to the north or south of it. The easternmost section, of a more pronounced massive structure than that of the intermediate is none the less the result of the same intense orogenic movements which have given to the range its highly complex folded structures and metamorphic characteristics.

The data obtained at the south and north end of Hogback Mountain as well as along the New Haven River east of Ackworth prove quite conclusively that the valley of Baldwin and Lewis Creek is synclinal in structure and that Hogback Mountain and South Mountain constitute a large part of the west limit of the syncline. Vertically dipping beds of Cambrian quartzite and dolomite beds of Starksboro and easterly dipping beds on Hogback Mountain, classify the structure as an asymmetrical syncline but pitching anticlinal structure at the north end of Hogback bears evidence of anticlinal structure only for the north end of the west limb.

Assuming that Hogback Mountain forms the western limit of an asymmetrical syncline and that the dolomite of the Champlain valley is stratigraphically younger a possible solution for the problem of the structure at the valley-range contact would seem to be, tho in nature of a hinge fault, the abrupt mountain wall taking on the character of an escarpment. From the quartzite dolomite area of the intermediate structural province eastward the dips are prevailingly easterly with exceptions of occasional vertical, flat and westerly ones, so that the general structure throughout this area is that of open and closed anticlines and synclines with the possibility of some isoclinal development.

The detailed structures of this region have much to do with the cleavage and its relationship to the primary foliation plane presumably a bedding plane. In many of the schist exposures two cleavage planes have been developed and the distinctions could be made between the three divisional planes. Illustrations of these details will accompany the final report.

METAMORPHISM

Originally a part of a basin of deposition for sediments prevailingly clastic in composition and interbedded with calcareous and dolomitic beds this region has undergone many changes, the most important of which are the orogenic movements of Paleozoic age which resulted in the elevation and birth of the Green Mountain range accompanied by the most profound structural and metamorphic changes. Not only have those sediments which were originally sandstones been transformed into quartzites but all those of a conglomeratic and argillaceous character have assumed foliation planes and new mineralogical characteristics.

In many of the schists and gneisses it would be difficult to establish a metamorphic cycle unless there were exposures of both the unchanged and changed rock in uninterrupted continuity. Such a study for any of the metamorphic foundations constituting this part of the Green Mountain range would be a distinct contribution to the science of geology particularly so if such a study could be made to include the progressive metamorphism observed from the shores of Lake Champlain through the Green Mountain range.

Petrographic studies of some of the more important metamorphic rocks of this region are expected along with the final report.

THE STATE CABINET

During the last few months the various collections, which have been for many years displayed in rooms in the Capitol Building, were moved to rooms assigned by the Board of Control in the new State Building. While more space than can be afforded in this building is desirable for the best arrangement and exhibition of such specimens as the State possesses, it is yet in most respects quite satisfactory, and far better than that heretofore occupied.

The space assigned includes a part of the main corridor, a long and narrow room immediately at the end of the corridor opposite the front door, and the south end of the large north room which is mainly given to the library and collections of the Historical Society. A room in the basement is also assigned to the State geologist for an office and the storage of such specimens as it may not be possible to place in the cases on the ground floor.

The most important collections in the Cabinet are those of Marble, Granite and Slate. Commercially, no other exhibit can have for Vermont such importance, as these stones bring to the State an annual revenue of ten or twelve millions of dollars. Obviously these should be displayed as well as possible that not only the many visitors may see what is produced in Vermont in building and ornamental stone, but that contractors, architects, and builders may be attracted to use our products. For the present, as possibly a temporary arrangement, these are shown in a series of cases placed in the main corridor so that as one enters the building they at once come to his notice. Whatever may be said of this location, it is evident that the cases are not as suitable as can be built, but they are now used because we have them and it has not yet been practicable to provide new and better. This will be attended to as soon as possible.

In this collection special notice should be given to the splendid display furnished without cost to the State, by the Vermont Marble Company. Polished slabs of sufficient size to fairly show the veining and shading in the marbles and also the texture of the different varieties, are seen in these cases. There are also many cubes, mostly eight inches, which not only show a polished surface, but one rough hammered, one as left in sawing, one fine hammered, etc., so that builders can see the effect of different finishings. More than seventy varieties are shown and it is a true statement that nowhere the world over, at least so far as yet has been discovered, can such variety in color, veining and texture be found as is continually obtained in the quarries of this company.

The series of granites from the different Vermont quarries is

not as well prepared as is that of marbles, but it is very good and will soon be greatly improved, as the Barre Manufacturers, Association have a committee appointed who have taken up the matter and promise to send a better and more complete exhibit in the near future.

At the north end of this corridor, on the first floor, is a long narrow room which affords excellent positions for wall cases and here, in very satisfactory and handsome new cases are arranged the Mammals and Birds. There are four cases, each sixteen and a half feet long and seven feet high with plate glass fronts. Practically all the different species of quadrupeds and birds ever found in Vermont are here represented, in most cases by more than one specimen. As a rule they are well mounted and there is sufficient light, ordinarily, to show them to good advantage. All of the quadrupeds, except a few heads on the walls, and nearly all of the birds are from this State. In all there are here nearly five hundred specimens representing about 250 species.

Table cases on the floor of this space contain corals, tropical butterflies and the Fossil Whale, found many years ago in a deposit of clay in Charlotte, described and figured by Thompson in his "Vermont" and later and much more fully by the Geologist in the Sixth Report. This is by far the most valuable single specimen in the Cabinet. Several similar specimens have been found in Canada and are in the Museums at Montreal, Ottawa and Halifax, but not a single one has ever been found in the United States except this. Most fortunately nearly the entire skeleton was recovered and mounted. This whale belongs to the latest geological period and still exists in the Gulf of St. Lawrence. To us it is especially interesting as one of many evidences of the time when Lake Champlain was marine and extended much farther towards the Green Mountains than at present.

It may seem incongruous that corals and tropical butterflies should be placed with Vermont specimens and perhaps a word of explanation may not be useless. When the present Curator took charge of the Museum twenty years ago, it was his intention, following the plan of his predecessors, to limit the collections quite rigidly to Vermont objects, but, as has been stated elsewhere, after a few years of experience in meeting visitors, he found that some, especially the school children, made use of the specimens in reviewing and illustrating their work in nature study and that it was very desirable that groups of the animal kingdom not to be found in this State should be accessible. Therefore, while still keeping the whole museum to its original plan and as far as possible using only Vermont material, so that it might remain essentially a Vermont museum, he has added a small number of objects not obtainable here so that in some, however imperfect manner all the greater branches of the whole animal kingdom may be illustrated.

This is also in accordance with the intention that the State

Cabinet shall be not a gathering of curiosities because they are curious, but shall be primarily of educational value. It was with this plan in mind that some of the collections, as corals, tropical butterflies, Hawaiian lava, etc., have been added to the Vermont collections. These collections are, as in this case they should be, not numerous, but they are representative of the class of objects to which they belong.

For the same reason one section is devoted to an arrangement of specimens illustrating the various divisions of the whole animal kingdom, grouped in a small space—a sort of bird's eye view of the whole. Necessarily the representation of each group must be very limited, and also, only the large, main groups can be shown, but it is believed that such a synoptical case will be useful to students of Zoology in the public schools.

In the next room, which is occupied mainly by the Library of the Historical Society, space at the south end is allotted to cases of minerals on the west side and fossils on the east. All of the different kinds of minerals found in Vermont are represented and also such specimens as seemed desirable from elsewhere and the display will be found to be attractive as well as instructive. As most of the fossil bearing rocks in this State are of the older formations, the fossils from them must be of the older ages. Cambrian and Ordovician mainly, with a few from the Brandon Tertiary, mostly from the Champlain Valley, represent fairly the life of those most ancient seas. As in the collection of living animals, a few fossils from geological periods not found here are added to give some sort of completeness to the whole exhibit, but by far the greater number are from Vermont and illustrate its paleontology very well.

Arranged in a series of table cases in the same room are the Indian Relics. In all there are more than five thousand specimens, some of which are very rare and some very fine. Except the larger collections of the University at Burlington, no such series of Vermont Indian objects exists, nor is it possible to collect such extensive series of these at present, and anyone studying the archeology of Vermont must examine these two collections since none like them can be found elsewhere. In the same collection there are a few similar specimens from outside of the State, and especially, a fine series of chipped implements from the valley of the Tennessee River, collected by Mr. O. A. Humphrey of Northfield. These are very useful for comparison.

A room in the basement, well lighted and furnished with cases has also been assigned to the Curator and in this place. many less generally interesting specimens are kept. Of interest to road builders is an extensive series of the rocks of Vermont arranged by towns in such a manner that the principal varieties found in each town can be examined without trouble.

While the Museum belonging to the State of Vermont is not large, it does, never theless, show very satisfactorily the resources and the natural history of the State. Like all museums this is always glad to receive contributions of specimens and, so far as space will permit, to exhibit them to good advantage. In the Seventh Report of this series there may be found lists of the more important species contained in the Museum and plates of some of the most interesting, especially of the Indian relics.

MINERAL RESOURCES

As by far the most important part of the Mineral Resources of this State is found in the marble, granite, and slate, the manufacture and sales of these materials concerns us more than any other phase of this subject. As has been often noticed the mining interests of Vermont are not usually large for our mines are few and not very productive, except in a few instances, but the quarrying industry is one of the greatest we have. As on previous pages Professor Jacobs has discussed the copper and lime industries it will be unnecessary to consider them here.

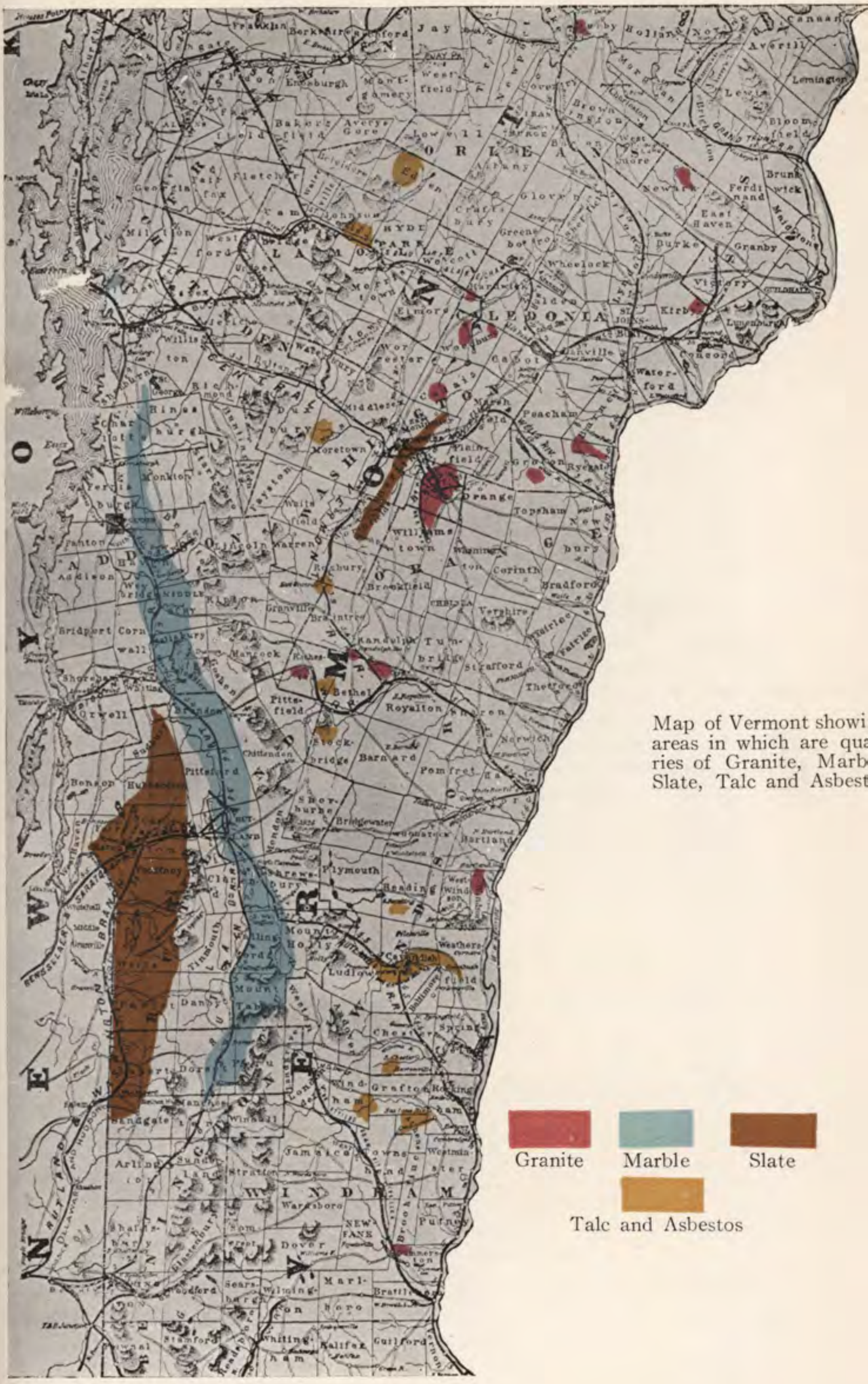
That Vermont leads the world in the production of marble and granite has become an oft repeated tale and a tale that is absolutely true. It has been for many years a satisfaction to call attention to the interesting fact that here in this, one of the smallest of the states in area, it is possible to obtain a larger amount and greater variety of marble than anywhere else, and certainly no finer granite is to be found. This is not idle boasting, but a simple statement of fact.

While our sales of slate do not at all equal those of Pennsylvania, they do far exceed those of any other state and are always of importance. Altho it is necessarily, in some measure, a repetition to give lists of those companies engaged in the stone industries of the State, yet it has been found useful to dealers and customers outside the State to have such lists which are kept up to date as far as possible. In the marble business there are few companies and few changes, but in slate and especially in granite companies, each two years brings about a number of reorganizations in the business.

As every one is well aware, the building conditions during the past two years have been very greatly disturbed and many forms of building have been impossible, and of course this has seriously affected the need for building stone. On this account that part of the stone business which has to do with building has been reduced in volume, especially in the granite business. Because of the unusual and uncertain condition of the stone industry it is not possible to give general statements as to the exact amount of sales, wages, etc., in money values, but certainly the total has been much less than it has been and less we may confidently expect than it will be in the immediate future, so that the figures for 1917-1918, could they be given, would not properly represent the usual extent of the business.

Another trouble which will readily occur to the reader has been the difficulty and sometimes impossibility, of getting workmen to execute what orders were sent in. For this reason it does not appear to be probable that the manufacturing companies

PLATE XVIII



Map of Vermont showi
areas in which are qua
ries of Granite, Marb
Slate, Talc and Asbest

could have filled the customary number of orders had they been received. Some of the largest companies report that only about half their full complement of workmen have been available during 1918.

MARBLE COMPANIES IN BUSINESS, 1918

The following companies have been producing marble during the last two years, but by far the greater part of the marble sold has come from the first named company.

The Vermont Marble Company, Main offices at Proctor.

Mills at Proctor, West Rutland, Center Rutland, Rutland, Florence, Middlebury, Swanton.

Quarries at Proctor, West Rutland, Florence, Brandon, Danby, Dorset, Swanton, Roxbury.

Eastman Marble Company, Quarries at West Rutland.

Manchester Marble Company, Dorset.

Clarendon Marble Company, Quarries and Mill, Clarendon.

Middlebury Marble Company, Quarry, East Middlebury.

Meadow Brook Marble Company, Quarry and Mill, Brandon.

United Marble Company, Quarries West Rutland, Florence, Mills, Rutland.

In marble as in granite, while the buildings sales have been greatly reduced, the demand for monuments and monumental stock has been increased and prices have been higher.

Several conditions, strikes, epidemic, lack of workmen, have reduced the normal amount of granite production much below its usual amount. In some of the granite fields this has not been in any way made up, but in some places, notably the Barre district, there has been during the past year the largest demand for monumental work ever known, and this has in some good degree compensated for the loss in sale of building material.

The following list of granite companies now doing business in Vermont is brought up to date as fully as possible. As in the preparation of former lists, Mr. H. P. Hinman, Secretary of the Barre Manufacturers Association has revised the names so far as that Association is concerned.

LIST OF GRANITE COMPANIES IN BUSINESS IN VERMONT, 1918.

Those working quarries are marked Q, the others operate only cutting plants.

BARRE AND VINCINITY

Anderson and Johnson.
Anderson-Friberg Co.
Apollo Granite Co.
Artistic Granite Co.
Ballastro & Labrano.
Barclay & Co, A.
Barclay Brothers, Q.
Barre Memorial Co.
Beck & Beck.
Bianchi Granite Co.
Biledeau, J. O.
Bond, G. E. Granite Co. Q.
Boutwell-Milne-Varnum Granite Co, Q.
Brown, Carroll & Co.
Brown & Son.
Brozicevic Brothers.
Brusa Brothers.
Bugbee & Co.
Burke Brothers.
Buzzi Granite Co.
Canas, A.

Canton Bros. Q.
Capitol Granite Co.
Carroll Bros.
Carswell-Wetmore Granite Co.
Caslani Bros.
Celente & Co.
Central Granite Co.
Chioldi Bros.
Ciresoli & Co.
Cole & Son, W.
Comolli & Co.
Corskie J. P. & Son.
Davis Bros West Berlin.
DeBlois, L. I. Granite Co.
De Regibus Granite Co.
Dessureau & Co.
Dewey Column and Monumental Works.
Freeman & Wasgatt.
Gasparello Bros.
Gelpi Granite Co.
Genest & Beaulieu.
Gerrard-Barclay Granite Co.
Glysson, E. C.
Grearson & Lane Co.
Giudici Granite Co.
Guidici Bros. Co.
Harrison Granite Co.
Hebert and Ladric.
Hedburg & Gustafson.
Hedwall, P. & Co.
Hoyt & Lebourveau.
Hoyt & Milne.
Johnson & Gustafson.
Jones Brothers Granite Co. Q.
Jones Granite Co, Williamstown.
LaClair & McNulty.
Littlejohn, Odgers & Milne.
Malnati Bros.
McDonnell & Sons.
McGovern Granite Co.
McMillan & Son.
Marr & Gordon.
Marrion and O'Leary.
Martinson Estate Co.
Mascitti, Paul.
Milne, Alex.
Milne Granite Co.
Mutch & Loranger.
Newcomb, T. J.
North Barre Granite Co.
Novelli & Calgani.
Oliver Granite Co.
Oleson & Nelson.
Parnigoni Bros.
Parry & Jones Co.
Peerless Granite Co.
Presbrey-Coykendall Co.
Provost & Son, West Berlin.
Redmond & Hartigan.
Reggiore & Puenti.
Rizzi Bros.
Rizzi, L. G.
Rizzi, William.
Robertson, J. C.
Robins Bros.
Ross & Ralph.
Rossi and Casselini.
Roux Granite Co.
Royal Granite Co, East Barre.
Russell & Brand Granite Company.
Saldi & Rossi.
Sanguinetti, A. & Co.
Sector, James & Co.
Smith, E. L. & Co, Q.
South Barre Granite Co.
Steele Granite Co.
Straiton, George.
Tosi E. & Co.
Union Granite Co.
Usle Granite Co.
Valz Granite Co.
Vanetti Granite Co.
Vermont Manufacturing & Quarry Co
Veronese Granite Co, East Barre.
Welch & Cobban.
Wetmore-Morse Granite Co, Q.
World Granite Co, East Barre.
Young Bros. Granite Co.
Zorzi, Giovanni.

MONTPELIER

These are all Cutting Plants.

Aja, U. Granite Co.
Ariole & Co.
Artistic Granite Co.
Bonazzi & Bonazzi.
Bianchi Granite Co.
Boutwell-Milne-Varnum Granite Co.
Canas, A.
Capitol Granite Co.
Columbian Granite Co.
Doucette Bros.
Emmons, H. C.
Excelsior Granite Co.
Fernandez, E.
Fraser, Robert M.
Garand & Forgue.
Gill, C. P. & Co.
Johnson Granite Co.
Lawrence, Robert.
LeClerc, R. A.
Lillie Granite Co.
Maloney & Clossey.
Menard & Erno.
Mills & Co.
National Granite Co.
Pando Granite Co.
Pillini Granite Co.
Poma, P. Granite Co.
Sheridan & Poole.
Sierra, R. Granite Co.
Sievewright, George.

Valley & Beaudet.
Vermont Granite Co.
Wetmore-Morse Granite Co.

NORTHFIELD

Cross Bros.
Pelaggi & Co.
Phillips & Slack.
Northfield Granite Co.

BETHEL

Woodbury Granite Co.

WATERBURY

Drew Daniels Granite Co.
O'Clair Granite Co.
Union Granite Co.

HARDWICK AND WOODBURY

American Granite Co., Hardwick.
Crystal Brook Granite Co., Hardwick.
E. R. Murch, Hardwick.
Floyd Fuller, Hardwick.
M. Ambrozini, Hardwick.
Eureka Granite Co., Hardwick.
John Hay, Hardwick.
Fred Calderwood, Hardwick.
V. W. Merriam, Hardwick.
Caledonia Granite Co., Hardwick.
Woodbury Granite Co., Hardwick.
Nunn & Fordyce, Hardwick.
Grant & McAdams, Hardwick.
M. J. Couhig, Hardwick.
P. Good, Hardwick.
Hardwick Polishing Co., Hardwick.
E. R. Fletcher, Woodbury.

Revised by Mr. George James of the Woodbury Granite Co.

GROTON AND RYEGATE

Checchi, A., Groton.
Hendry, C. H., Groton.
Blue Mountain Granite Works, South Ryegate.
Ryegate Granite Works Co., South Ryegate.

BARTON

Crystal Lake Granite Co., Q.
Barton Granite Co., Q.
Lewis, L. R.
Roy, T. F.
Smith, M. J.
Ward & Co.

CONCORD

Chapman, W. J.
Concord Granite Co., Q.
Daniels, J. C.
Keach, Willard.
Kirby Mountain Granite Co., Q.
Lillicrap, E. & Son.
Lillicrap, J.
Smith, L. E.

OTHER PARTS OF VERMONT

Eureka Granite Co., Adamant.
Patch & Co., Adamant, Q.
Haselton, C. S., Beebe Plain, Q.
Stanstead Granite Co., Beebe Plain, Q.
Goss, A. J., West Danville.
Newport Granite Co., Derby, Q.
Lyons, G. E. Dummerston, Q.
Union Granite Co., Morrisville.

The Slate business has, naturally suffered with other stone industries, but I judge, less than marble or granite from poor markets. It is reported as "fair to medium" for the years 1917-1918, but at the time of writing, December 1918, it appears to be improving. The following companies are now in business.

SLATE COMPANIES IN BUSINESS 1918.

CASTLETON

Hinchey, P. F. & Co., Hydeville.
John Jones Slate Co., Castleton.
Lake Shore Slate Co., West Castleton.
Penryn Slate Co., Hydeville.
West Castleton Purple Slate Co., West Castleton.
McDonough & O'Day Slate Co., Hydeville.

FAIRHAVEN

Clark & Flannagan Slate Co.
Dagnois, Joseph, Slate Co.
Durick, Keenan & Co.
Eastern Slate Co.
Eureka Slate Co.
Fairhaven Marble & Marbleized Slate Co.
Hampshire Slate Co.
Mahar Bros. Slate Co.
Old English Slate Co.

Young, A. B. Slate Co.

POULTNEY

Auld & Conger Slate Co.
Donnelly & Pincus Slate Co.
General Slate Co.
Green Mountain Slate Co.
Griffith, William, Slate Co.
Jones, Owen O., Slate Co.
New York Consolidated Slate Co.
Roberts & Carter Slate Company.
Sheldon, F. C. Slate Co.

WEST PAWLET

Hughes & Son Slate Co.

Rising & Nelson Slate Co.

WELLS

O'Brien Bros. Slate Co.
Williams, R. S., Slate Co.
Quarries in Vermont, offices as below.
Burdette & Hyatt, Whitehall, N. Y.
Norton Bros, Granville, N. Y.
Owens, O.W . & Sons, Granville, N. Y
Progressive Slate Co., Granville, N. Y
Sheldon, F. C. Slate Co, Granville N. Y.
Vermont Slate Co., Granville, N. Y.
Williams, H. G., Slate Co., Granville, N. Y.

As it is the purpose of the Geologist to keep these lists as up to date in accuracy as possible, it is desirable that anyone having additions or corrections, notify him. The lists have apparently proven convenient to dealers and customers over the country and of course, if they are to be serviceable they must be correct.

The following companies have been doing business in various sorts of Clays.

CLAYS

Horn-Crockett Co., Forestdale, P. O. Brandon.
American Paper Clay Co., Rutland.
Rutland Fire Clay Co., Rutland.
Lyon Brothers, S. C., Bennington.
Rockwood, E. F. Bennington.
Sibley, E. L., Bennington.

LIME

For producers of Lime the reader is referred to Professor Jacobs' article on this subject on preceding pages. (158-164)

PROGRESS OF STREAM GAGING IN VERMONT

During the two-year period ending Sept. 30, 1918

BOSTON, January 3, 1919.

To the Honorable, The Governor of Vermont, State House, Montpelier, Vt.:

Dear Sir:

As the representative of the United States Geological Survey in New England, I have during the past year continued the work which is being carried on by the Water Resources Branch of the United States Geological Survey in cooperation with the State of Vermont, in investigating the water resources of Vermont. The work has been carried on along the same lines as during the previous years.

In July a conference was held with Mr. H. M. McIntosh, State Engineer of Vermont, and various matters pertaining to the work were considered at that time. Owing to the comparatively small amount of funds available for this work, and also to the fact that our engineering staff was seriously depleted on account of the men being called into service in the Army, it was not found practicable to materially enlarge the scope of the work. Special efforts have, however, been made to continue the records at all gaging stations which were in operation at the beginning of the year, as a continuous record is of much greater value than one which is broken by lack of observations during part of the year; and each year's record, when used in connection with previous records, adds a value to the total much greater in proportion than the time ratio of the one year to the total period covered.

Assistance has been received from various engineers in the State and from private companies. This assistance has generally taken the form of services furnished by employees of the companies in obtaining records of the stage of the rivers.

The accompanying manuscript gives the results of observations, and computations based thereon, for the two-year period ending September 30, 1918.

United States Geological Survey Water-Supply Paper 424, "Surface Waters of Vermont," was issued early in the year and was widely distributed among engineers and others who it was thought would be particularly interested. Additional copies of this printed report which contains data up to September 30, 1916, may be obtained by those so desiring.

The results obtained during each year are printed in the regular Progress Reports of the United States Geological Survey.

Respectfully submitted,

C. H. Pierce,
District Engineer.

UNITED STATES GEOLOGICAL SURVEY IN COOPERATION WITH THE STATE OF VERMONT

Records of Stream Flow for the Two-Year Period Ending September 30, 1918.

- Lake Champlain drainage basin.
  - Lake Champlain (gage heights).
  - Otter Creek.
  - Winooski River.
    - Dog River.
  - Lamoille River.
    - Green River.
  - Missisquoi River.
- Lake Memphremagog drainage basin.
  - Clyde River.
- Connecticut River drainage basin.
  - Connecticut River.
    - Passumpsic River.
    - White River.

LAKE CHAMPLAIN AT BURLINGTON, VT.

Location.—On south side of roadway leading to dock of Champlain Transportation Co., at foot of King St., Burlington.

Records available.—May 1, 1907, to September 30, 1918.

Gage.—Staff. Comparisons of gage readings indicate that zero of gage at Burlington is at practically the same elevation as that of gage at Fort Montgomery, namely, 92.5 feet above mean sea level. Gage read by employee of the Champlain Transportation Co.

Extremes of stage.—Maximum stage recorded during year ending September 30, 1918, 6.78 feet on April 10 and 11; minimum stage recorded, 1.44 feet on September 14.

1907-1918: Maximum stage recorded, 8.20 feet on April 7, 1913; minimum stage recorded,—0.25 foot on December 4, 1908.

Ice.—Lake Champlain does not usually close over in its wider portion until the latter part of January. Occasionally the period of closure does not occur until February, and sometimes lasts only for a few days. At the northern end of the lake above the outlet the period of ice cover is usually from the middle of December to the middle of April.

Accuracy.—Gage read to hundredths once a day except on Sundays from October 1 to December 21, and from March 25 to April 20; readings at irregular intervals during the remainder of the year. When the lake is rough, there is considerable wave action at the gage and readings at those times may not be exact.

Cooperation.—Gage heights furnished through the courtesy of Mr. D. A. Loomis, general manager of the Champlain Transportation Co.

Daily gage height in feet, of Lake Champlain at Burlington, Vt., for the years ending Sept. 30, 1917-18

Day	Oct.	Nov.	Dec.	an.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1916-17												
1	....	1.11	1.50	1.80	....	....	....	5.65	4.15	....	2.80	1.96
2	1.25	1.13	1.52	1.80	....	....	5.15	5.63	4.13	4.00	2.74	....
3	1.20	1.15	....	....	....	....	5.50	5.60	....	3.98	2.70	1.85
4	1.20	1.15	1.60	....	....	....	5.76	5.55	4.08	3.98	2.65	1.85
5	1.18	....	1.65	....	2.00	....	5.87	5.48	4.02	3.95	....	1.82
6	1.15	1.11	1.68	....	....	1.95	5.98	....	3.95	3.90	2.53	1.78
7	1.13	1.05	1.75	....	....	....	6.05	5.35	3.90	3.80	2.47	1.78
8	....	1.00	1.88	1.82	....	....	....	5.28	3.87	....	2.44	1.76
9	1.05	1.00	1.92	....	....	....	6.18	5.20	3.83	3.68	2.40	....
10	1.05	1.00	....	....	....	....	6.20	5.15	....	3.55	2.37	1.74
11	1.03	1.00	1.95	....	....	....	6.20	5.08	3.98	3.50	2.30	1.74
12	1.02	....	1.98	....	1.98	....	6.05	5.02	4.30	3.48	....	1.72
13	1.02	1.05	2.00	....	....	1.98	5.98	....	4.52	3.42	2.25	1.69
14	1.00	1.05	2.02	....	....	....	5.90	4.95	4.65	3.38	2.25	1.68
15	....	1.04	2.02	....	....	....	....	4.93	4.82	....	2.20	1.65
16	1.00	1.04	2.03	....	....	....	5.75	4.90	4.86	3.30	2.18	....
17	.98	1.02	....	....	....	....	5.68	4.82	....	3.28	2.13	1.61
18	.98	1.02	2.05	2.10	....	....	5.62	4.70	4.83	3.25	2.16	1.59
19	.98	....	2.05	....	1.95	....	5.65	4.62	4.78	3.20	....	1.59
20	.98	.99	2.05	....	....	2.05	5.70	....	4.75	3.20	2.21	1.58
21	.98	.99	2.02	....	....	....	5.72	4.45	4.72	3.18	2.24	1.62
22	....	.97	2.02	2.10	....	....	....	4.42	4.65	....	2.28	1.60
23	1.18	.97	1.98	....	....	....	5.85	4.38	4.58	3.15	2.30	....
24	1.24	.95	....	....	....	....	5.90	4.38	....	3.10	2.30	1.57
25	1.24	.95	....	....	....	....	5.95	4.36	4.55	3.02	2.28	1.52
26	1.21	....	1.94	....	1.90	2.70	5.92	4.30	4.48	2.95	....	1.48
27	1.20	1.08	1.93	....	....	3.08	5.85	....	4.35	2.92	2.20	1.46
28	1.18	1.19	1.91	....	....	3.74	5.80	4.22	4.30	2.90	2.13	1.46
29	....	1.32	1.91	2.03	....	4.28	....	4.20	4.13	....	2.10	1.46
30	1.14	1.36	1.90	....	....	4.58	5.72	4.20	4.02	2.87	2.04	....
31	1.11	....	....	....	....	4.72	....	4.16	....	2.87	1.98	....
1917–18												
1	1.48	3.10	2.38	....	....	2.68	5.30	6.14	4.48	....	2.18	....
2	1.50	3.18	....	....	....	2.68	5.65	6.10	....	3.19	....	1.52
3	1.52	3.20	2.35	....	....	....	6.14	6.04	....	....	....	....
4	1.56	....	2.33	....	....	....	6.49	6.02	4.29	....	2.08	....
5	1.56	3.23	2.32	....	....	2.84	6.61	....	4.24	3.04	....	....
6	1.58	3.21	2.30	....	....	....	6.63	5.88	....	....	1.92	....
7	....	3.18	2.25	....	....	....	....	5.77	4.10	....	1.92	1.60
8	1.63	3.18	2.23	....	....	....	6.60	5.68	....	....	....	....
9	1.64	3.15	....	1.58	....	....	6.65	5.58	....	....	2.09	....
10	1.67	3.13	2.15	....	....	....	6.78	....	3.95	2.93	....	....
11	1.67	....	2.13	1.58	....	2.98	6.78	5.45	3.90	2.89	....	1.50
12	1.68	3.05	2.08	....	....	....	6.75	....	....	2.84	2.14	....
13	1.68	2.98	2.06	....	....	3.03	6.75	5.35	3.92	....	....	....
14	....	2.95	2.06	....	....	....	....	5.40	3.95	....	....	1.44
15	1.74	2.90	2.03	....	....	....	6.65	5.48	....	2.78	2.10	....
16	1.74	2.83	....	....	....	....	6.65	5.45	....	....	2.08	1.49
17	1.72	2.76	2.01	....	....	....	6.65	5.39	3.83	2.72	....	....
18	1.70	....	2.00	....	....	2.99	6.70	....	3.78	2.71	....	....
19	1.70	2.65	2.00	....	....	2.99	6.65	....	3.73	....	2.02	....
20	1.73	2.62	1.98	....	....	2.99	6.61	....	....	....	1.98	1.67
21	....	2.58	1.98	....	....	....	....	5.15	....	2.60	....	1.70
22	1.79	2.58	....	....	....	3.35	6.48	5.04	....	....	1.92	....
23	1.83	2.55	....	....	....	....	6.53	4.96	....	2.52	1.86	1.76
24	1.87	2.54	....	....	....	....	....	4.92	3.43	2.48	....	1.82
25	1.87	....	....	....	2.03	4.20	....	4.82	3.45	....	....	1.89
26	1.95	2.47	....	....	....	4.42	6.44	....	3.50	2.30	....	2.06
27	2.03	2.47	....	....	2.34	4.55	6.37	4.70	....	2.20	1.75	2.16
28	....	2.47	....	....	....	4.67	....	4.67	....	....	....	2.46
29	2.35	2.43	....	....	....	4.75	....	4.60	....	2.20	....	....
30	2.70	2.40	....	....	....	4.87	....	....	....	....	1.54	2.76
31	3.00	....	....	....	....	....	....	....	....	....	....	....

Otter Creek at Middlebury, Vt.

Location.—At the railroad bridge about half a mile south of the railroad station at Middlebury, Addison County, 3½ miles below mouth of Middlebury River, and 3½ miles above mouth of New Haven River.

Drainage Area.—615 square miles.

Records available.—April 1, 1903 to May 1, 1907, and October 5, 1910 to September 30, 1918.

Gage.—Chain; read by Almon Lovett

Discharge measurements.—Made from a boat just below railroad bridge, at the stone-arch highway bridge just above the dam, or by wading.

Channel and control.—Channel deep; current sluggish for several miles above the station. Control for low stages is gravel and boulder rips about 800 feet below gage, probably somewhat shifting; control at high stages is near the dam 800 feet farther downstream.

Extremes of discharge.—Maximum stage recorded during year ending September 30, 1918, 16.07 feet at 7.15 a. m. March 30 (discharge, 3,470 second-feet); minimum stage recorded, 11.75 feet at various times during the year (discharge, 202 second-feet).

1903-1907 and 1910-1918: Maximum stage recorded, 21.07 feet March 30, 1913 (approximate discharge from extension of rating curve, about 8,000 second-feet); minimum open-water stage recorded, 11.45 feet September 15, 1913 (discharge, 138 second-feet). A somewhat lower discharge has possibly occurred at various times when the stage-discharge relation has been affected by ice.

Ice.—Ice forms to a considerable thickness at the gage and occasionally at the control, affecting the stage-discharge relation.

Regulation.—Probably little if any effect from power developments above the station. Considerable storage has been developed on tributaries near the headwaters.

Accuracy.—Stage-discharge relation has changed somewhat in previous years, but apparently no change during 1917-18, except when affected by ice. Rating curve well defined between 200 and 4,000 second-feet. Chain gage read to quarter-tenths once daily. Daily discharge ascertained by applying rating table to daily gage heights, with corrections for ice from December to March. Results good.

Discharge measurements of Otter Creek at Middlebury, Vt., during the two-year period ending Sept. 30, 1918

Date	Made by—	Gage height	Discharge	Date	Made by—	Gage height	Discharge
1916.		*Feet.*	*Sec. ft.*			*Feet.*	*Sec. ft.*
Dec. 28	Hardin Thweatt	12.47	581	July 27	M. R. Stackpole	11.85	237
1917.				Dec. 11	do	12.24	368
Feb. 19	H. H. Khachadoorian	*a*12.35	357	1918.			
Mar. 12	do	*a*12.90	570	Feb. 1	M. R. Stackpole	*a*12.42	278
12	do	*a*12.90	568	Mar. 11	do	*a*13.25	592
30	do	16.05	3,530	Apr. 2	do	15.82	3,270
31	do	16.09	3,510	July 27	H. W. Fear	12.10	320
31	C. H. Pierce	16.10	3,440				

*a*Stage-discharge relation affected by ice.

Daily discharge, in second-feet, of Otter Creek at Middlebury, Vt., for the years ending Sept. 30, 1917-18

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1916–17.												
1	426	283	1,880	360	475	1,790	3,500	1,970	1,270	320	283	340
2	403	283	1,970	360	475	1,700	3,680	1,700	1,070	501	248	360
3	320	320	880	360	450	1,440	3,590	1,700	810	426	381	320
4	320	320	1,360	381	426	810	3,410	1,610	810	320	340	426
5	283	283	1,030	381	403	740	3,410	1,440	810	283	248	360
6	265	265	1,070	450	403	640	3,320	1,270	670	360	202	320
7	248	301	1,070	740	403	555	3,230	1,360	610	360	232	320
8	283	320	1,030	775	360	475	3,140	1,360	1,030	283	248	340
9	175	301	810	705	360	555	2,960	1,270	1,790	232	265	283
10	232	320	917	640	360	501	2,780	1,270	1,700	301	403	217
11	265	320	1,030	670	340	555	2,420	1,070	1,610	301	1,070	265
12	248	340	917	610	320	582	1,970	1,190	2,870	301	283	283
13	248	283	810	582	340	528	1,880	1,190	2,690	340	232	265
14	248	283	670	555	360	501	1,440	1,190	2,690	360	232	283
15	320	283	640	1,110	381	501	1,190	1,150	2,510	360	283	265
16	217	283	610	1,360	403	501	1,030	1,030	2,330	403	301	265
17	283	320	610	1,190	426	555	955	880	2,150	501	320	217
18	283	320	555	1,110	381	740	992	810	1,610	360	381	232
19	301	340	360	880	340	740	1,190	740	1,270	360	320	283
20	320	301	381	670	381	555	1,440	775	955	450	301	320
21	810	320	450	610	426	475	2,330	775	810	426	320	320
22	1,030	320	360	501	426	555	2,330	775	705	360	340	283
23	610	301	450	670	426	705	2,510	705	610	217	301	265
24	501	740	705	501	426	1,520	2,510	845	610	301	283	217
25	403	1,790	705	450	403	1,880	2,690	992	740	283	283	202
26	301	1,520	610	450	381	2,240	2,690	992	670	283	340	232
27	283	1,270	501	426	528	2,510	2,690	1,030	640	248	248	232
28	283	955	501	403	1,610	3,410	2,600	880	610	248	265	248
29	320	740	426	403	....	3,410	2,510	775	582	283	265	248
30	217	775	450	426	....	3,410	2,330	1,270	610	265	283	265
31	283	....	360	475	....	3,590	....	1,440	....	265	340	....
1917–18.												
1	232	2,510	360	220	280	2,400	3,230	1,440	810	320	283	320
2	283	2,510	501	210	280	2,500	3,320	1,700	670	360	248	360
3	265	2,330	360	210	280	2,400	3,320	1,790	555	403	232	403
4	265	2,060	450	220	280	2,200	3,230	1,610	450	340	232	360
5	360	1,610	426	250	220	1,800	3,140	1,360	426	301	202	320
6	403	1,190	403	220	220	1,350	3,140	1,030	426	320	248	301
7	403	917	320	210	250	1,100	3,050	955	450	340	265	320
8	403	775	403	220	250	880	2,960	917	610	360	248	301
9	403	670	301	210	230	740	2,870	1,030	555	450	381	248
10	381	610	202	280	250	660	2,690	880	528	450	501	265
11	340	610	360	280	250	580	2,600	1,190	610	450	360	301
12	320	450	301	300	230	520	2,510	1,150	670	501	283	301
13	403	501	265	280	250	520	2,420	1,150	955	670	283	301
14	450	475	320	280	320	660	2,060	2,600	1,110	381	320	320
15	426	475	360	220	400	1,200	1,970	2,510	880	810	403	301
16	475	403	381	300	500	1,100	1,970	2,330	670	640	403	248
17	426	450	265	320	1,250	740	1,970	2,150	475	501	360	301
18	426	450	320	320	1,100	740	1,970	1,700	450	501	301	426
19	403	320	360	320	960	1,100	1,970	1,190	403	475	248	528
20	450	403	403	320	960	1,700	1,970	992	403	450	232	555
21	501	426	403	220	2,300	2,100	1,880	1,070	360	381	283	640
22	381	426	381	220	2,200	2,300	1,970	1,110	360	320	248	775
23	403	501	360	230	2,200	2,500	2,060	955	555	320	265	880
24	403	705	283	230	1,950	2,690	2,150	810	1,360	340	248	640
25	501	640	283	260	2,100	2,780	2,060	670	1,440	320	248	1,030
...	740	450	283	300	2,500	2,780	1,970	670	1,030	320	217	775
26	740	340	300	340	2,400	2,960	1,790	640	670	320	202	2,330
27	775	381	280	340	2,400	3,050	1,520	740	528	283	248	2,240
28	670	340	360	280	....	3,140	1,360	810	450	265	265	1,970
29.30	955	283	280	250	....	3,500	1,360	810	450	202	265	1,880
31	2,690	....	220	280	....	3,320	....	810	....	283	283	....

Monthly discharge of Otter Creek at Middlebury, Vt., for the two-year period ending Sept. 30, 1918

[Drainage area, 615 square miles.]

Month	Discharge in second-feet				Run-off (depth in inches on drainage area)
	Maximum	Minimum	Mean	Per square mile	
1916-17					
October	1,030	175	346	0.563	0.65
November	1,790	265	493	.802	.89
December	1,970	360	778	1.27	1.46
January	1,360	360	619	1.01	1.16
February	1,610	320	444	.722	.75
March	3,590	475	1.250	2.03	2.34
April	3,680	955	2,420	3.93	4.38
May	1,970	705	1,140	1.85	2.13
June	2,870	582	1,260	2.05	2.29
July	610	217	332	.540	.62
August	1,070	202	317	.515	.59
September	426	202	283	.460	.51
The year	3,680	175	807	1.31	17.77
1917–18					
October	2,690	232	525	.854	.98
November	2,510	283	807	1.31	1.46
December	501	202	339	.551	.64
January	340	210	263	.428	.49
February	2,500	220	958	1.56	1.62
March	3,500	520	1,810	2.94	3.39
April	3,320	1,360	2,350	3.82	4.26
May	2,600	640	1,250	2.03	2.34
June	1,440	360	644	1.05	1.17
July	810	202	399	.649	.75
August	501	202	284	.462	.53
September	2,330	248	665	1.08	1.20
The year	3,500	202	854	1.39	18.83

WINOOSKI RIVER AT MONTPELIÈR, VT.

Location.—One mile downstream from the Central Vermont Railway station in Montpelier, Washington County, about three-eighths mile above mouth of Dog River, and 1¼ miles below mouth of Worcester Branch.

Drainage area.—420 square miles.

Records available.—May 19, 1909 to September 30, 1918.

Gage.—Gurley seven-day water-stage recorder on right bank, installed July 4, 1914; gage heights referred to datum by means of a hook gage inside the well; an outside staff gage is used for auxiliary readings; records June 16 to July 3, 1914, obtained from the staff gage. Chain gage at highway bridge just above the Central Vermont Railway station used from May 19, 1909 to June 30, 1914.

Discharge measurements.—Made from a cable or by wading.

Channel and control.—Channel deep and fairly uniform in section at the gage; control is formed by sharply defined rock outcrop about 500 feet below gage.

Extremes of discharge.—Maximum open-water stage during year ending September 30, 1918, from water-stage recorder, 11.45 feet at 9 p. m. October 30 (approximate discharge from extension of rating curve, 8,780 second-feet); minimum stage from water-stage recorder, 2.95 feet at 7 a. m. July 26 and 8 a. m. August 29 (discharge, 42 second-feet).

1909-1918: Maximum stage determined by leveling from flood marks preserved on building near present gage, 17.31 feet, April 7, 1912 (discharge not determined); minimum stage from water-stage recorder 1914-1918, 2.77 feet, August 13, 1914 and October 24, 1915 (discharge, 19 second-feet).

Ice.—Stage-discharge relation seriously affected by ice during the winter months. Discharge ascertained by means of gage heights, current-meter measurements, observer's notes, and climatic records.

Regulation.—Operation of power plants on main stream and tributaries above station cause large diurnal fluctuations in stage (see fig. 1, p. 41, Water-Supply Paper 424).

Accuracy.—Stage-discharge relation practically permanent except when affected by ice. Rating curve well defined between 30 and 5,000 second-feet. Operation of water-stage recorder satisfactory during the year, except during part of October and November when it was temporarily removed for cleaning. Sanborn water-stage recorder used from November 16 to December 17. Daily discharge determined by discharge integrator, except for high stages and during the period December to March, when mean daily gage heights were used. Results good for open-water periods and fair for the winter.

Discharge measurements of Winooski River at Montpelier, Vt., during the two-year period ending Sept. 30, 1918

Date	Made by—	Gage height	Discharge	Date	Made by—	Gage height	Discharge
1917		*Feet*	*Sec. ft.*			*Feet*	*Sec. ft.*
Jan. 5	Hardin Thweatt	[a]4.96	316	Oct. 31	M. R. Stackpole	7.57	3,460
Feb. 17	H. H. Khachadoorian	[a]5.13	306	Dec. 18	do	[a]4.80	389
Mar. 13	do	[a]5.25	303	1918			
Apr. 1	C. H. Pierce	8.16	4,140	Jan. 25	M. R. Stackpole	[a]5.06	275
Sept. 14	M. R. Stackpole	3.57	161	Mar. 1	do	[a]6.06	668
14	do	3.76	242	26	do	[a]7.23	1,650
15	do	3.47	153	Apr. 12	do	5.69	1,510

[a] Stage-discharge relation affected by ice.

Daily discharge, in second-feet, of Winooski River at Montpelier, Vt., for the years ending Sept. 30, 1917-18

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1916–17												
1	550	158	1,460	225	225	320	3,710	1,260	520	800	205	300
2	300	255	860	225	225	280	4,320	1,380	470	800	295	405
3	240	310	626	210	225	240	3,230	1,280	620	560	210	290
4	210	335	470	195	225	180	2,810	1,060	1,010	420	170	255
5	172	230	748	180	240	225	2,480	960	630	365	144	200
6	160	240	1,100	320	225	195	2,700	930	500	335	194	190
7	140	215	790	240	168	180	3,290	880	480	310	166	220
8	85	205	602	210	180	180	2,280	850	1,060	285	138	200
9	122	198	530	195	240	168	1,780	770	1,280	260	350	120
10	146	205	678	195	180	168	1,420	790	1,180	255	660	150
11	160	210	542	180	155	155	1,240	760	3,160	260	310	130
12	132	138	500	131	131	195	1,180	980	6,140	455	205	150
13	152	184	420	131	131	168	1,160	900	2,250	475	230	120
14	114	196	345	195	143	180	1,160	800	1,460	330	210	150
15	130	210	320	895	155	180	1,060	760	1,260	300	220	140
16	160	215	320	685	155	180	1,040	630	1,100	305	225	92
17	164	210	345	560	131	195	1,120	580	1,300	275	460	172
18	162	200	280	395	143	195	1,540	560	2,610	260	860	154
19	166	172	280	280	195	210	2,100	540	1,420	265	385	130
20	440	260	280	280	168	168	3,110	660	1,000	450	350	142
21	890	240	300	260	168	180	3,830	620	880	315	670	255
22	520	210	300	260	168	168	3,710	500	720	220	400	235
23	320	190	320	280	168	195	2,990	610	610	275	280	108
24	260	1,760	280	225	155	320	2,250	760	750	205	245	174
25	225	1,080	280	225	120	860	1,650	630	780	200	350	140
26	215	420	280	225	180	1,680	1,480	710	570	172	205	140
27	205	380	260	210	195	5,510	1,360	640	540	148	225	166
28	200	340	260	225	345	9,010	1,360	550	440	140	184	162
29	110	370	240	240	....	2,990	1,280	670	700	68	205	160
30	154	1,680	240	225	....	1,930	1,320	890	1,420	170	320	134
31	190	....	225	210	....	1,780	....	670	....	190	310	....
1917–18												
1	255	1,500	276	150	155	760	4,200	1,360	960	245	130	200
2	270	1,100	284	155	145	620	5,950	1,300	1,020	360	120	144
3	215	860	320	110	98	560	4,600	1,040	530	270	100	180
4	255	680	345	140	110	470	2,600	850	350	194	60	150
5	500	620	325	130	125	440	2,000	700	310	220	106	136
6	620	560	284	65	125	420	1,700	640	270	150	77	160
7	320	520	268	110	130	400	1,900	640	760	172	92	158
8	280	470	272	75	130	370	2,000	600	670	245	100	130
9	390	440	237	75	115	320	2,450	530	395	215	2,900	152
10	320	390	290	88	130	400	1,960	510	395	200	1,160	120
11	210	500	290	105	150	370	1,580	1,040	330	245	500	124
12	320	370	220	120	155	370	1,440	750	760	260	330	118
13	620	260	260	120	185	400	1,480	1,240	1,120	250	240	154
14	370	195	260	180	250	400	1,780	2,350	620	285	530	225
15	340	240	250	165	310	400	1,900	1,320	435	340	925	154
16	440	300	170	185	310	370	1,900	880	350	240	365	164
17	420	284	250	210	310	400	1,700	720	315	185	275	180
18	280	264	240	185	310	600	1,760	620	295	195	184	325
19	210	312	240	210	310	640	1,360	560	265	200	210	640
20	960	268	240	220	400	1,600	1,180	560	235	165	176	320
21	660	316	240	195	700	1,150	1,180	520	220	106	156	1,080
22	370	345	220	185	580	2,000	1,860	440	225	170	136	690
23	240	345	185	250	480	2,400	1,600	455	430	140	142	395
24	320	312	240	230	380	1,800	1,440	400	405	125	134	890
25	900	231	210	195	360	1,800	1,160	335	340	100	93	780
26	820	219	200	195	910	1,800	1,000	340	260	100	140	2,000
27	720	207	175	170	1,200	1,400	930	660	235	91	128	3,000
28	860	183	185	145	1,050	1,700	960	670	200	74	118	1,420
29	720	185	145	190	....	2,900	1,000	440	156	108	102	900
30	3,700	210	115	140	....	2,300	1,280	840	205	118	114	670
31	3,450	....	125	160	....	2,900	....	660	....	130	102	....

Monthly discharge of Winooski River at Montpelier, Vt., for the two-year period ending Sept. 30, 1918

[Drainage area, 420 square miles]

Month	Discharge in second-feet				Run-off (depth in inches on drainage area)
	Maximum	Minimum	Mean	Per square mile	
1916–17					
October	890	85	232	0.552	0.64
November	1,760	138	367	.874	.98
December	1,460	225	467	1.11	1.28
January	895	131	275	.655	.76
February	345	131	184	.438	.46
March	9,010	155	922	2.20	2.54
April	4,320	1,040	2,130	5.07	5.66
May	1,380	540	793	1.89	2.18
June	6,140	440	1,230	2.93	3.27
July	800	68	318	.757	.87
August	860	138	303	.721	.83
September	405	92	179	.426	.48
The year	9,010	68	616	1.47	19.95
1917–18					
October	3,700	210	671	1.60	1.84
November	1,500	183	493	1.17	1.30
December	345	115	236	.562	.65
January	250	65	156	.371	.43
February	1,200	98	343	.817	.85
March	2,900	320	1,050	2.50	2.88
April	5,950	930	1,930	4.59	5.12
May	2,350	335	773	1.84	2.12
June	1,120	156	435	1.04	1.16
July	385	74	193	.459	.53
August	2,900	60	321	.764	.88
September	3,000	118	525	1.25	1.40
The year	5,950	60	593	1.41	19.16

DOG RIVER AT NORTHFIELD, VT.

Location.—At highway bridge near Norwich University campus in Northfield, Washington County. Union Brook joins Dog River a short distance below station.

Drainage area.—47 square miles.

Records available.—May 14, 1909 to September 30, 1918. Records from May 14, 1909 to August 22, 1910, obtained at lower highway bridge, those from August 23, 1910 to date, at present location.

Gages.—Water-stage recorder on left bank below highway bridge; gage heights referenced to gage datum by means of a hook gage inside the well. Inclined staff on left bank read by Florence C. Doyle from August 30 to September 30, 1918.

Discharge measurements.—Made from highway bridge or by wading.

Channel and control.—Channel composed of gravel and alluvial deposits; subject to slight shifts.

Extremes of discharge.—Maximum stage during year ending

September 30, 1918, from water-stage recorder, approximately 5.05 feet on April 2 (discharge, 960 second-feet); minimum stage from water-stage recorder, 0.85 foot at 11 p. m. August 3 (discharge, 8 second-feet).

1910-1918: Maximum stage recorded at present site, 8.5 feet March 25, 1913 (discharge, 3,400 second-feet); minimum stage recorded, 0.60 foot September 10 and 11, 1913 (discharge, 3.0 second-feet). At the lower gage, 1909-10, flow was practically zero at various times when water was held back by dam above gage.

Ice.—River frozen over during winter; stage-discharge relation affected for short periods.

Accuracy.—Stage-discharge relation fairly permanent except when affected by ice. Rating curve well defined below 600 second-feet. Operation of water-stage recorder unsatisfactory during a considerable part of the year as shown in footnote to daily discharge table. Daily discharge ascertained by applying rating table to mean daily gage heights, determined by inspection of gage height graph, and from observer's readings (staff gage readings to quarter-tenths twice daily). Results fair.

Discharge measurements of Dog River at Northfield, Vt., during the two-year period ending Sept. 30, 1918.

Date	Made by—	Gage height	Dis-charge	Date	Made by—	Gage height	Dis-charge
1917		*Feet*	*Sec.-ft.*	1918		*Feet*	*Sec.-ft.*
Jan. 6	Hardin Thweatt.....	1.68	44.9	Jan. 24	M. R. Stackpole.....	*a*1.29	21.5
Feb. 16	H. H. Khachadoorian	*a*1.45	27.0	Feb. 28	.....do...........	*a*2.59	162.
Apr. 2	C. H. Pierce........	4.12	560.	Apr. 12	.....do...........	2.75	213.
Sept. 15	M. R. Stackpole.....	1.04	12.8	July 26	H. W. Fear.........	.92	9.4
Oct. 31	.....do...........	3.10	296.	Aug. 29	J. W. Moulton......	1.01	11.8
Nov. 16	.....do...........	1.61	49.5				
Dec. 18	.....do...........	*a*1.46	28.6				

*a*Stage-discharge relation affected by ice.

Daily discharge, in second-feet, of Dog River at Northfield, Vt., for the years ending Sept. 30, 1917-18

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1916–17												
1	22	22	....	....	....	....	495	215	88	85	15	28
2	17	22	....	....	....	....	570	235	78	90	15	31
3	15	33	....	....	....	....	415	225	91	68	14	24
4	14	30	....	....	....	....	402	187	95	56	13	20
5	13	25	....	....	....	....	378	168	63	50	11	20
6	13	24	....	....	....	....	378	185	55	47	10	21
7	12	22	....	....	....	....	365	169	65	40	11	21
8	12	22	....	....	....	....	285	166	162	37	10	19
9	14	22	....	....	....	....	243	166	158	35	50	19
10	15	26	....	....	....	....	201	158	158	35	34	18
11	14	20	....	....	....	....	179	152	390	33	12	20
12	13	18	....	....	....	29	175	151	680	58	11	14
13	13	18	....	....	....	28	172	144	275	43	14	14
14	20	18	....	....	....	29	183	130	235	38	12	14
15	15	....	....	....	....	29	179	116	185	35	15	13
16	13	....	....	....	....	30	170	98	172	34	109	14
17	14	....	....	....	....	32	203	86	207	28	108	12
18	14	....	....	....	....	31	275	79	217	30	63	10
19	18	....	....	....	....	31	390	78	152	35	37	9
20	78	....	....	....	....	33	555	88	127	34	30	17
31	66	....	....	....	....	31	602	77	108	26	41	18
22	35	....	....	....	....	33	555	79	90	23	33	14
23	27	....	....	....	....	37	465	100	74	24	28	12
24	23	....	....	....	....	80	365	100	97	22	34	11
25	22	....	....	....	....	147	275	102	82	20	33	10
26	20	....	....	....	....	224	241	104	69	19	25	9
27	20	....	....	....	....	355	235	92	46	18	22	10
28	19	....	....	....	....	700	225	79	51	18	20	10
29	18	....	....	....	....	365	215	118	52	16	25	11
30	18	....	....	....	....	285	225	140	59	26	27	14
31	18	....	....	....	....	275	....	102	....	19	25	....
1917–18												
1	16	198	....	....	....	....	570	157	....	23	10	33
2	12	153	....	....	....	....	760	135	....	28	9.6	16
3	12	127	....	....	....	....	585	119	....	21	8.6	13
4	18	106	....	....	....	....	390	104	....	18	8.4	12
5	30	93	....	....	....	....	302	95	....	16	9.0	13
6	39	89	....	....	....	....	255	90	....	14	8.8	19
7	25	85	....	....	....	....	315	89	....	15	9.0	19
8	19	75	....	....	....	....	315	85	....	14	11	14
9	19	74	....	....	....	....	390	80	....	....	196	14
10	17	73	....	....	....	....	....	81	....	....	66	12
11	16	65	....	....	....	....	....	138	....	....	43	12
12	20	63	....	....	....	....	....	101	....	....	33	14
13	63	54	....	....	....	....	....	158	68	....	22	16
14	34	53	....	....	....	....	....	249	50	....	67	19
15	34	49	....	....	....	....	....	155	40	....	....	14
16	41	51	....	....	....	....	....	124	34	....	....	16
17	32	48	....	....	....	....	....	108	28	....	....	19
18	25	48	....	....	....	....	....	94	27	....	....	32
19	23	50	....	....	....	....	....	83	24	....	....	47
20	44	....	....	....	....	....	....	75	22	....	....	62
21	38	....	....	....	....	237	227	75	20	....	....	107
22	30	....	....	....	....	304	270	67	37	....	....	49
23	27	....	....	....	....	304	229	....	43	....	....	35
24	33	....	....	....	....	281	217	....	37	....	....	54
25	128	....	....	....	....	281	169	....	30	....	....	48
26	61	....	....	....	....	264	146	....	23	9.8	....	268
27	46	....	....	....	....	225	145	....	20	9.8	10	257
28	128	....	....	....	....	235	223	....	19	9.6	11	190
29	79	....	....	....	....	281	186	....	19	10	11	104
30	527	....	....	....	....	315	207	....	32	13	12	83
31	327	....	....	....	....	444	....	....	....	11	12	..

Monthly discharge of Dog River at Northfield, Vt., for the two-year period ending Sept. 30, 1918

[Drainage area, 47 square miles.]

Month	Discharge in second-feet				Run-off (depth in inches on drainage area)
	Maximum	Minimum	Mean	Per square mile	
1916–17					
October	78	12	20.8	0.443	0.51
November	....	....	*a*42	.894	1.00
December	....	....	*a*53	1.13	1.30
January	....	....	*a*44	.936	1.08
February	....	....	*a*33	.702	.73
March	700	....	*a*100	2.13	2.46
April	602	170	321	6.83	7.62
May	235	77	132	2.81	3.24
June	680	46	146	3.11	3.47
July	90	16	36.8	.783	.90
August	109	10	29.3	.623	.72
September	31	9	15.9	.338	.38
The year	700	....	80.9	1.72	23.41
1917–18					
October	527	12	63.3	1.35	1.56
November	198	....	61.0	1.30	1.45
December	....	....	*a*28.0	.596	.69
January	....	....	*a*17.5	.372	.43
February	....	....	*a*42.5	.904	.94
March	444	....	138	2.94	3.39
April	760	145	285	6.06	6.76
May	249	....	99.2	2.11	2.43
June	....	19	39.5	.840	.94
July	....	9.6	16.7	.355	.41
August	196	7.0	25.3	.538	.62
September	268	12	53.7	1.14	1.27
The year	760	....	72.3	1.54	20.89

*a*Discharge estimated from results of discharge measurements and comparisons with records of White River and Winooski River.

LAMOILLE RIVER AT CADYS FALLS, VT.

Location.—About one-fourth mile below power plant of Morrisville Electric Light & Power Co., at what was formerly known as Cadys Falls, 2 miles downstream from village of Morrisville, Lamoille County.

Drainage area.—280 square miles.

Records available.—September 4, 1913 to September 30, 1918. A station was maintained at highway bridge near power plant at Cadys Falls from July 28, 1909 to July 13, 1910.

Gages.—Friez water-stage recorder in gage house on right bank, one-fourth mile below highway bridge at Cadys Falls. Gage heights are referred to gage datum by means of a hook gage inside the well; an outside staff gage is used for auxiliary readings.

Discharge measurements.—Made from a cable or by wading.

Channel and control.—Channel smooth gravel; well defined gravel control 500 feet downstream from gage.

Extremes of discharge.—Maximum open-water stage from water-stage recorder during year ending September 30, 1918, 10.66 feet at 7.45 p. m. October 30 (approximate discharge from extension of rating curve, 7,430 second-feet); minimum stage from water-stage recorder, 1.85 feet at 1 p. m. August 18 (discharge, 52 second-feet).

1913-1918: Maximum stage recorded, 10.66 feet October 30, 1917 (approximate discharge from extension of rating curve, 7,430 second-feet); minimum stage recorded, 1.82 feet August 17, 1914 (discharge, 50 second-feet).

Ice.—River freezes over during extremely cold weather; stage-discharge relation slightly affected by ice.

Accuracy.—Stage-discharge relation practically permanent, except when affected by ice. Rating curve well defined. Operation of water-stage recorder satisfactory throughout year except for periods during the winter when clock would not run on account of extreme cold. Daily discharge ascertained by discharge integrator. Results good.

Discharge measurements of Lamoille River at Cadys Falls, Vt., during the two-year period ending Sept. 30, 1918

Date	Made by—	Gage height	Dis-charge	Date.	Made by—	Gage height	Dis-charge
		Feet	*Sec. ft.*			*Feet*	*Sec. ft.*
1916				1918			
Dec. 29	Hardin Thweatt	*a*2.43	190	Mar. 2	M. R. Stackpole	*a*3.35	397
1917				27	....do	*a*3.89	804
Mar. 10	H. H. Khachadoorian	*a*2.72	198	Apr. 11	....do	4.42	1,150
July 23	M. R. Stackpole	3.94	895	11	....do	4.28	1,080
Dec. 15	....do	*a*2.39	167	July 25	H. W. Fear	2.22	147

*a*Stage-discharge relation affected by ice.

Daily discharge, in second-feet, of Lamoille River at Cadys Falls, Vt., for the years ending Sept. 30, 1917-18

Day	Oct.	Nov.	Dec.	an.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1916-17												
1	533	118	1,520	200	250	250	2,260	1,000	305	900	435	405
2	302	343	770	195	240	300	3,420	1,060	415	960	550	465
3	230	339	560	195	200	290	2,680	1,020	410	660	590	550
4	191	359	428	195	180	250	2,100	800	510	430	420	435
5	163	313	614	210	205	260	1,880	600	450	310	295	360
6	153	272	972	244	200	230	1,800	610	350	300	230	340
7	132	244	745	251	195	220	2,430	600	300	200	220	360
8	112	188	551	276	210	200	1,590	560	385	182	205	390
9	144	175	471	265	250	185	1,090	530	440	215	630	220
10	156	211	614	276	250	185	820	550	415	240	700	215
11	147	191	462	287	200	170	720	700	1,140	220	440	240
12	156	163	416	268	200	210	672	960	3,420	255	360	210
13	156	178	347	248	200	205	636	760	1,340	285	325	192
14	258	163	262	258	190	205	632	610	840	580	290	196
15	230	166	279	770	180	190	587	540	730	450	325	180
16	211	188	251	628	180	185	596	440	620	400	320	174
17	194	172	237	551	205	190	632	385	640	350	1,290	162
18	191	224	240	445	180	175	1,180	345	1,860	310	1,520	116
19	198	220	220	420	190	200	1,800	330	1,080	410	710	154
20	484	244	240	403	200	185	2,770	390	1,060	475	640	240
21	870	220	220	324	170	150	3,620	410	870	540	920	285
22	551	220	220	336	140	190	3,420	330	580	1,140	650	180
23	359	309	207	320	140	190	2,680	370	460	820	385	150
24	330	1,950	201	290	135	570	1,840	510	520	500	420	162
25	302	945	210	276	105	870	1,320	295	600	330	670	200
26	273	672	205	268	135	1,060	1,150	310	460	275	480	178
27	244	367	200	262	140	2,020	895	360	385	250	390	162
28	172	347	230	214	180	3,620	795	310	320	210	335	186
29	121	367	200	258	....	2,100	972	350	455	290	490	205
30	129	1,590	200	262	....	1,320	1,060	520	1,000	620	620	235
31	115	....	200	262	....	1,060	....	370	....	530	570	....
1917-18												
1	385	1,500	275	240	190	560	3,150	1,080	590	184	110	196
2	330	1,020	250	200	190	430	4,550	990	630	290	104	140
3	260	820	230	220	200	370	3,900	600	380	300	100	112
4	430	680	240	200	200	370	2,100	620	300	220	90	114
5	740	610	235	240	200	290	1,520	495	265	176	98	112
6	950	550	230	220	220	270	1,260	470	240	170	116	118
7	640	520	230	200	220	250	1,520	495	720	184	110	130
8	480	455	200	200	220	240	1,760	440	550	198	132	100
9	660	420	210	200	240	450	2,100	405	350	184	465	120
10	495	425	220	200	200	450	1,520	385	315	172	330	120
11	400	530	220	190	190	490	1,160	800	280	196	235	112
12	355	445	200	190	170	430	1,040	580	820	164	174	112
13	780	305	200	190	140	350	990	820	1,520	198	164	112
14	530	300	200	190	140	270	1,100	2,250	800	255	152	230
15	485	330	200	170	155	270	1,420	1,080	590	275	162	154
16	720	325	200	170	220	220	1,740	700	435	200	178	136
17	510	270	200	170	240	200	1,520	680	290	158	142	215
18	390	240	200	170	250	270	1,380	410	425	174	114	255
19	350	275	200	155	220	350	990	330	480	158	122	330
20	1,000	260	200	155	290	410	820	325	245	122	120	210
21	700	300	200	155	520	600	820	325	140	95	144	490
22	485	330	200	140	600	1,100	1,520	330	215	87	140	335
23	405	345	220	140	540	1,750	1,460	720	390	116	130	285
24	415	430	200	140	390	1,250	1,240	485	410	124	104	740
25	780	345	190	125	290	970	940	340	345	114	96	770
26	640	260	200	125	440	970	740	250	295	104	110	950
27	510	220	200	140	880	840	570	340	255	99	112	2,500
28	980	220	200	155	780	720	700	380	225	85	85	1,560
29	820	225	200	190	....	900	740	325	220	85	100	540
30	3,800	240	200	170	....	1,500	1,080	710	230	162	104	520
31	4,100	....	220	190	....	1,950	....	550	....	140	110	....

Monthly discharge of Lamoille River at Cadys Falls, Vt., for the two-year period ending Sept. 30, 1918.

[Drainage area, 280 square miles.]

Month	Discharge in second-feet				Run-off (depth in inches on drainage area)
	Maximum	Minimum	Mean	Per square mile	
1916–17					
October	533	112	252	0.900	1.04
November	1,590	118	382	1.36	1.52
December	1,520	200	403	1.44	1.66
January	770	195	312	1.11	1.28
February	250	105	188	.671	.70
March	3,620	150	562	2.01	2.32
April	3,620	587	1,600	5.71	6.37
May	1,060	295	546	1.95	2.25
June	3,420	300	745	2.66	2.97
July	1,140	182	440	1.57	1.81
August	1,520	205	530	1.89	2.18
September	550	116	252	.900	1.00
The year	3,620	105	518	1.85	25.10
1917–18					
October	4,100	260	791	2.82	3.25
November	1,500	220	440	1.57	1.75
December	275	190	212	.757	.87
January	240	125	175	.639	.74
February	880	140	305	1.09	1.14
March	1,950	200	629	2.25	2.59
April	4,550	570	1,510	5.39	6.01
May	2,250	250	604	2.16	2.49
June	1,520	140	432	1.54	1.72
July	300	85	167	.596	.69
August	465	85	144	.514	.59
September	2,500	100	394	1.41	1.57
The year	4,550	85	483	1.72	23.41

GREEN RIVER AT GARFIELD, VT.

Location.—At site of old dam above highway bridge at Garfield village, town of Hyde Park, Lamoille County. Green River is tributary to Lamoille River about 4 miles east of Morrisville.

Drainage area.—20 square miles (approximate).

Records available.—January 3, 1915 to September 30, 1918.

Gage.—Inclined staff on left bank in pool back of weir; read by P. M. Trescott.

Discharge measurements.—Standard sharp-crested weir of compound section; length of crest at gage height 0.00 is 9.0 feet; at gage height 0.83 foot, length of crest is increased 11.17 feet. Current-meter measurements made at footbridge about one-half mile downstream from weir, and at old bridge about one-half mile above weir.

Channel and control.—A pool of considerable size is formed in the old mill pond back of the weir; at ordinary stages the velocity of approach to the weir is very small. Some water leaks around the weir in the old tail-race on left bank.

Extremes of discharge.—Maximum stage recorded during year ending September 30, 1918, 3.03 feet at 9 a. m. October 31 and 5 p. m. April 2 (approximate discharge from extension of rating curve, 306 second-feet); minimum stage recorded, 0.29 foot August 28, 30, and 31 (discharge, 4.7 second-feet).

1915-1918: Maximum stage recorded, 3.6 feet at 9 a. m. April 12, 1915 (approximate discharge from extension of rating curve, 436 second-feet); minimum stage recorded, 0.29 foot August 28, 30 and 31, 1918 (discharge, 4.7 second-feet).

Ice.—Weir and weir crest kept clear of ice during winter; stage-discharge relation not affected by ice.

Regulation.—An old timber dam about 2 miles upstream affects flow to some extent. The dam leaks by an amount somewhat greater than the low-water flow. During prolonged low stages the surface of water in pond (103 acres) falls below crest of dam; subsequent increased flow into pond is retained until water again flows over crest, when the increased flow is apparent at gaging station.

Accuracy.—Stage-discharge relation practically permanent. Rating curve based on weir formula, $Q = 3.33 LH^{3/2}$ with corrections determined from current-meter measurements, and with logarithmic extension above gage height 1.90 feet. Gage read twice daily to hundredths. Daily discharge ascertained by applying rating table to mean daily gage heights. Results are good below 130 second-feet; at the higher stages the weir is flooded and results are somewhat uncertain.

Cooperation.—Gage-height records furnished by C. T. Middlebrook, consulting engineer, Albany, N. Y.

Discharge measurements of Green River at Garfield, Vt., during the two-year period ending Sept. 30, 1918

Date	Made by—	Gage height	Dis-charge	Date	Made by—	Gage height	Dis-charge
1917		*Feet*	*Sec. ft.*	1918		*Feet*	*Sec. ft.*
July 21	*a*M. R. Stackpole.....	1.60	89	July 25	*b*H. W. Fear.........	.39	6.9
21	*b*Hardin Thweatt.....	1.59	86	25	*a*....do............	.39	7.6

*a*Made at section just above Taylor's Brook; about ½ mile below gage.
*b*Made at old bridge about ½ mile above gage.

Daily discharge, in second-feet, of Green River at Garfield, Vt., for the years ending Sept. 30, 1917-18

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1916-17												
1	12	16	139	12	12	9.7	98	104	24	68	35	35
2	12	16	76	12	12	9.7	156	101	20	76	34	36
3	12	19	51	13	12	10	172	89	21	62	51	36
4	11	23	32	13	11	10	148	73	20	42	41	35
5	11	21	37	13	12	10	136	65	19	29	33	34
6	11	18	75	13	11	10	128	60	17	23	30	33
7	11	16	67	12	11	11	146	55	17	19	27	32
8	11	15	47	12	12	11	116	53	20	17	25	28
9	11	14	35	13	12	11	88	49	23	16	60	26
10	11	15	42	12	11	12	62	48	29	16	116	26
11	11	14	35	11	11	12	54	60	75	14	76	24
12	10	14	30	11	10	11	47	83	203	19	43	23
13	11	14	26	12	10	12	40	74	112	16	34	22
14	13	13	24	17	10	11	36	55	77	19	32	18
15	11	13	22	19	10	12	35	44	79	78	30	12
16	12	13	19	15	9.7	12	34	35	59	72	28	12
17	12	12	19	16	9.7	12	38	30	61	47	51	12
18	11	12	17	16	9.7	12	69	28	95	34	110	12
19	12	13	16	16	9.3	12	142	26	74	29	77	12
20	16	13	16	16	9.3	12	234	27	85	79	64	14
21	27	12	16	16	9.3	13	294	27	114	86	51	14
22	40	11	16	15	9.3	13	318	24	67	132	44	13
23	30	14	16	14	9.3	14	272	27	47	115	38	13
24	22	75	16	14	9.3	18	198	30	45	54	35	13
25	19	92	16	13	9.3	17	117	30	45	36	44	12
26	17	43	15	13	9.3	22	109	35	34	29	41	12
27	16	32	15	12	10	34	95	31	29	25	37	12
28	15	30	14	13	10	97	96	27	25	27	34	14
29	14	32	13	13	....	104	104	25	32	30	39	13
30	13	85	12	12	....	83	108	30	64	35	37	16
31	13	....	12	12	....	75	....	27	....	38	37	....
1917-18												
1	17	126	16	11	9.7	11	163	84	63	20	15	8.4
2	21	81	17	11	9.7	11	271	87	57	20	14	6.3
3	27	62	17	10	9.7	11	286	68	39	19	13	6.0
4	32	47	17	10	9.3	11	207	50	26	18	13	5.7
5	35	43	17	10	8 7	12	163	40	20	1	13	5.7
6	51	38	15	11	8.4	12	138	34	18	16	12	8.7
7	49	34	15	11	8.4	12	149	40	27	19	14	6.6
8	46	32	15	11	8.0	12	170	32	60	18	14	6.3
9	49	29	16	10	8.4	12	172	30	58	19	22	6.0
10	41	28	15	9.7	8.7	13	139	32	32	17	16	6.3
11	37	27	13	9.3	8.7	14	106	62	26	17	14	6.0
12	33	26	13	9.7	9.0	15	91	58	47	17	13	6.0
13	38	25	13	10	9.7	14	79	72	98	17	12	7.1
14	34	24	14	10	10	14	100	210	68	21	12	8.4
15	35	23	14	10	10	14	159	117	51	18	12	7.1
16	49	23	13	10	10	14	197	68	38	15	11	7.1
17	47	22	13	10	9.7	14	181	49	32	13	11	11
18	37	21	13	10	9.7	14	163	39	27	10	10	11
19	31	21	14	10	9.7	15	95	32	25	9.7	10	12
20	46	20	14	9.7	12	17	74	28	23	9.0	9.7	13
21	60	20	14	9.7	12	22	78	30	21	8.4	9.3	25
22	43	21	13	10	11	30	117	28	23	8.0	9.3	21
23	35	22	13	10	11	34	131	33	25	7.7	8.4	22
24	34	21	13	10	10	22	110	32	26	7.4	5.7	39
25	39	22	13	10	10	29	77	28	26	7.4	5.5	64
26	43	18	12	10	13	43	64	26	23	7.1	5.5	68
27	38	17	12	10	12	60	69	35	22	7.1	5.2	188
28	51	17	12	9.7	12	62	70	40	20	6.9	4.9	146
29	56	17	12	9.7	....	65	71	40	25	6.6	5.2	82
30	130	16	11	9.7	....	69	74	70	20	23	4.7	51
31	264	....	11	9.7	....	90	....	64	....	16	4.7	....

Monthly discharge of Green River at Garfield, Vt., for the two-year period ending Sept. 30, 1918

[Drainage area, 20 (Approx.) square miles]

Month	Discharge in second-feet				Run-off (depth in inches on drainage area)
	Maximum	Minimum	Mean	Per square mile	
1916–17					
October	40	10	14.8	0.74	0.85
November	92	11	24.3	1.22	1.36
December	139	12	31.8	1.59	1.83
January	19	11	13.6	.68	.78
February	12	9.3	10.4	.52	.54
March	104	9.7	23.0	1.15	1.33
April	318	34	123	6.15	6.86
May	104	24	47.5	2.38	2.74
June	203	17	54.4	2.72	3.04
July	132	14	44.6	2.23	2.57
August	116	25	46.3	2.32	2.68
September	36	12	20.5	1.02	1.14
The year	318	9.3	37.9	1.90	25.72
1917–18					
October	264	17	49.9	2.50	2.88
November	126	16	31.4	1.57	1.75
December	17	11	13.9	.695	.80
January	11	9.3	10.1	.505	.58
February	13	8.0	9.95	.498	.52
March	90	11	25.4	1.27	1.46
April	286	64	132	6.60	7.36
May	210	26	53.5	2.68	3.09
June	98	18	35.5	1.78	1.99
July	23	6.6	14.0	.700	.81
August	22	4.7	10.6	.530	.61
September	188	5.7	28.7	1.44	1.61
The year	286	4.7	34.6	1.73	23.46

Missisquoi River near Richford, Vt.

Location.—About three miles downstream from Richford, Franklin County, 3 miles below mouth of North Branch, and 2 miles above mouth of Trout River.

Drainage area.—445 square miles.

Records available.—May 22, 1909 to December 3, 1910, and June 26, 1911 to September 30, 1918.

Gage.—Gurley water-stage recorder on left bank, about one-fourth mile above highway bridge; chain gage on highway bridge used from June 26, 1911 to July 31, 1915. From May 22, 1909 to December 3, 1910, gage was just below plant of the Sweat-Comings Co. in Richford.

Discharge measurements.—Made from highway bridge or by wading.

Channel and control.—Channel deep, banks not subject to overflow; stream bed composed of gravel, boulders, and ledge rock. Control is sharply defined by rock outcrop about 100 feet below gage.

Extremes of discharge.—Maximum stage from water-stage recorder during year ending September 30, 1918, approximately 17.5 feet on April 1 (stage-discharge relation affected by ice); minimum stage from water-stage recorder, 2.16 feet at 4 p. m., August 30 (discharge, 44 second-feet).

1911-1918: Maximum stage recorded, approximately 17.5 feet on April 1, 1918 (stage-discharge relation affected by ice); minimum stage recorded, 4.15 feet by chain gage, July 14, 1911 (discharge, 8 second-feet).

Ice.—Stage-discharge relation usually affected by ice from December to March; discharge determined from gage heights corrected for backwater by means of current-meter measurements, observer's notes, and weather records.

Regulation.—Considerable daily fluctuation at low stages caused by operation of power plants at Richford.

Accuracy.—Stage-discharge relation practically permanent except when affected by ice. Rating curve fairly well defined below 6,000 second-feet. Operation of water-stage recorder satisfactory during the year except as indicated in footnote to daily discharge table. Daily discharge ascertained by applying rating table to mean daily gage heights determined by inspection of recorder sheets; determinations for periods for which no record was obtained are based on comparison with records of flow of streams in adjacent drainage basins. Results good for periods when water-stage recorder was in operation, and fair for other periods and during the winter.

Discharge measurements of Missisquoi River near Richford, Vt., during the two-year period ending Sept. 30, 1918

Date	Made by—	Gage height	Dis-charge	Date	Made by—	Gage height	Dis-charge
		Feet	*Sec. ft.*			*Feet*	*Sec. ft.*
1916				1917			
Oct. 3	Hardin Thweatt	3.80	644	Dec. 12	M. R. Stackpole	*a*4.26	315
Dec. 31	....do	*a*4.88	381	1918			
1917				Jan. 30	M. R. Stackpole	*a*4.69	160
Mar. 9	H. H. Khachadoorian	*a*4.50	288	Mar. 6	....do	*a*6.48	760
Apr. 2	....do	9.39	5,970	Apr. 1	....do	*a*13.49	4,730
July 25	Hardin Thweatt	3.65	486	1	....do	*a*13.69	4,800
26	M. R. Stackpole	3.57	417	8	....do	7.17	3,430
Oct. 11	....do	4.09	809	9	....do	7.69	4,090
				July 24	H. W. Fear	2.91	234
				Aug. 31	J. W. Moulton	2.20	51
				31	....do	2.35	84

*a*Stage-discharge relation affected by ice.

Daily discharge, in second-feet, of Missisquoi River near Richford, Vt., for the years ending Sept. 30, 1917-18

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1916–17												
1	1,350	545	3,740	360	430	460	4,050	2,100	640	2,240	296	585
2	900	700	3,140	360	410	520	5,880	2,540	600	1,880	314	600
3	668	720	1,600	310	360	490	8,000	2,440	625	1,200	391	680
4	488	732	980	310	360	460	6,480	1,840	1,170	770	339	536
5	418	668	1,450	310	360	430	5,160	1,480	950	575	268	407
6	350	575	1,800	360	360	410	4,380	1,280	710	487	225	391
7	292	521	1,250	520	360	380	4,600	1,240	650	415	200	399
8	250	488	1,000	460	380	360	4,050	1,170	600	363	200	355
9	258	488	860	410	430	310	2,740	1,140	650	335	363	307
10	327	830	1,050	360	430	280	1,920	1,170	1,500	350	1,170	482
11	322	830	840	310	410	280	1,440	2,200	2,150	293	800	455
12	292	420	760	310	360	360	1,360	2,840	6,120	300	482	383
13	341	440	640	310	340	360	1,360	2,060	4,600	375	359	332
14	1,740	440	580	360	310	360	1,240	1,560	2,540	383	307	300
15	1,390	440	490	1,500	310	340	1,140	1,520	2,440	428	318	276
16	935	450	460	1,250	310	340	1,140	1,200	1,720	469	545	359
17	935	460	460	980	360	340	1,140	960	1,440	375	1,640	367
18	970	480	430	840	310	340	1,640	925	1,920	424	2,640	304
19	935	488	410	760	310	340	2,440	890	1,880	1,720	1,520	279
20	2,050	557	410	700	360	340	3,720	1,000	1,030	1,640	1,600	960
21	3,130	510	410	660	310	310	5,040	1,050	1,320	960	1,640	1,100
22	2,530	466	380	640	270	360	6,240	900	960	1,060	1,060	770
23	1,600	521	380	580	250	520	6,240	1,030	680	1,030	740	492
24	1,150	3,130	360	540	250	1,050	4,820	1,200	565	710	585	391
25	970	3,330	360	520	230	1,500	2,840	1,280	570	585	565	328
26	865	1,350	360	490	230	1,800	2,100	1,240	496	455	555	300
27	798	1,230	360	460	310	3,300	1,760	1,060	460	371	433	282
28	732	1,110	360	410	410	5,600	1,640	830	424	318	367	293
29	635	1,190	360	460	....	3,200	1,720	740	469	282	355	375
30	575	3,530	360	460	....	3,200	1,920	740	1,600	307	514	469
31	521	....	360	430	....	3,390	....	710	....	314	710	....
1917–18												
1	770	5,280	380	185	82	1,050	5,800	1,720	438	615	324	456
2	1,140	2,590	400	170	160	1,000	9,000	1,880	510	620	258	300
3	890	1,720	420	145	160	960	8,000	1,720	383	446	248	240
4	1,140	1,360	440	130	130	900	6,720	1,480	282	379	186	179
5	1,520	1,100	420	170	94	820	4,270	1,320	248	318	150	168
6	1,680	995	380	170	72	760	3,280	1,240	215	300	1,240	194
7	1,360	890	320	185	120	700	3,170	1,200	482	268	710	272
8	1,060	830	280	160	145	560	4,050	1,170	995	307	575	227
9	1,200	770	300	82	160	500	3,940	890	590	324	698	203
10	960	740	300	120	160	460	3,170	710	395	314	800	200
11	740	680	300	120	170	420	2,340	890	332	290	500	168
12	750	650	320	120	170	360	1,880	1,440	610	258	363	152
13	770	635	320	130	160	380	1,680	2,100	3,060	339	321	203
14	995	565	320	145	130	300	1,880	2,240	2,840	860	282	307
15	1,140	496	320	160	82	280	2,440	1,640	1,480	668	286	395
16	1,920	510	280	220	72	260	2,850	1,140	995	550	237	343
17	1,360	460	300	200	145	260	2,650	830	680	480	200	1,760
18	960	440	300	185	600	300	2,390	710	545	505	170	1,170
19	830	500	300	185	700	340	1,880	570	456	500	179	1,140
20	2,240	500	300	185	900	380	1,680	500	387	400	145	860
21	1,880	575	260	200	960	560	1,700	510	324	282	132	1,600
22	1,200	585	230	185	1,100	1,500	2,500	407	314	234	122	1,840
23	960	860	200	130	1,100	3,200	2,700	325	590	230	140	1,170
24	830	740	230	170	700	2,800	2,440	363	1,280	212	100	1,560
25	1,640	590	300	120	410	2,400	1,970	325	860	170	108	1,640
26	1,880	400	280	130	700	2,200	1,480	310	536	150	125	1,360
27	1,280	350	170	160	1,150	1,550	1,320	318	420	185	125	4,600
28	1,440	320	170	170	1,100	1,050	1,440	367	339	152	100	5,160
29	1,800	320	120	145	....	1,150	1,520	363	339	150	92	3,500
30	5,760	350	120	160	....	1,950	1,600	324	474	209	102	2,200
31	6,720	....	120	130	....	4,000	....	363	....	541	110	....

Monthly discharge of Missisquoi River near Richford, Vt., for the two-year period ending Sept. 30, 1918

[Drainage area, 445 square miles.]

Month	Discharge in second-feet				Run-off (depth in inches on drainage area)
	Maximum	Minimum	Mean	Per square mile	
1916–17					
October	3,130	250	926	2.08	2.40
November	3,530	420	921	2.07	2.31
December	3,740	360	819	1.84	2.12
January	1,500	310	540	1.21	1.40
February	430	230	340	.764	.80
March	5,600	280	1,020	2.29	2.64
April	8,000	1,140	3,270	7.35	8.20
May	2,840	710	1,370	3.08	3.55
June	6,120	424	1,380	3.10	3.46
July	2,240	282	691	1.55	1.79
August	2,640	200	694	1.56	1.80
September	1,100	282	452	1.02	1.14
The year	8,000	200	1,040	2.34	31.61
1917–18					
October	6,720	740	1,580	3.55	4.09
November	5.280	320	893	2.00	2.23
December	440	120	287	.645	.74
January	220	82	157	.353	.41
February	1,150	72	415	.933	.97
March	4,000	260	1,080	2.43	2.80
April	9,000	1,320	3,060	6.88	7.68
Mav	2,240	310	947	2.13	2.46
June	3,060	215	713	1.60	1.78
July	860	150	363	.816	.94
August	1,240	92	294	.661	.76
September	5,160	152	1,120	2.52	2.81
The year	9,000	72	906	2.04	27.67

CLYDE RIVER AT WEST DERBY, VT.

Location.—Just below plant of Newport Electric Light Co., at West Derby (Newport), Orleans County; about 1 mile above mouth of river.

Drainage area.—150 square miles.

Records available.—May 25, 1909, to September 30, 1918.

Gages.—Water-stage recorder on right bank; referenced to gage datum by a hook gage inside the well; chain gage fastened to tree is used for auxiliary readings.

Discharge measurements.—Made by wading near gage or from highway bridge one-half mile downstream.

Channel and control.—Stream bed rough and irregular; covered with boulders and ledge rock; fall of river rapid for some distance below gage.

Extremes of discharge.—Maximum stage during year ending September 30, 1918, from water-stage recorder, 3.70 feet at 11 p. m. April 3 (discharge, 1,280 second-feet); minimum stage recorded, 1.87 feet at 5 a. m. September 1 (discharge, 40 second-feet).

1909-1918: High water of March 25-30, 1913, reached maximum stage of 5.8 feet, as determined by engineers of Geological Survey from high-water marks (discharge approximately 6,300 second-feet); minimum stage, 1.60 feet at 5.45 p. m. August 25, 1913, 7.30 p. m. July 30, and 4.50 p. m. August 17, 1914 (discharge, 17 second-feet).

Ice.—Ice covers large boulders below gage during greater part of winter and causes some backwater.

Regulation.—Flow at ordinary stages fully controlled by two dams at West Derby, but power plant is so operated that fluctuations in stage are not great. Distribution of flow affected also by several dams above West Derby. Seymour Lake and several smaller ponds in the basin afford a large amount of natural storage, but at the present time there is little if any artificial regulation at these ponds.

Accuracy.—Stage-discharge relation practically permanent, except when affected by ice; individual current-meter measurements occasionally plot erratically, probably because of rough measuring section. Rating curve fairly well defined. Operation of water-stage recorder unsatisfactory during a part of the year, as indicated in footnote to daily-discharge table. Daily discharge ascertained by applying rating table to mean daily gage heights, using observer's reading of chain gage when recorder was not in operation. Results fair.

Discharge measurements of Clyde River at West Derby, Vt., during the two-year period ending Sept. 30, 1918

Date	Made by—	Gage height		Discharge
		Chain	Hook	
1916		*Feet*	*Feet*	*Sec. ft.*
Oct. 4	Hardin Thweatt	2.53	2.57	254
4	....do	2.53	2.57	247
1917				
Jan. 1	Hardin Thweatt	[a]2.40	[a]2.49	170
Mar. 8	H. H. Khachadoorian	2.15	2.60	124
Apr. 3	....do	3.48	3.48	886
July 24	M. R. Stackpole	2.46	2.61	234
24	Hardin Thweatt	2.46	2.61	219
Oct. 12	M. R. Stackpole	2.55	2.64	272
Dec. 13	....do	[a]2.49	[a]2.53	138
1918				
Jan. 29	M. R. Stackpole	[a]2.08	[a]2.15	80
Mar. 5	....do	2.42	2.48	215
28	....do	2.70	.....	357
29	....do	2.75	.....	385
July 23	C. H. Pierce	2.32	2.32	157
Sept. 1	J. W. Moulton	2.70	2.68	335

[a] Stage-discharge relation affected by ice.

Daily discharge, in second-feet, of Clyde River at West Derby, Vt., for the years ending Sept. 30, 1917-18

Day.	Oct.	Nov.	Dec.	Jan	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1916–17												
1	170	140	360	145	110	120	500	755	290	172	127	397
2	197	140	390	120	110	155	710	755	280	165	127	404
3	218	145	435	105	110	115	850	800	280	159	138	336
4	221	150	420	110	110	120	900	800	260	150	144	295
5	214	155	400	135	115	115	900	755	240	130	162	280
6	182	155	387	155	110	110	900	665	232	115	165	260
7	158	150	375	146	105	102	900	580	228	110	153	270
8	138	146	350	140	100	115	850	540	216	105	144	210
9	135	145	320	140	100	120	755	540	204	105	200	140
10	120	140	305	135	95	120	665	500	216	110	228	140
11	115	140	315	130	95	95	580	460	228	115	216	145
12	110	135	298	128	90	105	540	500	264	125	220	130
13	122	135	265	130	90	95	460	540	268	150	236	115
14	100	140	255	140	90	90	432	580	310	180	232	100
15	102	146	245	195	85	112	411	580	348	205	228	90
16	110	140	240	155	85	110	390	540	336	200	204	80
17	120	135	230	155	80	95	378	500	378	180	236	80
18	125	130	230	150	80	102	404	453	460	165	272	80
19	128	128	220	140	80	90	432	425	425	195	300	85
20	143	140	220	135	80	86	540	397	418	215	360	100
21	173	120	210	130	80	100	665	384	397	230	411	110
22	197	115	205	125	80	90	950	366	354	240	418	110
23	207	105	205	120	80	90	1,180	372	315	240	378	95
24	218	205	205	120	80	110	1,370	360	272	244	360	90
25	228	215	205	115	85	130	1,370	354	285	236	384	85
26	214	243	200	110	90	155	1,240	348	300	228	418	85
27	194	255	195	110	95	210	1,060	354	272	196	425	80
28	182	275	185	110	110	364	900	325	244	175	432	75
29	170	284	180	110	....	449	800	320	200	162	453	80
30	155	350	175	110	....	505	755	310	179	150	445	100
31	145	....	175	110	....	505	....	300	....	133	439	....
1917–18												
1	160	950	280	68	74	230	389	655	255	194	204	99
2	230	1,060	260	70	70	250	810	810	288	194	218	96
3	220	1,000	270	80	70	250	1,220	860	278	184	222	102
4	240	850	260	82	70	240	1,120	810	264	198	213	99
5	300	755	210	80	70	217	1,170	702	229	167	187	93
6	360	620	200	80	68	205	1,060	610	209	167	175	102
7	380	500	210	80	76	200	1,010	533	211	164	204	123
8	330	460	175	80	64	195	910	509	213	155	220	99
9	315	411	175	80	52	184	910	478	217	155	245	100
10	330	378	160	80	66	170	810	485	221	146	286	100
11	360	354	120	80	78	160	1,120	471	221	149	292	99
12	310	336	115	82	84	145	1,010	525	304	152	280	99
13	315	310	115	82	100	140	960	493	408	161	259	105
14	290	300	110	82	112	140	702	610	356	264	238	107
15	330	280	90	80	130	140	655	655	304	274	204	113
16	342	264	90	82	167	140	702	702	310	316	182	138
17	354	260	90	82	143	140	810	655	299	304	164	131
18	330	256	84	80	135	140	810	655	274	310	145	152
19	336	248	80	78	138	140	800	610	255	274	128	160
20	397	244	80	76	198	140	860	541	225	245	138	156
21	411	244	80	74	149	150	810	450	200	225	134	200
22	397	244	76	72	140	180	810	415	188	205	105	218
23	384	256	72	70	140	230	702	402	191	191	126	238
24	390	248	68	76	160	275	655	350	209	152	141	286
25	404	236	74	70	177	310	655	288	209	128	191	322
26	378	270	76	68	180	350	610	304	233	119	171	328
27	360	280	76	68	184	363	760	293	217	126	160	422
28	378	290	70	70	205	370	655	264	209	119	145	540
29	372	290	68	80	....	327	610	255	205	107	138	557
30	620	280	66	74	....	389	610	274	209	145	128	565
31	800	....	64	72	....	344	....	269	....	178	76	....

Monthly discharge of Clyde River at West Derby, Vt., for the two-year period ending Sept. 30, 1918

[Drainage area, 150 square miles.]

Month	Discharge in second-feet				Run-off (depth inches on drainage area)
	Maximum	Minimum	Mean	Per square mile	
1916–17					
October	228	100	162	1.08	1.24
November	350	105	167	1.11	1.24
December	435	175	271	1.81	2.09
January	195	105	131	.873	1.01
February	115	80	93.6	.624	.65
March	505	86	157	1.05	1.21
April	1,370	378	760	5.07	5.66
May	800	300	499	3.33	3.84
June	460	179	290	1.93	2.15
July	244	105	170	1.13	1.30
August	453	127	279	1.86	2.14
September	404	75	155	1.03	1.15
The year	1,370	75	262	1.75	23.68
1917–18					
October	800	160	359	2.39	2.76
November	1,060	236	416	2.77	3.09
December	280	64	128	.853	.98
January	82	68	76.7	.511	.59
February	205	52	118	.787	.82
March	389	140	221	1.47	1.70
April	1,220	389	824	5.49	6.12
May	860	255	514	3.43	3.95
June	408	188	247	1.65	1.84
July	316	107	189	1.26	1.45
August	292	76	184	1.23	1.42
September	565	93	198	1.32	1.47
The year	1,220	52	290	1.93	26.19

CONNECTICUT RIVER AT FAIRLEE, VT. (ORFORD, N. H.)

Location.—At covered highway bridge between Fairlee, Vt., and Orford, N. H., about 8 miles below the mouth of Waits River and 22 miles above the mouth of White River.

Drainage area.—3,100 square miles.

Records available.—August 6, 1900, to September 30, 1918.

Gages.—Chain on upstream side of bridge and inclined staff on left bank 25 feet below bridge.

Discharge measurements.—Open-water measurements made from the bridge or from cable 500 feet above the bridge.

Channel and control.—Channel wide and deep with gravelly bottom; control for low stages slightly shifting; at high stages the control is probably at the dam at Wilder.

Extremes of discharge.—Maximum open-water stage recorded during year ending September 30, 1918, 21.5 feet at 7 a. m. April 3 (discharge, 29,300 second-feet); minimum stage recorded, 3.08 feet at 6 p. m. August 30 (discharge, 920 second-feet).

1900-1918: Maximum stage recorded, 33.4 feet at 12 noon March 28, 1913 (approximate discharge by extension of rating curve, 57,300 second-feet); minimum 24-hour discharge, 288 second-feet, September 28, 1908.

Winter flow.—Stage-discharge relation seriously affected by ice, usually from December to March; records based on gage heights, current-meter measurements, observer's notes, and weather records.

Regulation.—Distribution of flow not seriously affected by the operation of any power plants above the station. Some storage has been developed on reservoirs in the headwaters.

Accuracy.—Several rating curves have been used, each fairly well defined for the period covered; results considered good. Precipitation records at St. Johnsbury, Vt., are given for purposes of comparison only, as it is not probable that records at St. Johnsbury indicate fairly the average rainfall in the upper Connecticut basin; the precipitation is probably considerably greater at places of higher altitude than along the river valley.

Monthly discharge of Connecticut River at Fairlee, Vt., (Orford, N.H.), for the two-year period ending Sept. 30, 1918.

[Drainage area, 3,100 square miles]

Month	Discharge in second-feet				Run-off (depth in inches on drainage area)	Precipitation in inches at St. Johnsbury, Vt.
	Maximum	Minimum	Mean	Per square mile		
1916–17						
October	5,920	2,150	3,310	1.07	1.23	1.65
November	7,810	2,500	3,600	1.16	1.29	2.94
December	17,800	2,450	6,190	2.00	2.31	1.80
January	3,650	2,100	2,700	.871	1.00	2.84
February	2,450	1,550	1,850	.597	.62	1.21
March	26,500	1,700	5,200	1.68	1.94	2.13
April	29,500	7,320	16,900	5.45	6.08	2.29
May	15,900	7,180	10,500	3.39	3.91	1.82
June	27,100	5,200	12,000	3.87	4.32	6.13
July	9,620	2,030	3,900	1.26	1.45	3.10
August	9,700	1,950	4,870	1.57	1.81	7.86
September	5,640	1,720	2,670	.861	.96	1.61
The year	29,500	1,550	6,150	1.98	26.92	35.38
1917–18						
October	21,800	2,350	5,190	1.67	1.92	5.63
November	24,300	2,020	5,910	1.91	2.13	1.04
December	2,670	1,530	2,040	.658	.76	1.77
January	1,720	1,300	1,500	.484	.56	2.46
February	4,590	1,150	1,840	.593	.62	2.85
March	12,500	2,090	4,730	1.53	1.76	1.78
April	28,900	10,200	15,500	5.00	5.58	1.48
May	20,500	2,650	9,860	3.18	3.67	3.32
June	5,700	2,030	3,910	1.26	1.41	3.05
July	4,430	1,430	2,500	.806	.93	1.82
August	7,420	980	2,340	.755	.87	3.62
September	17,200	1,350	4,620	1.49	1.66	6.30
The year	28,900	980	5,000	1.61	21.87	35.12

PASSUMPSIC RIVER AT PIERCE'S MILLS, NEAR ST. JOHNSBURY, VT.

Location.—At suspension footbridge just below Pierce's mills, about 2 miles below mouth of Sheldon Branch, 4 miles above mouth of Moose River, and 5 miles north of St. Johnsbury, Caledonia County.

Drainage area.—237 square miles.

Records available.—May 26, 1909, to September 30, 1918.

Gage.—Staff, in two sections; low-water section a vertical staff bolted to ledge just above bridge; high-water section an inclined staff bolted to ledge below bridge; read by W. I. Cox and Clinton G. Taylor.

Discharge measurements.— Made from footbridge or by wading below the bridge.

Channel and control.—Channel composed of ledge rock partly covered with gravel and alluvial deposits. At high stages the control is probably at the dam near Centervale.

Extremes of discharge.—Maximum stage recorded during year ending September 30, 1918, water over top of gage on mornings of October 31 and April 3 (approximate discharge, 2,900 second-feet); minimum stage recorded, 1.2 feet at 6 p. m. August 25 and 5.30 p. m. August 31 (discharge, 71 second-feet).

1909-1918: Maximum stage recorded, 14.8 feet during the night of March 27, 1913, determined by leveling from flood marks (discharge not computed); minimum stage recorded, zero flow at various times due to water being held back by mills.

Ice.—River freezes over at the control, causing the stage-discharge relation to be seriously affected; ice jams occasionally form below the gage.

Regulation.—There is a small diurnal fluctuation caused by the operation of Pierce's mills*, just above the station, and by other mills farther upstream. The effect of the diurnal fluctuation was studied by means of a portable automatic gage from August 16 to September 11, 1914. Although the results obtained from twice-a-day gage heights were found to be occasionally in error for individual days, yet the values of mean discharge for the period as determined from twice-a-day gage heights and from hourly values were found to be identical.

Accuracy.—The stage-discharge relation has remained practically permanent, except when affected by ice. Rating curve fairly well defined below 2,000 second-feet. Gage read to quarter-tenths twice daily, except from December 20 to March 24 when it was read once a day. Daily discharge ascertained by applying rating table to mean daily gage heights. Results good.

---

*Pierce's mills not in operation during the summer of 1918.

Discharge measurements of Passumpsic River at Pierce's Mills, near St. Johnsbury, Vt., during the two-year period ending Sept. 30, 1918

Date	Made by—	Gage height	Discharge	Date	Made by—	Gage height	Discharge
1917		*Feet*	*Sec. ft.*	1918		*Feet*	*Sec. ft.*
Jan. 2	Hardin Thweatt	a2.38	213	Jan. 28	M. R. Stackpole	a2.60	134
Mar. 7	H. H. Khachadoorian	a2.45	153	Mar. 4	....do	a3.00	223
Apr. 4	....do	4.55	1,310	28	....do	a2.87	407
July 20	M. R. Stackpole	2.48	467	Apr. 10	....do	4.09	1,050
20	Hardin Thweatt	2.47	447	10	....do	4.10	1,050
Oct. 10	M. R. Stackpole	2.40	396	July 23	C. H. Pierce	1.54	138
Dec. 14	....do	a2.30	210				

aStage-discharge relation affected by ice.

Daily discharge, in second-feet, of Passumpsic River at Pierce's Mills, near St. Johnsbury, Vt., for the years ending Sept. 30, 1917-18

Date	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1916–17												
1	640	260	1,560	220	240	300	1,660	1,040	360	870	202	405
2	375	600	790	215	240	240	2,000	1,220	360	1,000	176	530
3	290	420	560	220	240	240	1,760	1,120	360	600	164	460
4	245	360	420	220	240	220	1,260	870	560	420	176	320
5	216	290	640	230	220	190	1,170	830	375	390	176	275
6	202	260	870	290	190	190	1,220	790	340	390	152	305
7	189	260	600	260	210	170	1,560	750	290	360	152	360
8	189	230	500	260	210	170	1,120	710	420	260	152	260
9	202	245	460	230	220	170	870	710	670	260	460	245
10	216	290	560	230	220	160	670	710	500	245	670	290
11	189	260	460	220	220	150	600	870	830	216	320	260
12	189	230	420	230	210	160	600	950	2,000	340	230	230
13	189	230	320	230	210	150	600	830	1,040	320	176	230
14	320	202	300	230	190	140	640	710	640	275	164	202
15	260	260	290	520	190	150	600	750	560	750	189	202
16	216	260	300	400	190	150	640	600	500	360	530	202
17	230	260	290	340	190	140	600	560	530	275	1,560	202
18	230	245	280	240	190	140	1,000	530	1,660	245	1,510	176
19	202	245	290	240	190	130	1,360	530	790	275	670	176
20	750	260	260	240	200	100	1,880	670	560	360	830	216
21	870	230	250	240	190	120	2,480	600	530	560	1,080	360
22	530	245	260	240	190	120	2,480	500	460	530	600	245
23	360	245	260	240	190	140	2,480	560	390	420	420	202
24	290	1,560	260	240	190	220	1,710	640	530	290	420	202
25	275	910	230	240	190	520	1,080	560	500	230	1,000	202
26	275	500	260	240	190	830	1,080	530	390	202	500	164
27	260	460	250	220	280	1,510	950	460	360	176	360	164
28	245	460	200	220	440	3,140	950	405	305	152	305	176
29	230	305	230	220	....	2,240	1,040	390	500	152	530	176
30	216	1,660	230	240	....	1,310	1,120	500	1,360	216	560	320
31	216	....	230	240	....	950	....	405	....	305	500	
1917–18												
1	390	1,080	260	110	130	460	2,120	1,310	640	245	176	202
2	340	790	230	110	130	360	2,600	1,260	640	500	130	420
3	260	670	245	110	130	260	2,480	1,000	390	275	130	202
4	460	600	260	90	130	215	1,460	790	290	230	122	105
5	640	530	230	90	130	215	1,080	750	260	202	202	117
6	830	530	230	100	130	200	1,040	600	245	189	360	120
7	530	530	260	110	130	200	1,260	640	870	152	202	202
8	375	420	260	120	110	200	1,410	560	600	275	202	126
9	530	420	200	150	130	175	1,760	530	420	460	1,000	120
10	375	460	260	120	130	175	1,120	500	340	375	460	126
11	320	420	260	110	130	175	1,040	1,000	290	260	260	109
12	290	460	275	130	130	190	950	640	500	245	216	93
13	600	360	290	130	140	200	1,080	870	830	340	189	152
14	405	290	215	130	150	230	830	2,000	530	390	176	216
15	390	290	200	130	175	230	1,220	1,120	390	360	230	164
16	600	360	215	130	175	230	1,510	790	360	260	164	130
17	405	340	230	130	175	260	1,360	560	320	320	130	164
18	340	305	230	130	150	320	1,260	460	360	360	120	360
19	305	460	200	130	150	320	870	420	290	230	122	460
20	670	360	230	130	175	390	790	390	245	176	111	275
21	500	320	165	130	230	420	830	390	216	164	105	910
22	375	320	200	110	175	500	1,310	375	530	152	101	500
23	320	405	175	130	175	530	1,410	600	640	141	109	305
24	320	390	215	130	150	560	1,260	460	560	130	91	530
25	790	230	175	150	150	600	870	340	375	141	82	530
26	500	275	175	130	260	600	790	305	290	126	78	910
27	390	305	150	130	670	530	830	530	230	122	82	1,880
28	670	260	150	130	600	670	870	600	176	117	91	910
29	530	230	150	150	....	750	1,120	420	245	120	89	560
30	1,510	260	140	150	....	950	1,360	560	460	260	91	420
31	2,300	....	130	150	....	1,560	....	500	....	260	75	....

Monthly discharge of Passumpsic River at Pierce's Mills, near St. Johnsbury, Vt., for the two-year period ending Sept. 30, 1918

[Drainage area, 237 square miles.]

Month	Discharge in second-feet				Run-off (depth in inches on drainage area)
	Maximum	Minimum	Mean	Per square mile	
1916–17					
October	870	189	300	1.27	1.46
November	1,660	202	408	1.72	1.92
December	1,560	200	414	1.75	2.02
January	520	215	253	1.07	1.23
February	440	190	217	.916	.95
March	3,140	100	470	1.98	2.28
April	2,480	600	1,240	5.23	5.84
May	1,220	390	687	2.90	3.34
June	2,000	290	622	2.62	2.92
July	1,000	152	369	1.56	1.80
August	1,560	152	482	2.03	2.34
September	530	164	259	1.09	1.22
The year	3,140	100	477	2.01	27.32
1917–18					
October	2,300	260	557	2.35	2.71
November	1,080	230	422	1.78	1.99
December	290	130	213	.899	1.04
January	150	90	125	.527	.61
February	670	110	187	.790	.82
March	1,560	175	409	1.73	1.99
April	2,600	790	1,260	5.32	5.94
May	2,000	305	686	2.89	3.33
June	870	176	418	1.76	1.96
July	500	117	244	1.03	1.19
August	1,000	75	184	.776	.89
September	1,880	93	377	1.59	1.77
The year	2,600	75	424	1.79	24.24

WHITE RIVER AT WEST HARTFORD, VT.

Location.—About 500 feet above the highway bridge in the village of West Hartford, Windsor County, and 7 miles above the mouth of the river.

Drainage area.—687 square miles

Records available.—June 9, 1915, to September 30, 1918.

Gage.—Inclined staff on left bank; read by F. P. Morse.

Discharge measurements.—Made from cable 1,500 feet below the gage or by wading.

Channel and control.—Channel wide and of fairly uniform cross-section at measuring section; covered with gravel and small boulders. Control formed by rock ledge 100 feet below the gage, and well defined.

Extremes of discharge.—Maximum stage recorded during year ending September 30, 1918, 10.0 feet at 5 p. m. October 30 (approximate discharge by extension of rating curve, 10,000 second-feet); minimum stage recorded, 2.22 feet at 7 p. m. August 4 (approximate discharge by extension of rating curve, 35 second-feet).

1915-1918: Maximum stage recorded, 11.1 feet at 6 p. m. June 12, 1917 (approximate discharge by extension of rating curve, 11,700 second-feet); minimum stage recorded, 2.33 feet at 6 a. m. August 29, 1916 (approximate discharge by extension of rating curve, 26 second-feet). The highwater of March 27, 1913, reached a stage of 18.9 feet, as determined from reference point on scale platform opposite gage (discharge not determined).

Ice.—River freezes over at the gage; control usually remains partly open, although ice on the rocks and along the shore affects the stage-discharge relation.

Regulation.—There are several power plants on the main stream and tributaries above the station, the nearest being that of the Vermont Copper Co. at Sharon; when this plant is in operation it causes some diurnal fluctuation in discharge at low stages. The effect of power plants farther upstream is eliminated by the large amount of pondage at Sharon.

Accuracy.—Stage-discharge relation practically permanent except when affected by ice. Rating curve fairly well defined between 150 and 5,000 second-feet. Staff gage read to quarter-tenths twice daily. Daily discharge ascertained by applying rating table to mean daily gage heights. Results good.

Discharge measurements of White River at West Hartford, Vt., during the two-year period ending Sept. 30, 1918

Date	Made by—	Gage height	Dis-charge	Date	Made by—	Gage height	Dis-charge
1916		*Feet*	*Sec. ft.*	1917		*Feet*	*Sec. ft.*
Oct. 27	Hardin Thweatt.....	3.37	286	Dec. 19	M. R. Stackpole.....	[a]3.83	428
1917				1918			
Jan. 4	Hardin Thweatt.....	[a]4.08	405	Jan. 22	M. R. Stackpole.....	[a]4.15	303
Feb. 15	H. H. Khachadoorian	[a]3.92	296	Feb. 27	....do.............	[a]7.98	2,820
Mar. 14	....do.............	[a]4.46	455	Mar. 21	....do.............	[a]7.36	2,430
Apr. 3	C. H. Pierce........	7.21	4,440	Apr. 13	....do.............	6.31	2,780
5	H. H. Khachadoorian	7.10	4,110	July 28	H. W. Fear.........	2.96	165
July 17	M. R. Stackpole.....	3.90	550	Aug. 27	J. W. Moulton......	3.00	171

[a] Stage-discharge relation affected by ice.

Daily discharge, in second-feet, of White River at West Hartford, Vt., for the years ending Sept. 30, 1917-18

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept
1916–17												
1	465	260	2,880	340	460	1,050	3,930	2,610	1,570	1,120	240	280
2	440	300	1,770	440	440	740	5,270	2,880	1,470	1,040	205	320
3	240	300	1,290	360	360	640	4,410	3,170	1,290	855	166	365
4	222	280	1,120	390	360	580	4,250	2,610	1,380	690	166	320
5	222	280	1,380	390	440	520	4,090	2,350	1,120	660	205	260
6	188	320	1,670	600	390	440	3,930	2,610	1,040	630	172	205
7	134	260	1,570	960	340	420	4,350	2,480	855	490	205	222
8	74	280	1,570	680	360	440	3,620	2,350	1,290	465	172	205
9	163	260	1,040	540	390	440	3,020	2,230	2,480	440	205	240
10	169	280	1,200	520	340	460	2,480	2,230	1,770	390	820	166
11	169	365	960	460	300	390	2,110	2,110	2,880	390	465	188
12	123	300	925	280	360	520	2,230	2,110	10100	342	280	205
13	151	300	855	300	340	440	1,990	2,110	5,270	690	300	205
14	169	320	570	490	340	390	2,110	1,880	3,320	570	240	205
15	188	300	540	1,550	320	420	1,990	1,770	2,610	570	205	205
16	205	260	520	1,550	320	420	1,990	1,670	2,110	720	320	139
17	240	205	420	1,200	300	440	1,880	1,470	2,230	515	440	145
18	188	240	340	1,100	300	520	2,610	1,380	2,610	465	570	157
19	240	320	360	960	340	440	3,020	1,380	1,770	465	465	166
20	960	342	320	820	340	340	5,630	1,770	1,470	660	365	142
21	960	342	280	680	360	420	7,500	1,880	1,290	465	320	166
22	785	280	320	720	340	460	7,500	1,380	1,120	342	320	188
23	515	222	360	680	320	520	7,500	1,470	855	465	280	188
24	415	3,320	340	580	340	740	5,090	1,990	1,120	342	300	166
25	342	2,110	340	580	320	2,000	3,770	1,670	1,290	280	570	160
26	320	925	300	520	360	4,200	3,320	1,770	1,040	280	365	157
27	280	785	240	460	390	6,730	3,020	1,670	960	280	320	72
28	280	855	320	440	1,400	8,700	2,740	1,470	855	280	260	154
29	260	785	280	540	....	4,200	2,480	1,380	820	240	205	157
30	260	3,020	280	440	....	3,300	2,610	2,350	1,770	260	280	160
31	260	....	260	460	....	2,900	....	1,880	....	240	320	....
1917–18												
1	170	2,570	320	370	190	1,200	6,300	3,300	718	472	158	67
2	215	1,860	370	230	175	880	9,580	2,700	785	530	146	230
3	200	1,550	400	210	160	1,050	8,740	2,200	590	420	138	188
4	200	1,200	280	190	230	820	5,500	1,860	445	325	64	230
5	248	1,040	420	190	190	880	4,000	1,650	345	305	124	165
6	620	1,040	370	130	200	880	3,300	1,460	305	305	138	162
7	530	925	280	190	175	820	3,470	1,550	472	325	200	160
8	395	855	280	190	230	750	3,640	1,460	925	325	175	155
9	345	785	210	200	175	680	5,700	1,370	560	345	590	146
10	345	750	320	230	150	620	4,540	1,280	652	325	820	170
11	285	685	320	250	175	500	3,470	2,200	685	370	395	165
12	248	652	320	280	260	560	2,990	1,550	652	370	370	200
13	445	620	340	200	230	620	2,700	1,860	1,040	500	370	175
14	620	590	340	175	260	750	2,990	3,470	820	785	345	175
15	445	590	370	320	750	620	3,300	2,320	685	685	285	132
16	560	445	320	370	680	500	3,640	1,750	472	472	325	126
17	590	530	370	320	820	680	4,000	1,550	472	395	265	170
18	445	500	420	210	620	820	4,730	1,370	445	395	248	148
19	370	472	370	280	400	880	3,300	1,120	395	370	200	500
20	345	420	400	260	620	1,100	2,840	1,200	370	285	200	472
21	620	445	400	280	2,400	2,200	2,840	1,200	345	285	200	750
22	530	530	420	280	1,100	2,800	5,110	1,120	420	248	188	820
23	420	560	420	280	920	4,700	3,640	1,040	820	200	155	445
24	370	590	370	280	880	3,500	3,640	925	890	200	248	445
25	1,280	395	420	280	880	3,300	2,700	960	750	175	200	500
26	1,200	400	440	320	880	3,300	2,320	1,080	590	215	175	1,300
27	855	370	300	210	3,000	2,800	2,200	890	445	215	175	6,570
28	1,200	250	260	210	1,650	1,650	2,200	1,120	395	188	175	2,200
29	1,280	190	370	250	....	2,200	2,320	1,040	445	144	152	1,300
30	4,730	280	250	250	....	5,900	2,990	750	445	130	118	1,172
31	5,900	....	280	260	....	4,540	....	652	....	160	67	....

Monthly discharge of White River at West Hartford, Vt., for the two-year period ending Sept. 30, 1918

[Drainage area, 687 square miles.]

Month	Discharge in second-feet				Run-off (depth in inches on drainage area)
	Maximum	Minimum	Mean	Per square mile	
1916–17					
October	960	74	311	0.453	0.52
November	3,320	205	614	.894	1.00
December	2,880	240	794	1.16	1.34
January	1,550	280	646	.940	1.08
February	1,400	300	392	.571	.59
March	8,700	340	1,430	2.08	2.40
April	7,500	1,880	3,680	5.36	5.98
May	3,170	1,380	2,000	2.91	3.36
June	10,100	820	1,990	2.90	3.24
July	1,120	240	505	.735	.85
August	820	166	314	.457	.53
September	365	72	197	.287	.32
The year	10,100	72	1,070	1.56	21.21
1917–18					
October	5,900	170	839	1.22	1.41
November	2,570	190	736	1.07	1.19
December	440	210	347	.505	.58
January	370	130	248	.361	.42
February	3,000	150	657	.956	1.00
March	5,900	500	1,690	2.46	2.84
April	9,580	2,200	3,960	5.76	6.43
May	3,470	652	1,550	2.26	2.61
June	1,040	305	579	.843	.94
July	785	130	338	.492	.57
August	820	64	239	.348	.40
September	6,500	67	649	.945	1.05
The year	9,580	64	983	1.43	19.44

INDEX

Volume XI, 1917-1918