THE GEOLOGY AND PETROGRAPHY
OF A PORTION OF MARLBORO AND BRATTLEBORO
TOWNSHIPS, WINDHAM COUNTY, VERMONT.

BY

Elizabeth Putnam Richards

A thesis in Geology submitted to the
department of Geology and Geography
in partial fulfillment of the require-
ments for the Degree of Master of Arts.

OBERLIN COLLEGE
JUNE, 1931.
APPROVED BY:

1. C.Y. Rogers, Chairman Faculty Committee on Graduate Study.

2. Fred Foreman, Acting Chairman of the Department of Geology and Geography.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>1. Location and Area</td>
<td>1</td>
</tr>
<tr>
<td>2. Statement of the Problem and Methods</td>
<td>1</td>
</tr>
<tr>
<td>3. Acknowledgments</td>
<td>1</td>
</tr>
<tr>
<td>4. General Geology</td>
<td>1II</td>
</tr>
<tr>
<td>Physiography</td>
<td></td>
</tr>
<tr>
<td>1. Drainage</td>
<td>1</td>
</tr>
<tr>
<td>2. Special Topographic Forms</td>
<td>3</td>
</tr>
<tr>
<td>3. Moraines</td>
<td>6</td>
</tr>
<tr>
<td>4. Fluvio-glacial Deposits</td>
<td>7</td>
</tr>
<tr>
<td>5. Valleys</td>
<td>9</td>
</tr>
<tr>
<td>6. Alluvial Deposits</td>
<td>12</td>
</tr>
<tr>
<td>Descriptive Geology</td>
<td>14</td>
</tr>
<tr>
<td>1. Sedimentary Rocks</td>
<td></td>
</tr>
<tr>
<td>a. Barrows Schist</td>
<td>14</td>
</tr>
<tr>
<td>b. Central Mountain Schist</td>
<td>17</td>
</tr>
<tr>
<td>c. Marlboro Formation</td>
<td>21</td>
</tr>
<tr>
<td>1. Black Phyllite or &quot;Efflorescent&quot; Schist</td>
<td>21</td>
</tr>
<tr>
<td>2. The Quartzitic Phase</td>
<td>23</td>
</tr>
<tr>
<td>3. The Micaceous Phase</td>
<td>24</td>
</tr>
<tr>
<td>4. The Hornblendic Phase</td>
<td>25</td>
</tr>
<tr>
<td>5. The Chloritic Phase</td>
<td>26</td>
</tr>
<tr>
<td>6. The Porphyroblastc Phase</td>
<td>27</td>
</tr>
<tr>
<td>7. Summary of the Marlboro Formation</td>
<td>32</td>
</tr>
<tr>
<td>d. The Ames Hill Schist</td>
<td>34</td>
</tr>
<tr>
<td>e. The Round Mountain Schist</td>
<td>41</td>
</tr>
<tr>
<td>f. The Wheatstone Schist</td>
<td>44</td>
</tr>
<tr>
<td>2. Igneous Rocks</td>
<td>48</td>
</tr>
<tr>
<td>a. Acidic Intrusions</td>
<td>48</td>
</tr>
<tr>
<td>b. Basic Intrusions</td>
<td>50</td>
</tr>
<tr>
<td>Age and Correlation</td>
<td>52</td>
</tr>
<tr>
<td>Structure</td>
<td>60</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>62</td>
</tr>
<tr>
<td>Metamorphic History</td>
<td>67</td>
</tr>
<tr>
<td>Physiographic History</td>
<td>80</td>
</tr>
<tr>
<td>Economic Values</td>
<td>90</td>
</tr>
<tr>
<td>Bibliography</td>
<td>94</td>
</tr>
<tr>
<td>Plate</td>
<td>Description</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Plate I</td>
<td>Map of Southern Vermont and Northwestern Massachusetts</td>
</tr>
<tr>
<td>Plate II</td>
<td>Geologic Map and Location Grid of the Area</td>
</tr>
<tr>
<td>Plate III</td>
<td>Lakes of the Area</td>
</tr>
<tr>
<td>Plate IV</td>
<td>Unconsolidated Glacial Deposits</td>
</tr>
<tr>
<td>Plate V</td>
<td>Topographic Features</td>
</tr>
<tr>
<td>Plate VI</td>
<td>Topographic Features</td>
</tr>
<tr>
<td>Plate VII</td>
<td>Alluvial Deposits</td>
</tr>
<tr>
<td>Plate VIII</td>
<td>The Marlboro Formation</td>
</tr>
<tr>
<td>Plate IX</td>
<td>Whetstone Formation and Talc Deposit</td>
</tr>
<tr>
<td>Plate X</td>
<td>Quartz Dikes</td>
</tr>
<tr>
<td>Plate XI</td>
<td>Quartz Stringers Following, Cutting, and Buckling Schistosity</td>
</tr>
<tr>
<td>Plate XII</td>
<td>Correlation Table</td>
</tr>
<tr>
<td>Plate XIII</td>
<td>Geologic Cross-Section of the Area</td>
</tr>
<tr>
<td>Plate XIV</td>
<td>Minor Faults</td>
</tr>
</tbody>
</table>
Southern Vermont and Northwestern Massachusetts
INTRODUCTION

Location and Area. The territory covered in this report is a roughly rectangular area of about fifty square miles. It is situated partly in Marlboro and partly in Brattleboro township, in Windham county, southeastern Vermont. It runs from 42°50' to 42°55' north latitude and from 72°37' to 72°47' west longitude. Geologically the region is a part of the Green Mountains while physiographically the area is in the New England Upland section (1).

Statement of the Problem and Methods. The origin, history, and correlation of the country rock of the region is the particular problem with which this thesis is concerned. Some attention has been directed toward the physiographic problems and the economic resources of this section of Vermont.

During the summer of 1930, the Oberlin Geologic Survey spent seven weeks in Marlboro township, Vermont. Hand specimens of the various rock types were collected, and the field relations of the formations were studied. Following the return from the field, about a hundred thin sections made from hand specimens were examined with the petrographic microscope, and a qualitative chemical analysis was made of a few of the more important minerals. The aim of this thesis is to state and to interpret the results.

II.

obtained from these lines of investigation.

Acknowledgements. Thanks are due to Professor Hubbard for his selection of an area which has heretofore received little attention from geologists, and for his help during the time he remained with the field party. I am indebted to Dr. Foreman for his constant guidance and advice especially in connection with the research work, and to Prof. Mathews and Mr. Frost for their patient, careful, and constructive criticism of the manuscript. I am also under obligation to several friends for the use of their photographs.

General Geology. The rocks in this portion of Vermont are severely metamorphosed early Paleozoic strata which form a northeast to southwest trending monocline that dips steeply to the east and which is part of the east limb of the Green M't anticline. The truncated formations are intruded by numerous quartz stringers and by small pegmatites. In one spot in the western part of the area there is a small basic intrusion.

Following the deposition and consolidation of the sediments, considerable metamorphism of both the progressive and retrogressive types has occurred so that the rocks are largely coarse crystalline schists. Most of the metamorphism and the deformation of the strata to their present monoclinal position occurred during the profound diastrophism of the Appalachian Revolution.

The area was next subjected to a considerable period of erosion which reduced the topography to late maturity. A verti-
III.

cal uplift occurred at the close of the Cretaceous which tilted the old erosion level upward on the northwest and downward on the southeast. Further erosion in the old drainage channels resulted in deep, V-shaped valleys. Continental glaciation followed which rounded many of the hills and deposited thick beds of coarse drift on the lowlands. Post-glacial erosion is working in the old valleys, removing the drift and cutting along preglacial lines.
Drainage. The streams of the area are small but fairly numerous, and drainage lines on the whole are well defined since lakes are few and swampy areas but very local phenomena. The dendritic drainage pattern is generally independent of geologic structure and is especially well developed in the vicinity of the Augur Hole and in the eastern part of the region. In the neighborhood of Brattleboro the stream valleys are anywhere from 300-500 feet deep. The major stream valleys descend from an elevation of 1000 feet to the level of the Connecticut River, a drop of about 800 feet in five miles.

Most of the major valleys have glacial drift on their floors through which the streams have cut small V-shaped valleys that in some cases have reached bedrock. Where the streams are found flowing across the strié of the bedrock, small cascades and falls are frequent and seem to be largely due to the frequent variations in the character of the rock which result in the unequal weathering of the surface. Quartz lenses are especially effective in causing rapids as is also the porphyroblastic phase of the Marlboro formation. A stream in the Wickoppee Hill area flowing obliquely across the Ames Hill schist has a six foot fall due to the occurrence of a sandy limestone lens whose contact with the typical Ames Hill is a plane of weakness.
The effects of the country rock upon the course of the streams can be observed on Gulf Brook, the river flowing through Reid Hollow, and the brook flowing into the Augur Hole from the small lake at W-15.

The water of the streams under ordinary conditions is quite free from sediment. Where the streams flow on bedrock the reason for this absence of suspended material is that the supply is practically lacking, but where the streams flow in glacial drift, the water is also clear because the stream beds are now paved with boulders that cannot be carried by the streams rather than with fine material. The boulders of the streams are of two types; those of local origin derived from the local bedrock, and those foreign to the region which found their way to the rivers from the surrounding glacial drift. The finer material formerly associated with them has long since been carried away, and the boulders remain as a residual accumulation. Boulders from local quartz stringers and from the porphyroblastic lenses are especially striking types of local rock in the stream beds. The rivers seem to be lacking in lime for the water is exceedingly soft. This condition is to be expected since the rivers have their sources and courses in country rock whose lime content is almost negligible.

Since drainage lines on the whole are quite well established, it is not particularly surprising that only three lakes are found in the district. South Pond and North Pond apparently
Plate III

North Pond

South Pond
are the result of glacial drift which has interrupted the former drainage. That an earlier drainage of South Pond may have been to the north is suggested by the large deposit of drift directly to the north that stands between the pond and a fairly well defined tributary of Whetstone Brook. The present outlet of the pond is to the southwest and the stream which drains the lake describes a large semicircle in order to join the Connecticut River to the eastward. The small pond about two miles north of Brattleboro very curiously drains in two directions, east by way of Whetstone Brook, and west into the Augur Hole. All three lakes show the influence of surface ice by the boulder concentrates along their shores.

Swampy spots are rather frequent but small in the area. Their occasional location on hillsides (at u-16, and on the slope of Round Mountain at u-22) and their occurrence on high places (the ridge directly to the east of camp) suggest the disruptive effects of glaciation upon the normal drainage system of a maturely dissected region. Those which occur in valleys along streams are connected with the small flood-plains of the brooks, especially on Gulf Brook and on the creek north of camp. The area south of Wickopoe Hill is very swampy, and the lack of many outcrops in the area points to the presence of a large deposit of ground moraine.

Special Topographic Forms. While the geologic formations appear
to have had little influence upon the drainage pattern of the area, some of the hills seem to be due to the relative resistance of the rock strata of which they are composed. Of special interest in this connection is the row of hogback-like hills, namely, from northeast to southwest along the strike, Hill 1284, Round Mountain, Ginseng Hill, and Governors Mountain. Possibly Hill 1347 may be included. These hills occur along the strike of the slightly westward dipping, siliceous Whetstone formation and the hornblende Round Mountain schist. They are characterized by a gentle west slope and an abrupt east front. That they are true hogbacks seems unlikely because the west slopes do not coincide with the dip of the formations. They may be in some way connected with the resistance of the formations to erosion because the gradational contact of the Whetstone with the Ames Hill passes near the cols directly to the west of the summits of these hills, and because the very resistant Round Mountain schist is confined to the belt in which these hills occur. Possibly some structural break may have had some influence upon the formation of this conspicuous row of hills. A marked change from a NE-SW to a SE-NW strike in the locality of Hill 1347 and a local fault breccia zone such as the one at the east base of Ginseng Hill suggest that some movement has taken place in this vicinity. The crumpled nature of the siliceous bedrock of Hill 1906 and the presence of the igneous
talc deposit at its base also indicates a structural influence.

The fact that the Augur Hole valley has drift on its floor shows that it is in the main a pre-glacial form, but it has been profoundly altered by the action of the glacier. The trend of the valley is roughly that of the formations and it drains to the north-east. The valley has steep walls about five hundred feet high near its head and increasing to about eight hundred feet in depth northward due to the gradient of the valley floor. These walls are too steep for the natural slope angle of the Central Mountain schist for great quantities of slumping rock were observed on both the east and west sides of the valley near the headwall. The valley floor, in contrast with those of the majority of the streams, is broad and fairly level except where modified locally by drift forms. The present stream is not in harmony with the size of the valley features. The steep walls and broad floor give the valley a U-shaped form which distinguishes it from all others in the area. The shape of the valley along with the presence of lateral and recessional moraines makes it plain that the valley was once occupied by a lobe of the continental ice sheet. The exact mode of formation of the cirque-like headwall is still somewhat of a mystery for it seems to indicate the plucking action of a small valley glacier while the fact that the concave sides of the loop moraines face northward shows without doubt that the ice must have come from and receded to the north.
Moraines. Ground moraine is scattered over the area quite generally so that the bouldery soil is evident on every hand. It is more abundant in the stream valleys than on the highlands. Where post-glacial streams have dissected it, it forms the river banks as in the case of the stream south of Hill 1906, of Gulf Brook below its waterfalls, and of the stream that flows eastward to the south of Wickopee Hill.

In the highland areas the ground moraine was noted on the northerly slopes of the hills. Especially was this true of Hill 1720, of Ames Hill, and of the hill south of Marlboro Ridge, but this occurrence was not particularly noticeable over the area as a whole. It indicates deposition due to the pressure and consequent melting of the advancing ice, and the result of the deposition was to lessen the gradient at these places and to cover the bedrock with debris. Near the road about half a mile west of Marlboro, bedrock under about two feet of glacial till has been uncovered by excavations for road material. The rock was worn smooth by the glacier, so that both the early corrosive action and the later depositional work of the glacier can be observed at the same spot.

The morainic material is heterogeneous both as to size and nature of the constituents. The drift is commonly coarse and sandy, and the boulders vary in size from several inches to perhaps four or five feet in diameter. The larger boulders were more frequent on or near the surface of the drift than below the surface
Plate IV

A typical drift deposit in Marlboro township

Photo by E. Frank

Fluvio-glacial gravel deposit near Hill 1284

Photo by F. Foreman

Fluvio-glacial sand in New Hampshire

Photo by J. Maharry
as exposed in the few open cuts that were available for study. The boulders appear to be working to the surface by the removal of the fine material from around them and by frost action. The pebbles are sub-angular to rounded and consist of a wide assortment of specimens both local and foreign. The foreign boulders are schists, igneous rocks, and a peculiar type of sugary, pinkish quartzite. This pink quartzite was absent from the formations of the area.

Recessional moraines were recognized only in the Augur Hole where the valley lay at some time during the latter stages of glaciation. Four recessional moraines, concave to the northward and about sixty feet high were mapped between the head of the valley and the confluence of Adams Brook.

Lateral moraines are also confined to the Augur Hole valley, and there are several which can be traced as rather poorly defined terraces. On the west side of the valley near its head there is a poorly developed lateral moraine about fifty feet wide, while at the mouth of Gulf Brook the lateral terrace is about fifty feet high and has partially choked the lower end of the tributary valley with glacial till.

**Fluvio-glacial Deposits.** The fluvio-glacial deposits are decidedly local in occurrence, and can only be recognized where cuts have exposed cross-sections of the deposits. On the south slope of Hill
1284 there is a mound which is being excavated for road gravel. The pit exhibits unconsolidated fluvio-glacial material ranging from sand to coarse and sub-angular glacial boulders perhaps a foot or more in diameter. Examination of a pile of these boulders taken from the road gravel showed it to be a heterogeneous collection of rocks mostly foreign to the area. This deposit is stratified with two sets of low angle dip slopes, and is overlain unconformably by a couple of feet of unstratified glacial till. The presence of glacial boulders within the deposit and the till cap show that the stratified gravel is fluvio-glacial. The exact nature of the deposit is somewhat obscure for it is hill, and therefore resembles a kame while the cross-bedding, since it is quite well defined is strongly indicative of an alluvial cone deposit.

The Augur Hole also contains a crossbedded, stratified deposit which probably is fluvio-glacial. Very near the confluence of the nameless brook flowing from the small lake at W-15 near camp and Marlboro Branch Creek the undercutting of the latter stream has exposed a 100 foot bank of unconsolidated, fine micaceous sand, coarser sand, and a greenish clay capped by about four feet of coarse, roughly stratified drift material. Most of the drift in the valley shows the effects of a slight reworking by the waters of the pro-glacial lake which at one time occupied the valley, because, although there is much typical moraine topog-
raphy on the valley floor, few of the drift forms, show the customary coarse composition. Fine, micaceous and sandy soils with some clays are the rule, and in these fine soils there are occasional large, sub-angular boulders which indicate that the water-laid deposits are not independent of glaciation.

Valleys. All the valleys in the region with the exception of the Augur Hole are to be classed as erosional. They are surprisingly independent of the structure in their development for the main drainage lines run from west to east across the strike at almost right angles showing thereby that the Connecticut River drainage has been the most important factor in their development. Since the valleys are almost without exception pre-glacial, it follows that they have had considerable of a pre-glacial career because they are several hundred feet deep and the post-glacial erosion in them has not exceeded fifty feet of actual cutting and is ordinarily under ten feet. There is a possibility that the pre-glacial erosion can be divided into at least two cycles since the upper portions of many of the hills have gentler slopes than the lower parts. This change in slope angle can be seen especially well from the Augur Hole by looking up the valley of Gulf Brook. The pre-glacial V-shaped valley of the stream does not extend to the tops of the bordering hills, but instead the valley slopes become less steep at about the 1600 foot level so that the tops of
Unglaciated valley west of the Augur Hole.
(A young valley in a maturely dissected upland)

Hummocky Moraine Topography in the Augur Hole

View up the valley of Gulf Brook from the Augur Hole.

Photos by G. Croll.
the hills show a much maturer topography that the present valleys indicate. The presence of the ridges running west from 1284, Round Mountain, Ginseng Hill, and Governors Mountain which connect these hills with the upland areas to the west seems strongly indicative of a general, late mature surface on the upper portions of the area. Aside from occasional unreliable panorama views from high spots such as the ridge north of Reid Hollow, 1284, and 1906 which reveal an apparent upland of late mature topography, there is little evidence beyond that cited above for two pre-glacial periods of erosion.

An examination of the maps of the immediate surroundings of the area has some interesting results, since the change in the erosion cycle is much more obvious, especially in the northwestern portions. In the vicinity of West Dover there is a fairly well developed change in slope at about the 2300 foot level; around East Dover no slope change is obvious; at South Newfane the 1500 foot level seems significant; and around West Dummerston the 1400 foot level marks the slope change approximately. A survey which runs through the area shows that at Wilmington the 1900 foot level, near Marlboro about the 1650 foot level, and at West Brattleboro the 1200 foot level are all critical with respect to a change in slope. No erosion level is present in the vicinity of Hogback Mt. A west to east examination in the south shows that the 1750 foot level at Whitingham which is
Plate VI

Looking south from Hill 1347. (left to right)
Hill 1084, Round Mt, Ginseng Hill, Governor's Mt.

Looking southeast to the Connecticut from Round Mountain

View eastward toward the Connecticut from 1284

Photos by J. Mahony and C. Crowe
very poorly developed, a possible 1700 foot level at West Halifax, the 1400 foot level near Reid Hollow, and the 1200 foot level in the neighborhood of Guilford are prominent. Since the levels which mark the change in slope tilt downward to the southeast in compliance with the present topographic development, it seems logical to conclude that the uplift which separated the two erosion cycles of pre-glacial time was either purely vertical or else it tipped the old surface slightly downward to the southeast. The fact that the erosion levels of the Berkshire Hills a short distance to the southward in Massachusetts have an eastward dip supports but by no means proves the suggestion that the Vermont area ever experienced an eastward tilt. That these successively lower altitudes of change in slope do not mark a series of smaller uplifts with their respective short erosion cycles seems to be upheld by the fact that in almost every instance the slope below the critical line is constant to the valley bottom. The lack of a critical level in the vicinity of East Halifax and Hogback Mountain might be explained by the fact that the Whites Hill-Cooper Hill-Higley Hill-Hogback Mountain range is the divide area between the Deerfield and the direct Connecticut drainage and has consequently been considerably dissected by many small streams.

The altitudes of the hilltops for the most part show a definite decrease as the valley of the Connecticut is approach-
ed so that the influence of this river upon the erosion history of the area as a whole is emphasized further.

Alluvial Deposits. In the Augur Hole, and on the east flank of the Higley Hill-Hogback Mountain ridge, the best developed alluvial fans were found. The physiography of the area is somewhat obscured by the forest growth, and such small topographic forms as these might be very easily overlooked. In all places where they were recognized, the fans were under cultivation, covered with grass, or with but a very sparse tree growth. Two fans were mapped on the east slope of Hogback Mountain. The fans in the Augur Hole are frequent but small, being thirty by fifty feet in dimension. The small size of the fans is due mainly to the protection from sediments offered on the west by the tributary valley and on the east by the slope toward the Connecticut and away from the valley drainage.

The biggest fans mapped were in the valley to the west of the Augur Hole, while the fan at the mouth of Adams Brook (U-8) is the most prominent of all. It is about two-thirds of a mile long and half a mile wide, and it narrows the Augur Hole valley considerably at the point where it occurs. It is responsible for the right angle confluence of Marlboro Branch creek and the stream flowing from the valley to the west which was
Plate VII

Alluvial fans east of Hogback Mt. from Hill 1906

Alluvial fan in the Augur Hole
obliged to seek a channel a bit to the south of its previous course. At present Adams Brook is flowing in a small valley which is forty or fifty feet deep on the eastern edge of the fan. The other fans in the valley have an area that can be measured in hundreds of square feet, and they seem best developed on the western flank of the valley since the source of material is much more extensive here than on the eastern side where the Augur Hole drainage spoils the collecting ground. The fans force the main valley stream over to the eastern side of the valley and in some places the stream is cutting into the fans.
DESCRIPTIVE GEOLOGY.

Sedimentary Rocks

Upon the basis of lithologic character, the sedimentary rocks of the district are divided into six major formations. These formations will be described in chronological order beginning with the oldest. Since their age and correlation are a special problem in themselves, the discussion of this aspect of the formations will be given a separate place.

BARROW'S SCHIST.

The Barrows Schist lies directly to the west of the Central Mountain and is separated from the latter formation by an exceedingly irregular contact which is probably gradational since in travelling westward toward the contact, one encounters a thin hornblende strip about a foot or so wide which is finely plicated within the siliceous schist of the Central Mountain formation. Another band of Central Mountain schist about 100 feet wide must be crossed before the main outcrops of the Barrows are reached. Since the western contact of the formation was not located, it is impossible to calculate its thickness, but, judging from the width of the formation so far examined, it is safe to say that the Barrows is at least 2000 feet thick. Strikes taken within the formation vary from N 41° E. just west of 1906 to N 22° W. in the southern part of the
area. Dips ranged from perpendicular at the talc deposit north of West Marlboro to 45 degrees S.E. in the same locality, and the formation consequently must have been somewhat disturbed, partly from the intrusion of the steatite.

The Barrows Schist consists chiefly of an amphibolite of high specific gravity whose color is characteristically dark gray to black. A fresh fractured surface at right angles to the cleavage of the rock shows a fine banding due to alternate layers of hornblende and granular quartz. Some phases of the formation have a dull, slaty lustre while others, because the splendid lustre on the cleavage faces of hornblende crystals oriented in the cleavage plane, sparkle brilliantly on surfaces parallel to the rock parting. The amphibolite phase is associated with a siliceous, micaceous, garnetiferous schist somewhat resembling the efflorescent schist phase of the Marlboro formation.

A study of a thin section under the microscope reveals that the rock is roughly 75% hornblende and that the long hornblende crystals are oriented in the plane of schistosity but that they show little or no linear orientation. The hornblende is more prevalent in certain layers which frequently have a matrix of finely divided pale green, non-pleochroic material. There is about 4% of epidote present which occurs primarily in the horn-
blendic layers and which therefore is to be considered as derived from the hornblende (1). About 20% of quartz is present in layers consisting of large, clear, re-crystallized (2) grains. There are occasional large, lens shaped grains of quartz which have many minute inclusions and which show anomalous extinction. Small quantities of magnetite, chlorite, and biotite are present, the magnetite in laths among the hornblende crystals which appear to be pseudomorphic after the hornblende, while the chlorite is large altered from biotite. The biotite, in turn, was found including and cutting hornblende crystals obliquely to the schistosity. Being also more or less interstitial in occurrence and irregular in outline, it is considered to be later than the hornblende.

The rock has a well developed slaty cleavage parallel to the planes of the quartzite and hornblendic layers, and some specimens show one well developed system of joints almost at right angles to the cleavage plane, but on the whole the rock has a massive appearance. Quartz lenses and pegmatites are common. A steatite-amphibolite deposit occurs in the formation to the north of West Marlboro.

(1) Hornblende as source of epidote. Van Hise, Metamorphism, P. 331.

(2) Leith and Mead, Metamorphic Geology, P. 125. (Criteria).
THE CENTRAL MOUNTAIN SCHIST.

The Central Mountain Schist outcrops in a band about two and a half miles wide at the northern end of the area, and about three fourths of a mile wide at the southern end. This means that the thickness is from 11,500 to 4,000 feet. The change in width of outcrop is due to the irregular contact with the Barrows Schist which swings suddenly eastward in the central part of the region. The irregular contact is partly because of stream erosion to the south. Both contacts are gradational, that with the Marlboro is characterized by a decrease in silica content to the eastward which takes place in about 400 feet. The strikes taken in the area vary all the way from N. 45° E to N. 2° W but the one most commonly encountered was N. 15° E. The dips are steep to the east although one vertical and one steep west dip were recorded. Considerable structural disturbance has taken place in the neighborhood of 1906 where the talc-amphibolite intrusion has apparently had some part in the local contortions.

The Central Mountain Schist is a light buff to pearly, quartzitic, micaceous schist. The mineral composition and hence the physical characteristics vary considerably from place to place, but the rock which is considered typical of the formation consists principally of layers of granular, impure quartz sepa-
rated by thin, silvery, micaceous layers which are responsible for the schistosity. A surface cut parallel to the schistosity is pearly, shining silvery gray, often with flecks or bars of chlorite mica which produce green blotches. The mica is almost un-noticable in a fracture at right angles to the schistosity and cleavage. Quite frequently the rock changes lithologically across the strike so that there are some quartzitic phases and some which are more micaceous. In the region around 1906, the Central Mountain formation is largely composed of quartz. Some phases contain garnets which usually bend the schistosity but occasionally seem to cut it.

Under the microscope the predominant mineral in the typical Central Mountain formation is quartz which may constitute about 95% of the total mineral composition and which is present in a mosaic of subangular to rounded recrystallized grains of various sizes. The extinction in some of the smaller grains is not sharp, and a previous state of granulation of the quartz is thereby suggested from which recrystallization has not been quite complete. Muscovite is the next most prominent mineral but it can hardly be considered more important than an accessory. It occurs as colorless needles which are usually in among the quartz grains. These grains are occasionally found cutting
across two adjacent grains of quartz, other muscovite crystals in which case the crystal cut is badly crumpled, or across two concentric growths of biotite. It therefore seems likely that there are two ages of muscovite or that the muscovite is among the later formed minerals. The remaining accessory minerals are biotite which occasionally exhibits two successive stages of concentric growth, acid plagioclase, probably albite, which generally shows signs of strain such as minute shearing and strain extinction; rutile in aggregates of stubby, striated, and sometimes elbow-twinned crystals, and chlorite in irregular grains occasionally with pleochroic haloes. In one instance epidote was found as an inclusion in quartz.

There are some thin hornblende phases in the Central Mountain Schist that, under the microscope, show a considerable amount of hornblende which has many inclusions of quartz, small needles and flecks of zoisite, some epidote and a little iron oxide. The quartz is still essential and is but partially re-crystallized since the smaller grains show anomalous extinction. Garnets about .42-1.68 mm. in diameter are abundant. They contain numerous bright inclusions which are more plentiful near their centers and which appear to be zoisite needles and flecks of epidote. The garnets are occasionally included in the hornblende. Feldspar, probably orthoclase, judging from the index
of refraction, the lack of twinning planes and the position of the cleavage planes, is a more prominent accessory than in the typical Central Mountain. Zoisite is present in the ground mass and is scattered among the quartz grains. Rutile is also present and in some instances in greater abundance than in the typical schist. Chlorite, sericite, muscovite, biotite altering to chlorite and iron oxide are the remaining minor constituents.

The rock is massive, tough, hard to break, and usually weathers to a grayish exterior with garnets weathering out giving the surface a bumpy appearance. Some phases weather to a porous, chalky white, flaky mass stained with limonite. Jointing seems to be rather poorly developed, and joint planes are infrequent. Some phases of the rock are finely plicated, while in the 1906 area the folds are measurable in feet. Bedding planes are locally definite.
MARLBORO FORMATION

The Marlboro formation outcrops in a band about two to two and a quarter miles wide. Strikes correspond roughly to those which are general in the area, and dips are steep toward the east. The western contact with the Central Mountain is gradational, and the eastern contact with the Ames Hill is sharp. The formation is probably about 10,000 feet thick.

The Marlboro formation is an aggregate of thin-bedded strata of exceedingly variable composition and lithologic character. The rocks differ conspicuously both along and across the strike, but they may be roughly grouped into several characteristic types.

The Black Phyllite or "Efflorescent" Schist. The black phyllite is a black to grayish, fine cleavable rock with a submetallic lustre on an unweathered surface and with a rusty brown exterior due to limonite stain on scales of mica. In dry weather the cleavage cracks are frequently lined with a white to yellowish efflorescence, probably of a sulphate of iron, from which the rock derives its name. Most of the northern phases weather to a tan or buff, micaceous, scaly, fine cleavable rock; while the southern portions usually remain dark because of the larger graphite content.
A petrographic examination of a very dense, black phase showed considerable amounts of graphite disseminated through the rock and included in the quartz, garnet, and biotite which are present as accessories. The other essential mineral constitutes the major part of the micaceous looking ground mass, and is considerably obscured by the graphite, but appears to be a fine crystalline muscovite whose sub-parallel orientation is responsible for schistosity of the rock. Recrystallized quartz is the most plentiful accessory, and is free from all signs of strain. The biotite occurs in crystals which generally show anomalous extinction while some grains whose cleavage is parallel to the schistosity show some shearing. In some cases peripheral growths of secondary biotite are present. Occasional garnets are present which spread the schistosity without showing any anomalous extinction, and which appear to have an outer rim of garnet nearly free of graphitic inclusions in marked contrast to the interior of the crystal. The garnets are surrounded by lenses of granular quartz which show a little anomalous extinction. A little pyrite occurs in small lenses which generally align themselves with the schistosity and occasionally cut it at low angles.

The rock is generally quite massive because it is usual-
ly lacking in well developed joints. It has, however, a fairly good, fine cleavage developed parallel to the schistosity. This cleavage is especially noticeable in the weathered portions and accounts for the breaking of the rock into papery fragments.

The black phyllite is common in the southern and central parts of the area although it has been found as far north as the hills just south of Wickoppee Hill. It almost always has sharp, well defined contacts, and it has been found in outcrops at least a hundred feet wide measured across the strike.

The quartzitic Phase. The quartzitic phase of the Marlboro formation is a tough, massive, resistant rock whose predominant color on both fresh and weathered surfaces is a light gray. It is finely granular, compact, and impure. The impurities give it a black speckled, often roughly banded appearance. Where the impurities are micaceous, as frequently is the case, a cleavage is developed parallel to and within the thin micaceous layers. If the mica content is exceedingly low, the rock breaks into irregular chunks. Some phases, located in the southern part of the area seem to have a higher iron content because weathered portions show a limonitic stain, and in one case the stain can be traced directly to disseminated pyrite.

A microscope study of this phase shows the rock to be
composed of at least 80% of quartz, recrystallized in a mosaic of angular to rounded grains and exhibiting a very rough dimensional orientation parallel to the poorly developed schistosity. Some grains show undulatory extinction which indicates that the quartz is not wholly recrystallized. Muscovite is present in lamina between the quartz layers, and its dimensional orientation develops the schistosity. It sometimes comprises as much as 15% of the rock. Biotite altering to chlorite, pistacite, garnet, magnetite, pyrite, and plagioclase are the remaining minor accessories. Of these the biotite is the most important and is usually in irregular flecks or in laths parallel to the schistosity. In some specimens plagioclase becomes an essential mineral and occurs in large crystals. Much granulated quartz and some mylonitic patches are present locally.

The quartzitic phase occurs chiefly in the northern part of the area, but some thin beds are encountered in the south at U-30 and T-39. Since the rock is tough and compact, it resists erosive agents, and is occasionally found causing cascades on brooks. Its contact with adjoining phases, including the porphyroblastic, are sharp, and the rock does not appear to be contorted except in cases where the mica content is high.

The Micaceous Phase. The micaceous phase is typically a silvery to pearly, papery, fine cleavable schist with a cream to pale green
color. The most abundant mineral is quartz, but thin layers of muscovite which are interlaminated with the granular quartz give the rock its schistosity. Some phases are somewhat plicated, and one specimen from V-18 shows a beautifully developed strain-slip cleavage. Some of this phase contains calcite, but mostly the micaceous phases appears to lack lime. This phase of the Marlboro formation seems to be found most in the central and eastern portions of the formation. The beds are never very extensive either across or along the strike.

The Hornblende Phase. This phase of the Marlboro formation is not uniform and the representatives are grouped together only because they have a development of hornblende in common. The hornblende crystals either show no particular orientation, or they are oriented with respect to parallel planes along which the rock has a tendency to cleave. Granular quartz, in the hand specimens appears to be the only other significant constituent, although one specimen effervesced in cold hydrochloric acid thereby showing the presence of some calcite.

A petrographic study of the hornblende schist at the contact with the Ames Hill shows the presence of about 70% of hornblende in a mat of acicular crystals oriented with respect to the plane of schistosity. Quartz constitutes about 20% of
the rock and is partly in large, clear, recrystallized grains while the rest is in small, uniform, strained grains. About 5% of calcite is present in small, granulated veinlets parallel to the schistosity. Ilmenite (?) occurs as laths in among the hornblende crystals. Chlorite and zoisite are the remaining accessories.

The hornblende phase is especially characteristic of the eastern contact of the formation in the localities where the sharp contact could be examined, it is the type of rock found adjacent to the Ames Hill. The bands are never more than about five feet wide, and are usually no more than two or three feet wide.

The Chloritic Phase. The chloritic phase, a tough massive rock, is usually so coarsely crystalline as to have almost a granitic texture. The main body of the rock is largely composed of granular quartz which, in the more weathered portions, is stained with limonite. Large and frequent aggregates of chlorite or green hornblende give the rock a mottled green and white appearance, and some specimens, especially from the finer grained portions show considerable development of pyrite porphyroblasts in cubes often as large as a quarter of an inch on a side. Some beds are garnetiferous.

Under the microscope some varieties of this phase con-
The efflorescent schist of the Marlboro Formation.

The porphyroblastic phase of the Marlboro Formation

Photos by J. Maharry
sist primarily of quartz, biotite and chlorite. The quartz comprises anywhere from 20 to 45% of the total rock and is partially recrystallized. As much as 25% of the rock may be clear brown biotite which occurs scattered through the rock mostly in irregular flecks. The chlorite has been in most cases altered from biotite with which it is sometimes closely interlaminated. In other instances the chlorite has numerous inclusions of ilmenite or magnetite which suggest the same source (1). Chlorite is also present as pseudomorphs after garnet. Small amounts of muscovite occur which in some instances cut chlorite-biotite aggregates and which are therefore probably later. Disseminated and porphyroblastic pyrite are present in some varieties.

The rock resembles the porphyroblastic phase in its massiveness and its resistance under the hammer. Jointing is well developed in some places so that the rock has a chunky appearance, without any slaty cleavage. This phase seems to occur largely in conjunction with the black phyllite and the porphyroblastic phase in the center of the formation. It has been found on 1731, at X-20 and on the ridge south of Marlboro.

The Porphyroblastic Phase. There are some strong reasons for thinking that this phase of the Marlboro may be of igneous origin, but because it occurs only in this formation, it will be describ-

ed in this connection. Because of its persistent occurrence throughout the formation and its peculiar lithologic character, this phase is the most noticeable rock of the Marlboro.

It is a dense, massive, dark green-gray to black, even grained, phaneritic rock which contains light colored porphyroblasts in quantities that vary from place to place. These porphyroblasts are sometimes granular and sometimes composed of a single crystal. They are usually lens shaped or rounded, but occasionally where the porphyroblasts are comparatively few, they are rectangular. The edges of the porphyroblasts are interlocked with the crystalline matrix.

The more schistose varieties with many porphyroblasts occasionally have a poorly developed cleavage, and in these varieties the porphyroblasts show tabular schistosity. On faces at right angles to the schistosity the porphyroblasts appear as stringers and thin lenses, while sections parallel to the schistosity show the porphyroblasts as irregular discs. The more schistose portions without many blasts, on the other hand, develop in the matrix a mineral alignment parallel to the schistosity. Where few porphyroblasts occur, there is no alignment with the schistosity, and the porphyroblasts are scattered at random.

The irregular distribution of the blasts within the hornblende matrix is peculiar. Frequently a single lens of the rock will show within a small space portions completely free from the porphyroblasts, those which contain them in moderation, and
those in which the porphyroblasts are very numerous. These sudden changes in composition generally take place across the strike but are not abrupt enough to make the assigning of their origin to bedding planes a justifiable hypothesis. Where the contact between phases having few or no porphyroblasts and those in which they are abundant is sharp, the line of demarcation is often so irregular as to suggest an igneous rather than a sedimentary origin.

Under the microscope the matrix of the porphyroblastic phase seems to consist principally of a mat of intergrown hornblende needles whose extinction angles in the vertical zone in some instances suggest the basaltic type since it is around 11 degrees. Grains of quartz are sparingly present. Some grains are recrystallized while others show signs of strain. Ilmenite altering to rutile is disseminated through some specimens and rounded stubby crystals of zircon are also found. The whole ground mass, especially the hornblende, exhibits a mashed and mangled appearance.

The porphyroblasts in the rock consist in some instances of rectangular crystal of feldspar containing considerable amounts of zoisite needles which are usually scattered irregularly through the porphyroblasts but, in some cases, show a roughly parallel alignment. Other porphyroblasts are composed of fine grains of
quartz, both granulated and recrystallized, zoisite and epidote, minute hornblende needles, grains of acid plagioclase, probably albite, and small amounts of chlorite and sericite. Cross-sections of several of the porphyroblasts show that zoisite with some epidote is the most important mineral. Zoisite constitutes anywhere from 35 to 80% of the porphyroblasts and is usually in the upper part of this range. Quartz commonly constitutes from 19 to 21% and has been reckoned as high as 35%, but such a high percentage is uncommon especially since it is almost entirely lacking from the blasts which still consist of single crystals of feldspar. When feldspar was found in the granular porphyroblasts, it formed as high as 23% of the composition. About 2% of hornblende seem to be a fairly constant factor, and the biotite content may reach as much as 5%.

It seems likely that in the porphyroblastic phase we have a porphyritic development of basic feldspar which is suggested by the large quantities of zoisite with its calcium, and which accounts for the rectangular shape of many of the porphyroblasts. The feldspar is now in various stages of saussuritization (1). The blasts which still consist of a single crystal of feldspar, and often show strain extinction are yet in an early stage, while those now in smaller grains have advanced further, toward complete saussuritization, undoubtedly with the aid of mechanical deformation.

The porphyroblastic phase has almost every possible mode of occurrence. It is largely found in lenses anywhere from two inches to perhaps twenty-five feet wide and has sharp contacts with the adjoining rock. The schistosity of the surrounding rock usually bends around the lenses. However, it is also known to occur in irregular rounded masses. This occurrence suggests an igneous rather than a sedimentary origin but the outcrops never show the branching characteristic of dikes. This porphyroblastic phase is also found in zigzag streaks apparently failing to comply with either schistosity or bedding. Slightly gradational contacts with the phyllite were found at E-25 the porphyroblastic phase passes into the phyllite by becoming more schistose near the contact.

The porphyroblastic phase is generally massive with a well developed system of rectangular jointing. This jointing is conspicuous in contrast to the shaly parting of the enclosing weathered phyllite. It is tough and breaks with an irregular fracture. In the area studied no evidence of contact metamorphism between the prophyroblastic and the enclosing rock was found which could not be attributed to the intruded quartz and pegmatite dikes.

There are strong arguments for either igneous or sedimentary origin of the rock.
IGNEOUS : SEDIMENTARY

1. The presence of sausurite (1).
2. The low % of quartz. (15%).
3. Its irregular modes of occurrence difficult to explain by processes of sedimentation.
4. Its occurrence in lenses cutting or spreading the schistosity.
5. Apparent predominance of cataclastic deformation over recrystallization.
   The Round Mt. hornblende schist, on the other hand, shows more crystallization than granulation. This discrepancy could be explained if the porphyroblastic were intruded after the recrystallization of the country rock and before the last deformation.
6. Matted intergrowth of hornblende needles does not show recrystallization under conditions of rock flowage.

1. The occurrence only within the Marlboro formation.
2. The presence of sandy phases interstratified with the rock.
3. The alignment of the lenses with the bedding and schistosity of the region.
4. Lack of branching in the dikelike bodies.
5. The presence of rounded zircons while resemble the original clastic grains (3) present in other formations of known sedimentary origin.
6. Lack of unquestionable contact metamorphism. This is not a very strong argument. If the rock were igneous, the smallness of the bodies and their basic character would mean a lack of mineralizers.

Summary of the Marlboro Formation. From the foregoing rock descriptions, it has been shown that the Marlboro formation is extremely variable in lithologic character. It contains rocks which, except for their occurrence between the limits of well defined formations—the Central Mountain and the Ames Hill—and

(2) Bastin, E. S., Jour. Geol., Vol. 17, 1909, P. 449.
their association with each other, would not be classed as belonging to the same formation. This rough division of the formation into six rock types by no means includes all the rocks represented in the Marlboro, for there are many unique and intermediate phases which defy classification at this present time. There is a biotitic, siliceous phase with a gneissoid appearance, a slaty phase spangled with oval porphyroblasts of phlogopite or biotite, a siliceous phase which appears to be pebbly but which really contains a few large crystals of feldspar, and so on --- indefinitely.....

Bedding planes within the different phases, with the exception of the porphyroblastic are frequent and manifest themselves by giving the rock a banded appearance due to minor mineralogical changes. At W-18 these bands in two adjoining beds come together at an angle in a way suggestive of a local unconformity probably due to cross-bedding.
AMES HILL SCHIST

Ames Hill schist outcrops in a bed about one and a half to two miles wide with an average strike of N.20 E. The strata are practically all on end since the dips are all steep, generally not less than 65 degrees, and they have a fan-like arrangement. The western half dips slightly to the east while the eastern part maintains a steep, persistent west dip. The point where the dip is perpendicular was found to be slightly west of the center of the Ames Hill formation. The schist is about 5,500 feet thick, and is remarkably homogeneous in lithologic character both along and across the strike.

The western contact is largely concealed. At the one place where the contact was found, it was sharp, and the Ames Hill was typical to the contact. The contact was crossed in several localities, and at a spot where it was located within five feet, no gradation was found. The eastern boundary of the schists marked by about half a mile of micaceous siliceous rock which is gradational between the Ames Hill Schist and the Whetstone siliceous schist.

The typical Ames Hill schist is a slaty blue-gray to almost black rock with a submetallic lustre on its unweathered surface. It possessed a dense, compact, phyllitic matrix which exhibits on a surface parallel to the schistosity, a shining metallic appearance, but which, when broken across the schistosity shows a dull, sooty lustre. Numerous garnets from 1/16 to 1/4 inch in diameter
are distributed fairly evenly throughout the rock, and since they part the schistosity, they produce a knotty, irregular surface parallel to the schistosity and an augen structure to a perpendicular surface. Occasionally there are small lenses of mica whose cleavage is at right angles to the schistosity, and which like the garnets, also produce an augen structure. The rock has a high specific gravity, and the varieties which are least pli-cated and siliceous have a greasy feeling.

A microscope study of the Ames Hill schist shows the rock to be composed essentially of quartz and muscovite with much disseminated graphite in fine particles. There are fairly numerous garnet crystals, both with pseudo-idiomorphic and with irregular outlines, lenses of biotite, as well as minor amounts of biotite in irregular flecks of pyrite, and of magnetite or ilmenite. Limonite is present as a weathering stain along cracks in garnets and between quartz grains.

The quartz content is occasionally as high as 60% but is generally somewhat lower. It is ordinarily recrystallized in bands and lenses of clear, subangular, closely fitting grains that show no anomalous extinction, but in the more siliceous phases it occurs also in scattered grains in the main mass of the rock. The grains in the mosaic show no optical orientation, and do not in any way contribute to the schistosity of the rock because they have no dimensional alignment.

The schistosity is highly developed by a colorless mineral of high refractive index which occurs in small acicular grains.
The mineral is considerably obscured by the presence of the graphite, and is apparently muscovite. The muscovite is predominant in irregular bands that lie between the quartz aggregates, and the schistosity due to the muscovite bends around quartz, garnet, and biotite alike. The fine plications and the strain-slip cleavage of the schist are also developed in the muscovite.

The graphite is present pretty generally in very small particles which cloud unevenly the main body of the rock and which are found as inclusions in the quartz and garnet. It, therefore, existed in its present form before the garnet and quartz reached their present crystal form.

The garnets which comprise perhaps about 4% of the rock, and which chemical tests have shown to be of the andradite type with some isomorphous aluminum, are usually pseudo-idiomorphic crystals in a granular matrix of recrystallized quartz. They contain inclusions of quartz and an opaque mineral, probably magnetite, and while they exhibit no anomalous extinction whatever, they do show a radial type of fracture often accentuated by strains of limonite. Some of the crystals have ragged outlines, and are often surrounded by quantities of such accessories as graphite, pyrite, and limonite than those found adjacent to the fully developed crystals. Garnets spread the schistosity instead of cutting it.

Biotite of at least two ages is present, occasionally comprising as much as 30% of the mineral composition but ordinarily of no greater importance than the garnet. It occurs fre-
quentiy in lenses as long as 1/8 inch, which spread the schistosity. The cleavage of the biotite in this case is almost without exception at a low angle to the schistosity. Irregular crystals of biotite also occur intimately associated with recrystallized quartz. This quartz is closely interlocked with the periphery of the biotite crystals, and is also found developed along the cleavage plane within a crystal or cutting the cleavage of a biotite crystal that is strung out along the schistosity. Although no feathering out or bending(1) of the biotite crystals was observed, it seems rather apparent that the biotite is older than the recrystallization of the quartz, and that it is primary or depositional. The secondary biotite is found developed around the edges of the older biotite, often with the same optical and crystallographic orientation. It is a clearer, purer, and brighter brown than the earlier biotite. Some of the older biotite has inclusions of elongated particles of an opaque mineral, probably magnetite or ilmenite.

The Ames Hill Schist on the whole is rather massive but some portions of it have a fairly well developed system of almost parallel joints, perhaps two feet apart, at right angles to the direction of schistosity. Due to the reorientation of original lines of schistosity(2), the typical schist exhibits fine plications which are locally, so close as to produce almost a strain-slip cleavage. The plicated, contorted character of the rock seems to

(1) Leith, Rock Cleavage - P. 26
decrease toward the western contact and to be modified somewhat toward the eastern border by an increasing siliceous content which reduces the magnitude and sharpness of the plications. The rock weathers to a soft, papery, easily pulverized mass, especially where the quartz content is low. Bedding planes in the Ames Hill schist are more evident in the eastern portion of the formation. Sandy and limy phases are also noticeable here, and in some outcrops the rock has a definite banded appearance. On the whole, the trend of the bedding planes seems to conform with that of the schistosity although local variations in which the discrepancy was as great as twenty degrees were measured. Quartz, pegmatite stringers and lenses are common throughout the formation and are usually accompanied by characteristic chlorite, ilmenite and pyrite mineralization. The lenses are mostly contorted with the schistosity.

The eastern half of the formation is characterized by the intercalation of lenses of a very siliceous limestone ranging anywhere from about three inches to eight feet in thickness and from six to 200 feet in length. The limestone is a massive, brownish gray, compact looking rock. It is unjointed, very tough, and difficult to break with a hammer. It weathers peculiarly. Flecks of limonite disseminated throughout the unweathered rock may be seen without the aid of a hand lens. On a weathered surface the limonite becomes so dominant that the rock possesses a brown, porous, friable coating occasionally as thick as four
inches, which can be removed easily. A section across weathered and unweathered portions reveals a very sharp dividing line between the two. Weathering appears to be complete to the line of demarcation while within the weathered boundary the rock is perfectly fresh and unaltered. Hydrochloric acid tests show that it is the calcite cement which is removed by weathering. The unweathered rock is impervious, and weathering agents can work only upon the outer surface or can penetrate into the limestone only so far as the porous weathered portion will permit. This weathering process with the general lack of a joint system makes the rock quite resistant, and the lenses may be frequently seen standing above the enclosing rock in dark brown, smooth, sausage-like bosses. Where they outcrop on the hills, they weather into the enclosing rock because the porous cap is being removed more quickly by mechanical means.

Under the microscope the main body of the limestone is seen to be composed of calcite and quartz. The calcite is in small grains which seem to be mainly responsible for the fairly well developed banding the limestone exhibits on an exposed surface. The quartz is in recrystallized grains which are embedded in the calcite and which have a rough dimensional orientation parallel to the schistosity. The slide examined had more biotite than the lenses possess on the average. It occurs in irregular grains whose cleavage is generally parallel to the schistosity, and the grains are firmly interlocked with the quartz and calcite.
A few flecks of biotite cut the schistosity obliquely. Clinoc- chlore is present in small amounts interlaminated with the biotite and obviously altered from it. Graphite occurs as a cloud of disseminated particles throughout the entire rock, and limonite stain is quite noticeable in the slide.
THE ROUND MOUNTAIN SCHIST

The Round Mountain formation occurs as a large lens within the Whetstone formation. This lens occurs as far north as 1284 from whence it trends southwest with the general strike of the region. It outcrops in a band about half a mile wide which thins to a quarter mile wide on Ginseng Hill. Here it is accompanied by a small lenticular mass which may be either a second lens in the Whetstone formation or a mass faulted down from the main lens. The latter possibility is suggested by the presence of the fault zone in the lens. The formation dips steeply and in general toward the west although some south and northwest dips were found. Because of the variations in width of outcrop and in dip and strike, the thickness is difficult to calculate, but the formation can hardly be over 2500 feet thick at the maximum.

Due to alternating thin layers of quartz and crystallographically oriented hornblende needles the Round Mountain schist is characterized by a fine black and white striped appearance. It is the hornblende crystals, oriented with respect to a plane parallel to the schistosity, which gives the fresh fracture, especially one which is parallel to the schistosity, a flashing, splendent or adamantine sparkle, and to the rock as a whole, its black color. The lithology changes frequently across the strike, and very siliceous, magnetitic, or micaceous phases are common. In two localities, on Round Mountain and on 1284,
the quartz layers contain lens-like nodules of pistacite, which follow the schistosity.

It is not surprising to find under the microscope that quartz and hornblende are the two principal minerals and that sometimes one and sometimes the other is predominant. The amount of hornblende varies inversely with the amount of quartz present. Sometimes it is scarce enough to be classed as an accessory or plentiful enough to comprise about 80% of the rock. It is in the form of long, slender prismatic crystals, with tabular rather than linear orientation, which alternate with the quartz layers. Quartz comprises anywhere from 15-80% of the total mineral content, and usually occurs in a mosaic of clear, unstrained, recrystallized grains which carry numerous minute inclusions often arranged in parallel lines. In some phases, the schist has magnetite both as inclusions and as interlocking grains. The recrystallized grains are non-uniform in size and vary anywhere from .845-.974 mm. in diameter. There are some grains which show wavy extinction, and since quartz is one of the first minerals to show signs of strain (1), these strained grains are evidence that the quartz is not entirely recrystallized.

Pistacite is to be classed as an accessory except in one instance (at c-31) where it constituted about 30% of the rock mass. It is usually associated with the hornblendiic layers where the hornblende needles are embedded in it and is practically (1) Leith, Rock Cleavage - P. 32
absent from the quartzitic layers showing that it has altered from the hornblende (1). Magnetite is universally present as a minor accessory, and in some phases it comprises as much as 15% of the total mineral constitution of the schist. It is more plentiful in the hornblendic layers where it occurs in small laths parallel to the schistosity, but it is also present in the quartzose layers. It occurs among and within the grains of quartz and hornblende. Sericite is present in minute quantities with the epidote and as dust on quartz grains. A peculiar nodule in a quartz layer was found to contain non-uniform grains of recrystallized quartz, pistacite, hornblende, sericite, and zoisite.

The schist is generally quite massive, but in some localities one system of joint planes is developed at an angle to the schistosity. Some quartz stringers have apparently followed these lines of weakness. On the top of Round Mountain a siliceous phase has three well developed joint systems, one parallel to the schistosity, and the others perpendicular to the plane of the schistosity so that the rock may be broken into fairly well defined diamond-shaped fragments. Rock contains, superimposed upon the schistosity, abundant small plications, and some drag folds, occasionally with well defined apexes, but mostly of the small open fold type. At the foot of Ginseng Hill there occurs a minor fault zone accompanied by slicken-sides and vein ultramylonite enclosing fragments of the schist. Quartz stringers and lenses are common in the formation.

The Whetstone schist lies directly east of the Ames Hill schist, and the contact between the two formations is gradational for perhaps half a mile across the strike. The Whetstone schist maintains the general northeast to southwest strike of the region, and it contains the lens of Round Mountain schist. Its total thickness is unknown for it extends beyond the limits of the area studied. Including the Round Mountain lens, it is known to outcrop in a band about two miles wide. By taking account of the steep west dip, it has been calculated to be at least 6,500 feet thick.

The Whetstone schist is a massive, highly siliceous, gray to tan rock with a moderately well developed coarse schistosity carried by thin micaceous layers and interlaminated with the granular quartz. Surfaces cut perpendicular to the schistosity exhibit a dull, almost earthy lustre while surfaces running parallel to the schistosity have a brownish, splendent gleam due to the micaceous scales. Garnets are frequently present in the rock. They are hardly more than 1/8 inch in diameter, and are largely confined to the micaceous layers where they usually spread the schistosity. Garnets are likely to be found in the rock around quartz dikes. The rock is extremely variable. Some phases are massive and sandy with flecks of mica while others have a low quartz content resulting in a platy appearance because of the predominance of mica. Flications are often highly developed.
The microscope reveals the dominant mineral of the formation is quartz which is mostly in non-uniform recrystallized grains. Undulatory extinction in some small grains indicates recrystallization is not quite complete, since strain after recrystallization should cause anomalous properties in the majority of the large grains. Some recrystallized quartz shows a tendency toward dimensional parallelism in accord with the schistosity, and this mineral constitutes anywhere from 80 to 90% of the rock. Biotite, the second most important mineral, composes anywhere from 10 to 15% of the rock and is present in brown, intensely pleochroic, acicular laths. These laths maintain a fairly strict parallelism either in straight lines or in faint plications which are poorly developed. The schistose property of the rock is obviously imparted by the biotite. The largest of the biotite laths frequently show a splendidly developed feathering out(1) of the cleavage laminae and an occasional stringing out of a single crystal along the schistosity. The crystals contain numerous radio-active inclusions so that pleochroic haloes from .01445 -.0153 mm. in diameter are common. Some of the biotite is altering to chlorite which, in several cases, possess pleochroic haloes that are .01190 mm. in diameter or somewhat smaller than those in the biotite.

The garnet is present in extremely porous looking crystals, usually with a rather ragged outline, which contain many inclusions of recrystallized quartz and some muscovite, and (1) Leith, - Rock Cleavage - P. 36.
Plate IX

Bedding planes in the Whetstone Formation at t-12.

Steatite-Amphibolite Deposit at F-17

Photos by J. Moharry and R. Rockwood.
which exhibit no signs of strain. In some instances, the garnets have partially altered to a fibrous material which appears to be mainly a mixture of sericite and fibrous chlorite, and which is pseudomorphic after the garnet. The muscovite, present in small quantities, has irregular outlines, cleavage perpendicular to the schistosity, and inclusions of biotite and quartz oriented with the schistosity. Magnetite occurs in laths in biotite, as rounded inclusions in muscovite, and as interstitial grains throughout the rock. A small amount of ilmenite often partially altered to rutile, occurs in laths. Sericite is present as a fine dust on grains of quartz. Zircon or rutile crystals occur as rounded prismatic crystals and are probably primary elastic grains. Some slides show the presence of minor amounts of disseminated graphite, and masses of finely comminuted material which, in one instance, was isotropic suggesting a cataclastic history previous to recrystallisation.

Conspicuous locally in the Whetstone formation are bedding planes that are often somewhat highly contorted. These bedding planes in general conform to the schistosity, but in some localities, notably in the neighborhood of 1347, discrepancies between the two become considerable and in one case reached an angle as high as 90 degrees (t-13). This variation is exceptional. Due to the weathering of ferruginous bands and the resistance of the more siliceous beds, the bedding planes occasionally give the rock a corrugated appearance.
The rock is characterized by the intercalation of the limestone lenses that are common in the eastern part of the Ames Hill schist. Joint systems are not well developed, but the more sandy phases often exhibit a fairly good jointing system which occasionally cut the frequent quartz stringers in the formation showing that the jointing is subsequent to these igneous intrusions. The rock is generally tough, and it weathers to a rough, gray exterior.
49.

IGNEOUS ROCKS

A. Acidic Intrusions

Lenses and stringers of quartz are common in all the formations of the area, and may be divided roughly into two types, those composed of massive, milky to transparent quartz, and those which consist of granular quartz.

The massive quartz usually occurs in lenses anywhere from one or two inches wide and a foot long, to six feet wide and about fifty feet long. These lenses are generally parallel to the general strike of the region, and they spread the schistosity of the country rock. Occasionally they are found cutting straight across the schistosity, and sometimes those lenses which cut the schistosity are plicated. Contact metamorphism may or may not be present. Where it occurs, it usually consists of a development of a higher mica content than is present in the typical country rock. Sometimes contact metamorphism produces an abnormal development of garnet or hornblende in the country rock, and occasionally local pyritization is present.

The granular type of quartz always occurs in thin stringers, usually less than an inch wide. They are seldom accompanied by contact metamorphism. When the stringers follow the schistosity, they are highly plicated with it, and are likely to be strongly contorted if they cut the
Quartz dike in the Marlboro at Y-17

Quartz stringer folded with the schistosity

Quartz dike cutting schistosity in the Marlboro

Quartz dike deformed with schistosity
schistosity at a high angle. Occasionally the thin strings which cut the schistosity are closely plicated in a way suggesting that they existed previous to the development of the schistosity. Mineralization is less common along these thin strings than along the larger lenses.

Several dikes were observed which seem to have served as competent (1) layers during the time of schist folding. Plications are locally developed around them while the lenses themselves generally follow the major lines of schistosity with little deformation other than a slight bending or pinching. This particular feature of the quartz dikes shows that they were present before the Appalachian Revolution and during the time of folding. The presence of the stress mineral cyanite in association with the quartz vein near Round Mountain, the recrystallized state of the quartz in the slides, examined under the microscope, the lack of comb structure, and the fractured state of many of the quartz lenses, all show that the lenses themselves have suffered some metamorphism.

The fact that the quartz veins are frequently found cutting each other shows that some are younger than others. Since there was no marked difference in the type of quartz dikes found in this relation. The simpler explanation is to regard them as successive intrusions of essentially the same age. The dikes are sometimes found along parallel lines which appear to be joint planes, and at other times they are cut by joint planes.

(1) Willis, - Geologic Structures - P. 247 - (Criteria)
Plates XI

In the Central Mt. at S-19 (Drawing 2 ft long)

In the Central Mt. at T-12 (Drawing 3 ft long)

In the Round Mountain at v-18 (Drawing 5 ft long)

Quartz Stringers Following, Cutting, and Buckling Schistosity.
Pegmatites are common in the area. They vary in composition from those essentially consisting of plagioclase with minor amounts of pyrrhotite, to those which, in addition to feldspar, are rich in quartz, blotchy chlorite masses, biotite, actinolite, ilmenite, magnetite, and tourmaline, with a few large rutile crystals sometimes half an inch long. The dikes are seldom more than three inches wide and ten feet long. The presence of chlorite (1), and of broken tourmaline crystals with quartz between the broken pieces, show that the pegmatites have been subject to some metamorphic changes; but the presence of well developed non-granulated feldspar crystals shows that the metamorphism has not been intense.(2)

B. Basic Intrusions.

Just to the south of 1906 there occurs a small oval outcrop of amphibolite perhaps 75 feet in length. On two sides the amphibolite grades into talc schist. The amphibolite is dense, tough, very heavy, grayish green rock characterized by a mat of intergrowing, finely acicular needles of tremolite which, under the microscope, appear to be embedded in a matrix of chlorite and accompanied by considerable disseminated pyrite and pyrrhotite. A little muscovite is also present. Toward the borders the amphibolite becomes more talcose and contains rhombohedra of ankerite. These rhombohedra weather away leaving a residuum of powdery limonite which emphasizes the pock-marked appearance of the rock. At the borders the tremolite has been almost entirely replaced by pseudomorphs of talc.

(1) Tyrell, - Principles of Petrology. - Pp. 310-311.
(2) Leith, - Rock Cleavage - P. 37. Feldspar granulates under intense metamorphism.
Fibrous serpentine and talc, irregular aggregates of ankerite, and stains of limonite occur also in the rock.

Another igneous intrusion occurs just outside the area in the Barrows formation. It is somewhat larger, and appears to have been quarried at one time. Because of the smallness of the deposit and the impurity of the talc, the quarry has been abandoned for some time and fair-sized trees are now standing in the pit.

There are some peculiar, thin, green stringers which occur at random through the Marlboro formation, and to some extent, in the Central Mountain schist. In several instances they appear to cut the fine quartz strings, and therefore they may be very small basic intrusions. If the porphyroblastic phase of the Marlboro is igneous in origin, it would properly fall under this heading.
### Correlation Table

<table>
<thead>
<tr>
<th>Eastern Vermont (Richardson)</th>
<th>Southeastern Vermont (Oberlin Geologic Survey)</th>
<th>Western Massachusetts (Emerson)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Randolph Phyllite and Waits River Limestone</td>
<td>Whetstone Formation Round Mountain Schist Ames Hill Schist</td>
<td>Conway Schist Goshen Schist</td>
</tr>
<tr>
<td>Missiquoi Group Bethel Schist</td>
<td>Marlboro Formation Central Mountain Formation Barrows Formation</td>
<td>Hawley Schist Savoy Schist Chester Amphibolite</td>
</tr>
</tbody>
</table>
AGE AND CORRELATION

It should be stated at the outset, that, since no fossils were found in any of the formations, the age of the strata could not be determined from evidence within the region studied, although an attempt was made to ascertain the age by means of pleochroic haloes (1). Correlations with the formations, whose age is fairly well established, are the only means of determining the age of the formations in question. This correlation can be done on a lithologic basis and by the aid of the relative positions of the beds.

Since the Ames Hill schist possesses the most persistent lithologic character, this formation has been used in attempting the correlation. Perry (2), working in the townships of Bridgewater and Plymouth about fifty miles to the north of the area covered by the present study, found the Randolph phyllite and the Waits River limestone, named by Richardson in 1924. The description of this formation seems remarkably like that of the Ames Hill schist.

"The phyllite is a dark, gray, strongly foliated, graphitic looking mica schist which parts readily into irregular fragments parallel to the imperfect schistosity. In addition to the essential quartz, mica, and dark coloring matter, the most abundant accessory is garnet, which often makes up more than a third of the volume of the rock. The garnet crystals are from one to two millimeters in cross-section and are evenly distributed through the phyllite. The mica laminae curve about the garnets and cause the uneven "fish scale" appearance along a plane of parting. Occasional biotite crystals are present, but are not sufficiently abundant to be characteristic of the formation. Pyrite is present

as small scattered cubes often much weathered to limonite(1).

The Waits River limestone, interstratified with the Randolph phyllite, is described as, "a uniformly slate gray massive rock with no fixed lines of parting. The essential components are calcite and quartz, both recrystallized from their original form, and black carbonaceous coloring matter evenly distributed through the rock. Sericite is present as scattered shreds but in insufficient amount to produce schistose parting. Quartz grains are so abundant in some parts of the formation as to make a quartzite rather than a limestone, but calcite is consistently present.... "The limestone weathers readily to a porous, seal brown rock on exposed surfaces, and is unique in appearance among the other rocks of the area." (1).

According to Perry, the Waits River limestone is more prominent in the eastern part of the formation than in the western (2), and this relation seems to hold in the Marlboro region since the limestone does not become noticeable until the eastern part of the Ames Hill is approached. Since the limestone is found in the Whetstone schist, and since the latter formation is distinguished from the former largely by a gradual increase in silica content, the Whetstone can be included in the Randolph phyllite-Waits River limestone formation.

In speaking of the western contact of the Randolph phyllite, Perry says, "The exact contact of the Randolph phyllite and the underlying formation was not observed at any locality, but was determined within fifteen feet at one point, and no marked change in lithology was evident in the phyllite near the contact (3)." This condition resembles that at the western contact of the Ames Hill schist. If the Ames Hill can

(2) Perry, - Op. Cit. P. 36 - (3)IBID - P. 35
be correlated with the Randolph phyllite, the Ames Hill schist, according to Perry (1) and Richardson (2), would be the lowest Ordovician in southeastern Vermont. The Randolph phyllite along with the Waits River limestone to the north of Marlboro and as near as Reading and Cavendish has yielded graptolites certainly of Ordovician, and most probably of Beekmantown age. The Irasburg conglomerate found in the northern part of the state at the base of the Ordovician is absent near Marlboro and in Plymouth, Bridgewater, Reading, Cavendish, and Chester townships (3) to the north. If the Ames Hill schist corresponds to the Randolph phyllite, then the latter formation does not disappear permanently to the south of Chester as Richardson (4) believes, especially since the formation continues into Massachusetts.

The Missisquoi formation of Richardson and Perry, directly underlies the Randolph phyllite and should correspond to the Marlboro formation; but because of the variations in lithology in the Marlboro, definite correlation is difficult. Perry's descriptions of the formation includes garnetiferous mica schists, micaceous quartzites, carbonaceous mica schists, and chlorite schists, and countless variations within these.

(1) Perry - Ibid - P. 35
(3) Ibid., - P. 230.
types (1) and Richardson's (2) description is similarly complex. By their very complexity, these descriptions suggest the Marlboro formation, but it is not safe to reach a conclusion without hand specimens.

Richardson's Bethel schist, judging from his outline of its general path through Vermont to the Massachusetts state line (3), should cut across the western part of the area in about the position occupied by the Central Mountain formation. His megascopic description of the Bethel schist does not seem particularly applicable to the Central Mountain formation. Perry's petrographic description if the same formation found in Bridgewater and Plymouth townships does have characteristics in common with the Central Mountain formation.

"Between the quartz laminae are layers of the micaceous minerals, chlorite and muscovite. The latter mostly in the form of sericite, occurs as an intimate mixture of tiny shreds with occasional patches of light green, clear chlorite up to one half millimeter in diameter and laths of muscovite of the same order of magnitude. The orientation of the tiny flakes of micaceous minerals parallel to the coarser laminae of quartz and mica, gives the rock its schistosity.... Microscopic prisms of tourmaline and less frequent rounded zircons are scattered through the schist. Garnets are locally abundant.... Biotite is occasionally present....."(4) Magnetite is a persistent accessory. It seems quite possible that the Central Mountain formation may correspond to the Bethel schist.

Nothing analagous to the Barrows hornblende schist seems to exist as far north as Plymouth and Bridgewater, and it

(1) Perry, - Op. Cit., - P. 33
(3) Ibid., - Pp. 219-220.
(4) Perry, - Op. Cit., - P. 30
seems highly probable that the hornblendic rock lenses out to the northward. This hypothesis is suggested by the widening of the Central Mountain formation and the thinning of the Barrows Formation toward the northward. The hornblende schist proper is apparently very narrow at about E-15, and a siliceous schist, perhaps a part of the Barrows formation but certainly of markedly different lithologic character, was encountered directly to the west of E-15.

Correlation of the Ames Hill schist with the Massachusetts formations toward the southward is not difficult, but a determination of the age of the formations is somewhat complicated because the formations, which correspond to those in Vermont, are considered younger by geologists working in Massachusetts.

Specimens obtained on the Mohawk trail from Emerson's Goshen and Conway schists are closely analogous to the Ames Hill schist, that of the Conway without a doubt is the same as the typical, plicated Ames Hill, while that of the Goshen to the west closely resembles the western, less plicated part of the Ames Hill. Moreover, Emerson states that the two formations, the Goshen and the Conway, grade into each other imperceptibly (1), and that the only real difference between the two is the general lack of limestone in the Goshen (1), and the corrugated nature of the Conway (2). This gradation is precisely like that found from the western to the eastern part

(2) Ibid, - P. 44.
of the Ames Hill and on into the Whetstone. The Whetstone then becomes a part of the Conway schist, and the Round Mountain formation is a continuation of a lens of hornblende schist in the Conway which passes just east of Shelburne Falls, Mass. (1). The base of the Goshen is marked by a bed of hornblende schist and is unconformable with the underlying Hawley (2). Of the two places in Marlboro, where the western contact of the Ames Hill was located, the contact was sharp and marked by a thin bed of hornblende schist. Both these facts indicated that the Goshen is comparable to the western Ames Hill and hence to the Randolph phyllite of Vermont geology. Daly correlates it with the Bradford phyllite at Ascutneyville and places it in the early Trenton (3). The break between the Randolph phyllite and the Missisquoi group, whether between Cambrian and Ordovician, as Perry and Richardson believe, or between the Ordovician and the Silurian as Emerson holds, apparently passes through Marlboro township, between the Ames Hill schist and the Marlboro formation, south into Massachusetts.

If the Goshen schist is comparable to the Ames Hill, then the Hawley schist should correspond to the Marlboro, provided, as is likely in two neighboring localities, the two regions have experienced the same history and are not separated by some fault or other structural break. Correlation on the basis of lithologic characteristics again is difficult on account of the lack of uniformity in the formation. It is described as a "soft, dark green chlorite schist commonly full

(2) Emerson, - U.S.G.S. - Bulletin 597 - P. 45.
(3) Daly, - U.S.G.S. Prof. - Paper 209 - P. 19.
of ankerite rhombohedra, and contains many quartzose pale-green beds of sericite schist penetrated with many long hornblende blades in a fasciculate arrangement....Thick beds of black hornblende schist run south with the bedding..." (1) This description fits some phases of the Marlboro, especially in the southern part, but does not resemble the Marlboro sufficiently to make correlation conclusive.

The Savoy schist is described as a "thick formation of light-gray, rather coarse muscovite or sericite schist, generally hydrated and greenish from the presence of a little chlorite, commonly derived from garnets, which are very abundant and large..... Large beds of sugary quartzite are intercalated in the schist and in many places are penetrated by long, flat hornblende schist like that of the Chester Amphibolite are formed." (2) Both the general description and the presence of the hornblende bands locally suggest the Central Mountain formation.

The next formation below the Savoy schist is the Chester amphibolite said to extend into Vermont and described as a "dark, green to black foliated or ligniform epidotic quartz-hornblende schist. At several places in this part of its course it is associated along its eastern (formerly the upper) border with lenticular masses of serpentine of igneous

(2) Ibid., P. 43
(3) Ibid., Pp. 41-42.
origin several hundred feet thick...." (1). The Chester amphibolite appears to correspond to the Barrows formation.

To correlate the formations of Marlboro and Brattleboro townships conclusively with the described formations to the north and south, with the exception of the Randolph phyllite-Ames Hill-Conway schist relationship, an actual comparison of hand specimens would be necessary. Verbal descriptions are somewhat suggestive that such a correlation could be carried out. Granting that the formations do correlate with those already described, because of the lack of agreement between authorities on the subject, the problem of the specific age is still unsolved. Emerson would class all but the Goshen and the Conway schist with the Ordovician and the above exceptions in the Silurian; while Richardson and Perry place the Vermont equivalents, with the exception of the Ordovician Randolph phyllite and the Waits River limestone, in the Cambrian. Since the area itself sheds no additional light on the subject, the question must be left unsettled.

(1) Ibid., - Pp. 41-42
Section Along Line A-B on the Geologic Map of the Area.

Horizontal and Vertical Scale: 2 inch = 1 mile.
The attitude of the formations is almost vertical. The older rock dip steeply toward the east while the younger strata, the eastern half of the Ames Hill schist, the Whetstone and Round Mountain formations, dip strongly toward the west. The rocks to the east of the area studied possess an eastward dip, as do the formations to the north and south (1), and the area is part of an eastward dipping monocline. The westward dips are local overturns which are confined to a narrow belt along the strike. It is evident that the change in direction of dip in the Ames Hill does not indicate the presence a syncline because the eastern contact of the Ames Hill is gradational for about half a mile into the adjoining Whetstone schist. This formation does not in any way correspond to the Marlboro formation which is separated from the Ames Hill on the west by a sharp contact.

Further investigation to the east of the region will reveal more evidence concerning the structural disturbance known to have taken place in the eastern part of the region. The presence of a marked change from a NE-SW strike in the neighborhood of 1347, of ultra-mylonite and cyanite on Round Mountain, and of a fault breccia and ultra-mylonite at the foot of Ginseng Hill, suggest a zone of movement in this vicinity, but the exact nature and limitations of the disturbance were not ascertained.

(1) Daly, U.S.G.S Prof. Paper 209, - P. 17.
Two inch band of the porphyroblastic phase offset by a small fault at e-5.

Fault with half an inch offset cutting green stringer in the Central Mt.

Two small faults cutting a quartz stringer in the Central Mountain at S-16.
There are signs of minor faulting at various points throughout the area as a whole. Ultra-mylonite veins were found in the Marlboro at about W-30, and offsets of quartz strings and of porphyroblastic bands measurable in inches were occasionally observed. In only one instance was there evidence to suggest that movement was any other than the normal faulting type. In this case two small faults cutting a quartz stringer produced a drag in the quartz, which, in view of the position of the fault planes, seems to indicate pressure rather than tension.
The metamorphic Rocks of the area have been assigned to a sedimentary origin for several reasons. Bedding planes conformable to and at variance with the schistosity (1) were found in all the formations except the Round Mountain schist and the Barrows formation. The former contained some siliceous stringers much resembling the Whetstone formation which suggest that evidences of bedding are present even here. In addition to the bedding planes, the formations vary both abruptly and gradually along and across the strike (2). This circumstance is notable in the Central Mountain, and is most characteristic of the Marlboro formation. The Ames Hill and the Whetstone formations are interstratified with an impure limestone certainly of sedimentary origin, and, therefore, the formations are very likely to be sedimentary. The contacts between the formations, with the exception of that between the Ames Hill and the Marlboro, are all gradational and can be proven sedimentary, all must be of sedimentary origin.

Certain aspects of the mineralogical composition of the rocks suggests a sedimentary rather than an igneous origin. Portions of the Marlboro formation and all of the Ames Hill, including the limestone, contain disseminated graphite, usually considered a criterion for sedimentary origin (3). Consider:

(2) Ibid., - P. 913
ing the whole area, silica is the most plentiful mineral in sedimentary rocks, its presence along with other criteria is an argument for the sedimentary origin of the country rock (1). To be sure, the quartz content is low in the more phyllitic phases of the Marlboro, and in the Ames Hill schist, but since these are precisely the rocks which contain the graphite, their lack of free silica is somewhat counterbalanced. The Central Mountain formation, and the porphyroblastic phase of the Marlboro contain rounded grains of zircon which suggest that they are remnants of original deposition rather than the products of recrystallization.(2). Cyanite is a mineral characteristically developed in argillaceous sedimentary rocks by the action of igneous intrusives (3), and its presence near a quartz dike in the Whetstone formation is an added criterion for sedimentary origin.

An attempt was made to estimate the chemical composition of the hornblende formations by a petrographic study and to determine the origin of the formations according to Bastin's criteria for distinguishing between igneous and sedimentary metamorphosed rocks, but, because of the inability to determine, by petrographic means, the variety of hornblende present, a proper chemical formula for this mineral could not be selected.

We know little of conditions of sedimentation during the early part of Barrows time, but in later time the deposits

(1) Ibid., - P. 913; Bastin, Journ. Geol., Vol. 17, - P. 449.
were quartz sands mixed with considerable quantities of ferro-
magnesian minerals, especially at certain periods, so that the
original consolidated sedimentary rock was a ferro-magnesian
sandstone (1) quite low in feldspar. The fact that the feld-
spar content is low, shows that the sands must have been
relatively free of undecomposed rock material and that, conse-
sequently, they had been considerably water worked before final
deposition. Because of the steep dips in the area which make
tracing the beds, in what must originally have been an east-
west direction, an impossibility, the position of the land
mass which supplied the sediments could not be determined.
The clastic, considerably reworked, nature of the original
sediments indicates that the source of material was probably
high above sea level and some distance from the place of dis-
position and that the sand may have received considerable
wave reassortment along a beach before final deposition.

Central Mountain time was marked by the deposition
of purer quartz sands than were laid down in Barrows' time,
and the contact, characterized by alternating bands of horn-
blende schist and quartz-mica schist as well as the occasional
thin bands of hornblende rock within the Central Mountain at
several points, indicates that the change was gradual rather
than abrupt. Sedimentation was apparently continuous and the
change in the type of sediments must have been brought about
by a change in the adjoining land conditions. Uplift may have
occurred nearby which would have brought the shoreline nearer the area and have caused the type of deposit to be accordingly more siliceous. The almost complete lack of feldspar shows a considerable sorting of the material before final deposition.

Conditions during Marlboro time were exceedingly changeable for the type of deposit ranged all the way from a carbonaceous mud (1) to an almost pure sandstone. Shallow water deposition is strongly indicated by the thinness of the beds, by their occurrence in frequent lenses, and by the occasional suggestions of crossbedding (W-18). The formation is more siliceous toward the north and phyllitic toward the south. It is possible that the shallow water deposition occurred early during the Green Mountain uplift (2) when the area was still under water, and was finally terminated by the emergence of the area at the close of Marlboro time. This hiatus is only indicated in our area by an apparently sharp contact. Both to the north and to the south evidences of an unconformity exist (3), showing that either there was no erosion in a lowlying territory, or the region was elevated so high that the last of the Marlboro sediments were eroded off before Ames Hill time commenced.

Following Marlboro time there occurred a period of continuous sedimentation which resulted in the Ames Hill, Whetstone, and Round Mountain formations. The Ames Hill was a

(3) See pp. 43-49 of this report.
thick deposit of mud, which, due to changing land conditions that were apparently rather local, since they were not to be found to the north or south, became more siliceous with local, thin beds of limestone. The Round Mountain schist was derived from local sandy muds which were deposited, largely to the southward, since the formation lenses out to the north of Round Mountain but continues some distance south into Massachusetts.

25,000 feet of clastic sediments indicate that near shore conditions with an abundant supply must have existed. We should expect from the location of the area, under geosynclinal conditions that there was a constant rising of the land areas, which supplied the sediments, and a slow sinking of the depositional area in order to maintain continuous marine conditions of sedimentation.
METAMORPHIC HISTORY.

The first event in the metamorphic history was a granulation of the rock due to low temperature and moderate pressure at intermediate depths (1). The evidence for this cataclastic type of metamorphism is somewhat obscure since considerable recrystallization and neomineralization have taken place. Quartz is quick to show signs of strain, (2) and since the majority of it shows no wavy extinction while the rest of the rock shows abundant signs of metamorphism, it has undoubtedly been recrystallized. However, in the Whetstone formation and to some extent in the Round Mountain, the Barrows, and the quartzitic phases of the Marlboro, finely granulated quartz is present, and is evidence for at least one period of cataclastic deformation. Some of the rocks under the microscope show small finely pulverized patches, in some cases isotropic, which are remnants of an early period of intense granulation previous to the general recrystallization.

The metamorphism following granulation of the rock was of the progressive type, that is, moisture was probably present and temperature and pressure became more intense. The changes which took place must therefore have occurred in a still deeper zone where conditions of mass mechanical metamorphism in the lower zone of anamorphism existed (1).

In the first place, the quartz is largely recrystallized, and often in such a way that the grains show the dimensional alignment parallel to the schistosity, indicating an adjustment to directional pressure and to movement (1). Furthermore, recrystallization of the quartz causes a decrease in volume over the granulated quartz, and an adjustment is thereby made to the great pressure (2).

During this time there also occurred the development of much of the hornblende of the Barrows, the Round Mountain, the hornblende, and perhaps the prophyroblastic phase of the Marlboro. All these occurrences of hornblende show an orientation of the prismatic crystals with reference to a plane of schistosity, but little linear schistosity has been developed. Both the development of the hornblende and its alignment with the schistosity are characteristic of mass-mechanical metamorphism (3).

The development of considerable biotite and muscovite is also characteristic of this same type of metamorphism, (4) especially where the minerals are oriented in such a way that their prominent cleavages or crystallographic forms, contribute

to the development of the schistosity. Since muscovite is largely responsible for the schistosity in the typical Central Mountain, the black phyllite, the quartzitic, and the micaceous phases of the Marlboro, and the Ames Hill schist, while biotite produces the schistosity of the Whetstone formation, and since minor amounts of these minerals are frequently present in almost all the formations, it is likely that both were developed at this time.

Finally, the black phyllite, the Ames Hill schist with its limestone lenses, and to some extent the Whetstone formation carry considerable amounts of graphite. This mineral is developed under conditions of great pressure and the consequent necessity for decrease in volume. The presence of graphite therefore indicates a period of recrystallization in the zone of anamorphism (1). The mass-mechanical metamorphism was responsible for the schistosity and resulted in a general decrease in the volume of the rock.

Then came the injection of some of the quartz dikes. It is fairly certain that some of them were injected after the schistosity was developed, for in some cases they spread or cut it. Furthermore, some thin strings are plicated with the schistosity while thicker lenses have caused buckling in the schist around them because of their resistance to deformation. Con-

sequentily the stringers must have been present before the minor folding of the schistosity occurred. The quartz stringers mark a period of hydrothermal activity (2) which took place during the Appalachian Revolution.

The evidences for a period of mechanical deformation following recrystallization are structural rather than mineralogical ones. Many phases, especially the more micaceous, exhibit folding and minute plications which in some cases approach a poorly developed strain-slip cleavage. This type of cleavage was found in the micaceous phase of the Marlboro, and in the Ames Hill schist. Since the cleavage is due to the re-orientation of older planes of weakness, which have been accentuated by previous metamorphism, (3) this period of deformation must have followed the development of the schistosity. Moreover, those formations, such as the Whetstone and some phases of the Marlboro, which have an abundance of the micas, especially biotite, show a feathering out of the cleavage fragments one upon the other due to molecular rearrangement under strain (4). They also exhibit a stringing out of a single crystal along the schistosity (5), and the arrangement of some of the smaller mica laths

in an undulatory manner which is no doubt responsible for the presence of the plications. Some of the feathered biotite, especially in some phases of the Marlboro, is enclosed in granular quartz. This fact together with the inclusion in grains of recrystallized quartz of such products of a previous mass-mechanical metamorphism as biotite, graphite, and muscovite suggests a second period of quartz granulation taking place at this time.

Cataclastic deformation is also noticeable in other minerals besides biotite, muscovite, and quartz, especially in the more hornblende phases of the Marlboro where much of the hornblende is considerably mashed. Microscopic evidences of cataclastic deformation are less noticeable in the western part of the area than in the eastern although plications are common. The Ames Hill Schist is an exception to this evidence of cataclastic deformation because it shows little trace of granulation, probably because, owing to its low silica and hornblende content and its high proportion of mica, it adapted itself to the pressure more by close folding than by an actual breakdown of mineral particles.

This period of mechanical deformation was probably due to continued compressive stresses set up by diastrophic movements. The plications are the result of pressure from the horizontal, and since the general strike of the beds is from northeast to south-
west, the pressure probably came from these directions. In addition to this factor, cataclastic deformation is the result of metamorphism in the upper part of the zone of anamorphism rather than at the greater depths of the previous metamorphism and this circumstance again points toward mountain building as a cause for metamorphism. It is therefore highly probable that this deformation occurred during the latter part of the Appalachian Revolution. Evidence of folding in compliance with east-west compression is either absent or was unrecognized because of the general absence of beds which might be used as markers. Some folding in this direction occurs near the contact of the Barrows with the Central Mountain formation at about E-20. However, the fanlike arrangement of the Ames Hill with the adjoining Whetstone formation may be due to continued thrust from the east after the strata reached their present position. The development of the cyanite on Round Mountain, the ultra-mylonite of several localities, and probably the minor faulting which has been observed can be placed in the latter stages of the Appalachian Revolution.

Following the diastrophic period came an interval during which the area was subject to mass-static metamorphism. This metamorphism took place in the zone of anamorphism under conditions of heat, of static pressures, and of moisture (1).

This period was marked by the development of porphyritic minerals of high specific gravity which are characteristic of the zone of anamorphism (2). The Ames Hill schist is full of garnets found in lenses of recrystallized quartz which spread the schistosity. The garnets are usually euhedral, but sometimes they are irregular in outline, and they always contain numerous small inclusions of recrystallized quartz. These garnets have grown by absorbing their constituent elements from the surrounding area and have included the excess quartz (3). Since the garnets are of the andradite type, the area about them has a low iron content. The garnets in the Whetstone are very poorly developed probably because of the preponderance of quartz and the lack of sufficient quantities of mica from which they are derived (3). Some of the garnets of the Marlboro show zonal growths characteristic of porphyritic crystals having this type of origin (3).

The hornblendic phases of the Central Mountain and of the Marlboro are characterized by the relatively large, porous hornblende crystals that contain inclusions of quartz and of the micas aligned with the schistosity of the rock. The crystals themselves do not always harmonize with the schistosity. These crystals have also developed after rock flowage ceased and static metamorphism became dominant. The diminution in volume and the increase in specific gravity of the newly formed minerals are a response to such conditions (4).

(2) Ibid., P. 700.
The porphyroblasts of basic feldspar in the porphyroblastic phase may have been formed at this time although the presence of strain extinction, in some instance, suggests that they may be older. This explanation of their origin would account for the rectangular shape of some of the porphyroblasts and for their random orientation. The lensing out of those which are now in a granular state could be accounted for by the influence of the great pressures still existent.

The Ames Hill schist and to some extent the Barrows schist contain flecks of biotite (1) which seem to be independent of the schistosity and which sometimes have around their borders secondary growths of the same mineral. That the crystals do not show strain and do not harmonize with the schistosity makes it seem certain that they developed under conditions of mass-static metamorphism, some of the muscovite found frequently cutting other minerals in the formations was formed at this time (2).

Much of the quartz which was granulated during the latter part of the Appalachian Revolution was recrystallized, this time including such minerals as graphite, biotite, hornblende etc., which were formed during the first period of recrystallization. The development of the porphyritic minerals

was due to the work of moisture in the rock pores which acted as the agent of solution and redeposition of the newly forming minerals (1). The growth of these minerals then was largely a process of replacement.

There has been no noticeable strain exerted upon the rocks since this period of mass-static metamorphism, for not even the recrystallized quartz shows signs of strain. The changes which have since taken place have been of the retrogressive type, and are represented by the breakdown of minerals in equilibrium in the zone of anamorphism to those which are stable in the zone of katamorphism or even under conditions of weathering (2). This process of breakdown of minerals was facilitated rather than hindered by the vertical uplift which occurred at the end of the Cretaceous and which served to bring the rocks farther out of the zone of anamorphism than was possible by erosion during the Mesozoic. Retrogressive metamorphism has probably been continuous since the close of the Appalachian Revolution.

The most universal evidence of retrogressive metamorphism is chloritization. Garnet and biotite have been frequently noted in the process of altering to chlorite (3). In the case

(3) Ibid., P. 8, 20.
of the garnets, the fibrous chlorite has been found in pseudo-
morphic aggregates while the biotite has been found altering
along its cleavage planes to chlorite, either clinochlore or
penninite. In some instances chlorite was found altered from
biotite as shown by abundant inclusions of magnetite or ilmen-
ite (1).

Hornblende altering to epidote (2) was found, most
frequently in the Round Mountain formation: Ilmenite alter-
ing to rutile (3) is most noticeable in the porphyroblastic
phase. These changes are both of a retrogressive nature.
Small amounts of sericite are present in all the formations (4).
The breakdown of the feldspar blasts in the porphyroblastic
phase to saussurite a mixture of albite, quartz, zoisite,
chlorite, and hornblende, is also a process which takes place
in the zones of moderately intense metamorphism (5).

The age of the steatite-amphibolite deposit at 1906
is somewhat difficult to determine. The only metamorphism
which it appears to have suffered is the development of the
talc around its borders probably due to hydrothermal alter-
ation by waters which accompanied or closely followed the in-
trusion of the amphibolite itself (6). Alteration of basic
(3) Ibid., P. 226.
minerals to talc usually occurs in the zone of katamorphism (1), and consequently the intrusion seems to have occurred after dynamic metamorphism ceased and before retrogressive metamorphism commenced.

The deposit is one of a series occurring in the older rocks of Vermont whose age is still an unsettled question. The serpentine deposits of the state bear a field relation to the steatite deposits, suggesting that the steatite is due to the alteration of a rock older than that from which the serpentine is derived (2). The talc and serpentine do not occur anywhere in the state in rocks younger than those underlying the Irasburg conglomerate (3). This occurrence points to an intrusion of the basic rocks previous to the deposition of the Randolph phyllite. Thus the intrusions would be pre-Ordovician (?) in age (3) and possibly associated with the Green Mountain disturbance. On the other hand, the intrusions spread the schistosity in some instances and therefore appear to be later than its development (4). This later appearance of the basic rock would likewise account for the lack of dynamic metamorphism which the deposit at 1906 exhibits. Wigglesworth believes that the period of intense metamorphism which developed the schistosity of the

(3) Ibid., P. 290.
(4) Ibid., P. 289.
country rock occurred at the end of the Ordovician and that the area was disturbed only mildly by the Appalachian Revolution (1). He, therefore, admits the possibility that the intrusion may have occurred after the Ordovician and probably before the Mesozoic (1). If the tough amphibolite does not show the effects of the metamorphism it has experienced, he believes it may be older than the metamorphism which developed the schistosity. This hypothesis has some support in this area because the two talc-amphibolite deposits are in the older rather than the younger formations which may mean that the intrusion occurred before the younger sediments were deposited. The field evidence in the locality under study merely shows that the intrusion occurred after the deposition of the enclosing rock and before the final metamorphic stages and the intrusions of the pegmatites. A small pegmatite was found cutting the amphibolite, and the pegmatites over the area show little evidence of having experienced such dynamic metamorphism. Since field evidence in the area suggests that the Appalachian Revolution developed the schistosity, the basic intrusion and the pegmatites were probably associated with this period of earth movement. The process of adjustment to conditions near the surface shows considerable lag and is not nearly complete, for the proportion of anamorphic minerals such as hornblende, the (1) Ibid., P. 239.
micas, and garnet, is much greater than that of the minerals such as chlorite, sericite, rutile, and limonite, which are stable under surface conditions.
Following the diastrophic movement which gave the formations their present attitude, there came a prolonged period of erosion. There are several lines of evidence for this erosion period. In the first place the geologic structure of the region is a truncated monocline, and while this circumstance alone would not be conclusive, the additional fact that the exposed rocks are those which have suffered regional metamorphism under conditions of great depth shows without doubt that considerable overlying material must necessarily have been removed in order for the rocks to be exposed. Furthermore, the region exhibits a well defined pre-glacial topography which could only have been well developed during a considerable lapse of time. The upland areas have the characteristics of late maturity showing that the area was fairly stable during the greater part of the pre-glacial erosion period.

After the first erosion cycle had reached late maturity, the region experienced a vertical uplift which, judging from the depth of the present valleys must have been several hundred feet. That erosion did not proceed to peneplanation before this uplift occurred is shown by the presence of considerable relief above the critical level which exhibits no accordant summit levels and which, consequently, can only be interpreted as mature relief of the first erosion cycle. The
present relation of the levels, which mark the change in slope, suggests that there was a slight tipping of the old erosion surface to the southeast. This apparent tip of the upland surface from 2800 feet in the northwest to 1300 feet in the southeast, makes it probable that the Cretaceous erosion level, so well developed in western Massachusetts, can be traced northward over this area. This old upland surface tilts toward the southeast, and according to Lobeck (1), is in the neighborhood of 2000 feet high in Massachusetts and 1000 feet high in central New Hampshire.

A second pre-glacial erosion commenced after this uplift which probably took place at the close of the Mesozoic era. In early Cenozoic time, we find the drainage lines of the former erosion cycle being emphasized by the cutting of steep sided, V-shaped valleys due to the rejuvenation of the streams flowing in them. The uplift does not seem to have changed the drainage lines at all, and since the process must have been gradual, it seems logical to suppose that the renewed cutting of the streams kept pace with the slowly rising terrain. If the area did receive a slight tilt to the east and south, the drainage east to the Connecticut, already well developed before the uplift occurred, must have been distinctly favored so that cutting across even such resistant formations as the Round Mountain schist was accomplished quite effectively. According to Schuchert (2), this uplift was

(1) Lobeck, A.K., - Physiographic Diagram of the U. S. (Text)
(2) Pirsson & Schuchert, - Textbook of Geology - Pt. II - P. 902.
caused by a geanticlinal bowing up of the Appalachian area which accompanied the Laramide Revolution at the close of the Cretaceous period and which amounted to a re-elevation of about 2000 feet.

The fact that the steep slopes of the valley walls are quite uniform from the old erosion level down to the valley drift deposits with the exception of some slip-off slopes and some narrow areas at several stream confluences leads one to conclude that no uplift of any great importance has occurred since the end of the Mesozoic and before glacial times.

The next great event in the physiographic history of the area was its subjection to continental glaciation in Pliostocene time. Evidence of both an erosional and a depositional nature for at least one period of glaciation, is present throughout the area, but criteria for distinguishing more than one period is rather limited. Glacial grooves found on an outcrop of the Marlboro formation along the road north of camp show that ice at that spot travelled S. 30 degrees W., but in the neighborhood of Reading and Chester townships, Richardson(1) found the general trend of the glacier to have been due south with variations locally all the way from S 20 degrees E. to S. 20 degrees W. The general trend of the glacier in Marlboro township was apparently more nearly from north to south than readings on one set of striae within the area would suggest.

The action of the ice on the highlands was to scrape

the bed-rock bare and then to scour and round off the out-
crops until roches moutonnees are quite numerous. Quartz
stringers and lenses, especially noted on 1906, were actually
polished where they were of the massive quartz variety, and
this corrosive action of the ice sheet indicates that the ice
must have had considerable thickness. The presence of evi-
dences of ice action on the highland areas as well as the
testimony it bears in regard to the thickness of the layer of
ice, is an important criterion for the conclusion that the
region has suffered continental rather than valley glaciation.

Most of the depositional effects of the ice are to
be found in the valleys and on the lower slopes rather than on
the hill-tops. Ground moraine is exceedingly common, and its
constitution is another strong argument in favor of continental
rather than local glaciation, for boulders foreign to the ge-
ology of the region can only be introduced by a carrying agent
coming from a distance. Most of the deposition of morainic ma-
terial probably occurred when the ice was melting back rather
than advancing.

The wasting away of the glacier was accompanied by
the deposition of some fluvioglacial material and by the forma-
tion of the recessional moraines in the Augur Hole. These re-
cessional moraines show that the melting of the ice was not a
steady process, but that there were at least four periods when
ice advance kept pace with melting and the ice front was, there-
fore, stationary. The loop moraines also reveal that the ice
remained longer in the Augur Hole than in the surrounding country and that the last traces of the ice took the form of a valley dependency from the main part of the ice sheet. This valley dependency had to be maintained during its stationary periods by ice from the north which necessarily had to advance up the slope of the valley since it travelled against the normal gradient of the pre-glacial valley, and therefore the ice was dependent wholly upon the mass of the ice to the north for driving power in its advance.

Since the natural drainage of the Augur Hole in both pre- and post-glacial time is to the northward, it is not surprising that we find evidence of the existence of a pro-glacial lake in the southern part of this valley. This lake was due to the damming up of the waters which must naturally have accumulated from the drainage from the south and from the melting of the end of the valley dependency. This pro-glacial lake was responsible for the re-working of the typical moraine topography which the ice sheet left in the southern end of the valley. The ground moraine is sandy and powdery on the surface because of the later deposition of fine material on the lake floor. However, glacial boulders showing the effects of continental glaciation previous to the existence of the lake can be dug from cuts in hummocks capped by clay and fine, micaceous soil. It is possible that some of the sub-angular boulders found in the fine sand were carried
out into the lake by floating ice from the glacier and allowed to fall to the lake bottom when the ice melted. Since the cross-bedded, fluvio-glacial sand bank contains a bed of greenish lake clay near the top, it is highly probable that some of the outwash from the glacier into this valley was deposited in the lake. The lake must have drained over or under the ice since no evidence of an outlet was found in the hills surrounding the valley. There is evidence for a second advance of the glacier in the till caps found on the fluvio-glacial deposit in the Augur Hole and on the one south of 1384. The deposit is not over three feet thick in both cases, and is composed of fairly well rounded boulders not much over four or five inches in diameter. It is likely that the till cap represents a minor advance of the glacier in the course of its retreat rather than a second ice age. If a second major advance ever occurred, it was not as extensive as the first because it did not destroy in any way the lake deposits in the Augur Hole.

There is another meager line of argument in favor of two periods of glaciation which would place the first period before the one which has been described above. As has been suggested in the chapter on Physiography, the headwall of the Augur Hole valley is too steep for the natural repose angle of the glacial material. The head of the valley is rounded in a manner much more characteristic of a cirque than of a normal erosion valley head. Moreover, except for recent slumped material, the amount of detritus near the head of the
valley, seems entirely too small for the amount of glacial cutting within the valley even granting that the moraine topography has been somewhat subdued by the lake deposits. The valley has been considerably widened and deepened in comparison with the other valleys in the area. Since the erosion was supposedly done by a valley dependency during the last stages of a retreating glacier, the detrital material from the northern end of the valley could not well have been carried out of the southern end beyond the headwall of the valley. The fact that almost no bed rock is exposed in the southern end of the valley might be an argument for the thickness of the drift at the head of the valley. One stream was found flowing on bed rock for a short distance, and therefore it does not seem probable that bed rock is very deeply buried here.

All these lines of evidence suggest the theory that, the valley was occupied by a small valley glacier previous to the period of major continental glaciation. The shape and slope of the head wall, the removal of the detrital products of glacial cutting in the valley out to the northward, and even the presence of the valley dependency itself in a valley already wider and deeper than its neighbors because of previous ice action could all be nicely explained. There are very serious difficulties connected with the location of a suitable collecting field for the ice of such a glacier and with accounting for a single valley glacier in a region full of other valleys equally adapted to being the location for a valley glacier.
For these reasons the evidence is insufficient for giving this hypothesis a place in the physiographic history of the region at present.

A third erosion cycle started after the last retreat of the glacier and the streams occupy the same channels that existed before the glacial advance. South Pond, the pond about two miles north of Marlboro, and perhaps North Pond are products of morainic damming and are, therefore, exceptions to the general compliance of post-glacial with pre-glacial erosion. Since there are numerous swampy spots and the rivers have cut more than eight or ten feet in the glacial drift, the new cycle has not progressed far. That the post-glacial cycle commenced before the area as a whole was free of ice is to be expected. Because its altitude is greater than that of the Augur Hole and because the bulk of the valley is to the south of the point where the ice must have lain at the time of the pro-glacial lake in the valley to the east, the V-shaped valley west of the Augur Hole must have been undergoing stream erosion while the valley dependency still lay in the Augur Hole. The alluvial fans in this valley are quite large and well developed, while the few that exist in the Augur Hole are comparatively small, hardly over fifteen or twenty feet high. Those fans in the valley to the west may have had considerable start over those in the Augur Hole. On the other hand, the source of alluvium must have been considerably less for the
Augur Hole streams, because of the limited drainage basin which the valley has, and the relative smallness of the Augur Hole fans might thus be accounted for.

The present streams are cutting channels in their own fans rather than depositing fresh material. This fact is due to the decrease in their loads because of the partial removal of some of the loose glacial debris in the early stages of post-glacial erosion and to the confinement of the remaining material by the roots of the post-glacial plant growth. It is possible that the region is experiencing a slight upward rebound due to the removal of the load of ice from the area. The erosion cycle is so little advanced that it is impossible to tell whether the cutting has been aided by a new supply of unconsolidated material in which the streams are entrenched or to actual diastrophic movement.

The lakes are short lived and will be drained quite soon. North Pond is already being threatened by the head waters of Gulf Brook whose headward growth, unless checked, will undoubtedly annex the lake and hasten its end. The small lake north of Marlboro is already draining in two directions, west into the Augur Hole and to the east via the head waters of Whetstone Brook. The westward flowing stream has a shallow valley, a bed of bedrock for almost the entire length, and no drift in the lower parts, all of which suggest that it may be post-glacial. The location of the lake on a divide area makes
it certain that its days are numbered. South Pond is being approached from the north east and the south east by headward working streams, and with three future outlets it cannot possibly exist long. The swampy areas will also soon be drained, of course, as the post glacial drainage lines become more firmly established.

Over the area as a while, erosion, if uninterrupted, will proceed in the same lines they are working in today. Valleys will be deepened, and their walls undercut so that the hills will gradually be lowered in the attempts of the stream to lower the terrain to the base-level which has been set for this area by the Connecticut River. It is quite probable that the string of structural hills may be the last to succumb and will, therefore, remain for a considerable time as monadnocks.
ECONOMIC VALUES.

Economic resources in Marlboro township are almost lacking, and what few do exist, with the exception perhaps of soil and scenery, have no more than local significance. The complete lack of mineral resources in commercial quantities has made the permanent residents turn to agriculture for a livelihood. Although the region is not well suited to agriculture, farming of an individual type is probably the best use to which the land may be put. Some of the resources do have a local significance and have economic value in a negative sense for they save the inhabitants from importing some materials because there is a local supply which will nearly fill the demand.

Probably the most useful rock in the area is the Ames Hill schist. Because of its tendency to cleave and its micaceous and garnetiferous composition which causes it to crumble easily, this rock has no value as a building stone or for purposes of export. As a rough foundation stone for farmhouses and summer homes built in the area in which it outcrops, as material for building crude, somewhat artistic walls for graveyards and other enclosures, and as stepping stones for summer homes, it serves very well indeed, for its steely appearance is pleasing, and its tendency toward a rough cleavage makes it fairly easy to handle.
The larger limestone lenses in the Ames Hill and Whetstone schists often show by the presence of drill marks that they have been quarried, and occasionally, pieces of this rock are in evidence as stepping stones.

One deposit of talc in West Marlboro (E-20) has come nearest to being economically exploited of any mineral resource in the region. Judging from its present appearance, this deposit was quarried for a time, but operations had ceased prior to the summer of 1930, and trees were growing on the quarry floor. Because the talc is impure and the supply is limited, the quarry was not a success and could not be profitably operated.

Garnets from the Central Mountain schist have been ground up and used as abrasives, but since they are impure and not of gem quality, their use is not extensive. This use of the garnets does not take place on a commercial scale.

The lakes of the area are small, hardly over half a mile long, and are not numerous. The part they play in the economic affairs of the people is almost negligible. One of the two small lakes mapped about two miles north of Marlboro was formed by a temporary dam doubtless at one time used in connection with lumbering operations which seem to
have taken place nearby. The lake is now extinct, and a swampy basin marks its former site. The only two lakes in the area of any significance are North and South Ponds, and these small lakes attract a summer population to their shores because of the opportunities for swimming and bathing. South Pond has in addition to the usual run of summer cottages, a boys' camp situated on the point of land between the thumb and fingers of the "mitten". A small logging camp on the southwest shore may derive some winter benefit from the lake because it is easy to haul the logs over the ice. The economic value of these lakes is therefore not only seasonal but indirect. Only as they attract the vacationist who in turn buys of the local merchants can they be of value to this region.

Surface streams in the area make a contribution worthy of mention in connection with economic values. A small stream with its headwaters just east of Wickopee Hill has been dammed up and the water conducted in a flume in the direction of Brattleboro. This region may have something to do with the water supply of Brattleboro. This seems a natural adjustment because the land is considerably higher than the level of the Connecticut River and gravity flow of the water is possible.

In spite of its limitations, soil is the biggest
economic resource of the area at present. Most all the soil of the area is transported rather than residual, and, because of the nature of the transportation agents, the soils are not very fertile. With the exception of some fine, powdery deposits in the Augur Hole, the soil is of the stony, heterogeneous type so characteristic of continental glaciation in New England. The rockier parts of the slopes support pasture grasses, and hence contribute to the dairying and sheep raising which are the most remunerative types of agriculture possible in this region. After clearing of boulders and fertilizing, the soil is capable of growing such products as hay, oats, and timothy. Sour, mossy soils yield a poor grade of hay, while sandy soils are sometimes planted to Irish potatoes. The finer, more workable alluvium of the valley floors is planted to sweet corn and other home garden products.

Gravels, sands, and clays are usually found as small fluvio-glacial or as alluvial deposits. A sand and gravel pit south of Mill 1284 is being worked and the products used locally as road material.
BIBLIOGRAPHY

Bastin, Edson S.,
Chemical Composition as a Criterion in Identifying Metamorphosed Sediments,

Daly, R. A.,
Geology of Ascutney Mountain, Vermont,

Emerson, B. K.,
Geology of Massachusetts and Rhode Island,

Fenneman, N. M.,
Physiographic Divisions of the United States,

Joly, John,

Knopf, Eleanora,

Leith, Charles K,

Leith and Mead,

Lindgren, W.,

Lobeck, Armin,


