DISCLAIMER

Before visiting any of the sites described in the New England Intercollegiate Geological Conference guidebooks, you must obtain permission from the current landowners.

Landowners only granted permission to visit these sites to the organizers of the original trips for the designated dates of the conference. It is your responsibility to obtain permission for your visit. Be aware that this permission may not be granted.

Especially when using older guidebooks in this collection, note that locations may have changed drastically. Likewise, geological interpretations may differ from current understandings.

Please respect any trip stops designated as “no hammers”, “no collecting” or the like.

Consider possible hazards and use appropriate caution and safety equipment.

NEIGC and the hosts of these online guidebooks are not responsible for the use or misuse of the guidebooks.
34th annual field meeting: October 14, 15, 16, 1938
Leader: Dr. George W. Bain, Amherst College; Place: Rutland, Vt.

This field trip is to a key region in the Taconic and Pro-Cambrian controversies of the Appalachian region. New significant features, bearing upon these problems, will be outstanding items of the main program. The route is arranged to interest students in all branches of the geological sciences.

A guidebook, organized on the pattern of the International Geological Congress type, is being lithoprinted, and will be obtainable at the start of the excursions. Those wishing advance copies should write to Dr. Bain for them.

Accommodations: Those who wish to attend the trip must make their own hotel accommodations. Hotel Berwick and Hotel Bardwell, in Rutland, are satisfactory commercial hotels. The Brandon Inn, at Brandon, and the True Temper Inn, at Wallingford, are good hotels in nearby towns.

Topographic maps to be used: Rutland, Rochester, Brandon, and Castleton quadrangles.

Travel: During the trips by cars. Train service to Rutland was available at last writing but should be verified before planning on railroad transportation to beginning of trip.

Excursions:

October 14: STRUCTURAL PETROLOGY: Group meets 2 p.m. West Rutland Office of the Vermont Marble Company. EVENING SESSION: Vermont Marble company show, Proctor, Vermont—6 miles from Rutland. Time 6:30 p.m. Exhibits of unique structural and fossiliferous slabs and drill cores. Motion pictures of industry.

October 15: Main excursion. Leave hotels 8:30 A.M. Take U.S. 7 for Pittsford and Mt. Notch. Geomorphologists and pre-Cambrian geologists should be prompt; late comers call at Hotel Berwick or Hotel Bardwell desk for complete guidebook. The pre-Cambrian succession, the Paleozoic succession, structure and intrusive will be examined; deformed fossils; overthrusts; klippe. Return about 6:30 p.m. A separate engineering excursion is also planned for Saturday. The Darby quarries will be visited.

October 16: The Ultra basic belt in the eastern part of the state will be visited. Many interesting features among which are: a) magmatic and tectonic flows directions in the ultrabasic bodies; b) structure of talc deposits; vein and "keel" deposits.

Make certain that you secure your own hotel accommodations in Rutland or nearby towns. It will be possible to a small number of people in private cars on the trips but everyone is advised to arrange transportation for the excursions in advance.

(Secretary's note: Amherst College suffered heavily in the storm of several weeks ago and Dr. Bain has been very busy. The secretary is attempting to assist him in mailing out notices to all who might be interested. The delay in mailing could not be helped. We beg your indulgence.

Signed: Lloyd W. Fisher
secretary
(Department of Geology
Bates College, Lewiston, Maine)

WRITE TO BAIN DIRECTLY IF YOU HAVE ANY QUESTIONS CONCERNING TRIPS included in this field meeting.
NEW ENGLAND INTERCOLLEGIATE GEOLOGICAL ASSOCIATION.

Hotel rates.  Hotel rates at the Hotel Berwick and Bardwell hotel, Rutland, Vermont are the same.

Single rooms.
- Room with running water: $1.50 to 1.75
- Room with bath: 2.50 2.75

Double rooms.
- Room with running water: $2.50 to 3.50
- Room with bath: 4.00 5.00

Business meeting.
The business meeting and the evening session will be held at Proctor which is 6 miles from Rutland. Information concerning the exact place can be obtained at the hotels in Rutland or at the exhibit of the Vermont Marble Company in Proctor. The group will sojourn to the marble exhibit after the business meeting and motion picture.

Scales.
The scale of the map in the guidebook is 1 inch to 6000 feet; you may find a 60 scale convenient in the field.

Clothing.
The days are usually cool at this season. You are advised to act accordingly in the matter of clothes. Your guide usually wears a windbreaker over a heavy sweater. A sheepskin is good.

The quarries do not vary far from 4°C at any time so that warm clothing will be needed by those going underground.

Lunches.
Saturday lunch will be at the Pittsford Valley quarries. You should bring your own lunch OR signify your approval of the following scheme, in writing c/o Mr. H. Ladd Smith, Vermont Marble Company. Your guide will procure adequate sliced bread, butter, cold cuts and jams and the utensils for each person to put his lunch together hastily in the field. Arrangements are being completed for a large pot of coffee to be boiled at lunch time. Lunch orders not received before Friday noon cannot be guaranteed. It is assumed that the cost of materials will be much below the cost of lunches at Rutland and the method will save individuals much trouble and time which may be used for discussion.

Affress until Thursday.
Geo. W. Bain,
Amherst,
Mass.

Address after Thursday.
Geo. W. Bain,
c/o H. Ladd Smith,
Vermont Marble Company,
Proctor,
Vermont.
The 34th excursion is scheduled for October 14 - 16, 1936 in the Rutland, Vermont district. This is a key region in the Taconic and Pre-Cambrian controversies of the Appalachian region. New significant features bearing upon these problems will be outstanding items of the main program. However the route is arranged to interest students in all branches of the Geological Sciences.

A guidebook, organized on the pattern of the International Geological Congress type, is being lithoprinted and will be obtainable at the start of the excursion. Those wishing advance copies should write for the same.

Please communicate the information in this circular to anyone whom you believe may be interested in this excursion.

HOTELS. Hotel Berwick and Bardwell hotel are satisfactory commercial hotels in Rutland. Roadside camps are available in and near Rutland. The Brandon Inn at Brandon and the True Temper Inn at Willingford are good hotels in nearby towns. Your guide is attempting to obtain a convention rate in the Rutland establishments. It will be necessary for each person to make their own reservation.

TOPOGRAPHIC MAPS. The trips are covered by topographic maps for the Rutland, Rochester, Brandon and Castleton quadrangles.

TRAVEL. Travel during the excursion will be by car. Train service to Rutland was available at last writing but should be verified not more than one week in advance by those coming that way. Bus service to New York and Montreal stops at Rutland.

EXCURSIONS.

October 14. STRUCTURAL PETROLOGY. Group meets at 2 P.M. West Rutland office of Vermont Marble Co. EVENING SESSION. Vermont Marble Co. show-rooms, Proctor, Vermont. 7:30 P.M. These are 6 miles from Rutland. Exhibits of unique structural and fossiliferous slabs and drill cores. Motion pictures of the industry. Return Excursion. Leave hotels 6:30 A.M. Take U. S. 7 for Pittsford and Mt. Dickwallowett. Geologists should be prompt. Late arrivals call for complete guidebook at Hotel Berwick or Bardwell desk. The Pre-Cambrian and Paleozoic succession, structure and intrusives will be examined; deformed fossils; over-thrusts and klippe. Return about 6:15 P.M.

October 15.
ENGINEERING EXCURSION. This is arranged primarily for students in mining engineering. The quarries will not be in full operation which will permit adequate exploration of the operating scheme. The morning excursion will be through the Danby quarries which work a horizontal deposit. The pillar spacing is particularly interesting. The afternoon excursion will be to the West Rutland quarries which are on a vertical deposit at one place and gently inclined at another. Pillar crushing in the old workings may be of interest.

October 16. ULTRABASIC BELT. The ultrabasic belt in the eastern part of the state has many interesting features. This excursion will be worked out to suit the group wishing to take it. Items which will be included are:

1. Magnetic and tectonic flow directions in the ultrabasic bodies.
2. Structure of talc deposits; vein and "keel" deposits.

CARS. Groups driving should travel in the lightest car available to the party in order to facilitate handling on narrow roads. It may be possible to accommodate a small number after arrival at Rutland but everyone is advised to try to arrange transportation during the excursions in advance.
THE CENTRAL VERMONT MARBLE BELT.

GUIDEBOOK PREPARED
BY
GEORGE W. BAIN,
AMHERST COLLEGE
AMHERST, MASS.
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## FIGURES 6 to 13
INTRODUCTION.

The Vermont marble belt lies between the Pre-Cambrian crystallines of the Green Mts. on the east and the Cambro-Ordovician slates of the Taconic Mts. on the west. Its sediments merge northward into the less metamorphosed correlatives in the Champlain lowland. Geomorphic features of this lowland protrude southward on the marble belt and send tributary fingers into the adjacent Taconic and Green Mts. Great shingled overthrusts are compressed into a narrow zone that spreads out farther north. The upper marbles have Chazy, Black River and Trenton fossils and are the easternmost fossiliferous horizons for their respective ages. Thus this is a key area in the study of some outstanding areal problems in each of the major geological sciences.

Deposits of commercial marble made geologic study desirable and necessitated delimiting formations more minutely over greater areas than for most areal work. Extensive exposures and underground workings allow accurate study of structures, variation in each type of metamorphism, and facilitate dating each geologic event. Thus detail of work supplements crucial position in making the area particularly attractive.

Summary of Problems.

This area offers an important contribution to many significant geologic problems. Most controversies in Appalachian geology might be argued on this ground.

The great baselevel of erosion, completed in Eocene time, has been described as relatively continuous. This surface is represented on the margin of the marble belt by a few straths heading as coves in the Green and Taconic Mts. and broadening out into a peneplain only northward along the Champlain and St. Lawrence lowlands. Rock terraces mark many of the great overthrust plates but bear no relation to the main baselevel.

Structures within the marble belt show that all folding, major shearing and metamorphism by mechanical and magmatic agencies had ceased before advent of the Monteregian intrusives. Likewise high temperature and pressure of the metamorphic stage disappeared throughout most of the region. These intrusives are assigned usually to a Carboniferous age. The folding and thrusting in the marble belt are older and are assigned to the Taconic revolution. An additional period of folding in middle or upper Cambrian time is suggested for the Taconic ranges.

Phyllites of Canajoharie age rest nonconformably upon Taconic slate at the north end of the West Rutland
valley. Long distance overthrusting, postulated on a sup­posed eastern, central and western sequence, is unjustifi­ied.

The Rutland formation of the marble belt is a gray­wacke at many places, has coarser, less decomposed rock fragments than contemporary slates to westward. It may be the on-shore rather than the off-shore phase of Cambrian sediments in the Taconic ranges.

The lower Cambrian Cheshire quartzite overlies non­conformably the Mendon series on the east margin of the marble belt. This pre-Cambrian series has a succession of beds and major lithological features similar to the Cambro­Ordovician sediments. Similarities in these two series may be responsible for much of the controversy over age of rocks in the Central Appalachians.

These major events have produced a number of cox­illary features including three types of rock fabrics, com­plex hydrothermal metamorphism and extreme compression at 30 feet from the present surface, adequate to reduce rock compressibility to only 4.17 x 10^-13 cms.² per dyne.

**GEOMORPHOLOGY.**

The Otter Creek starts at about 700 feet elevation near East Dorset, flows through the marble belt and enters Lake Champlain at 100 feet above sea level. Its many tributaries climb rapidly to 1500 feet. Occasional water­falls break its grade which rises at an otherwise approx­imately constantly increasing rate all along the valley. (Figure 1).

**Glacial Deposits.**

The present stream course, from Rutland to Lake Cham­plain is carved out of clay and sand. The clays were de­posited in the Champlain sea. The sands were left on gla­cial stream deltas built southward between the overlapping mountain spurs. Three of these delta deposits furnish sand for the marble mills.

**Age of the present valley or lowland.**

The glacial deposits lie in an earlier basin. Fire clay on this basin floor at Forestdale, near Brandon, con­tains Miocene (?) plant remains. These date the lowland as Miocene or earlier, probably corresponding to one of the extensive mid-Tertiary baselevels. Flat-topped hills surmounting the Champlain lowland and below the more ex­tensive Eocene baselevel, to be described later, suggest that the main lowland cannot be earlier than Miocene.
Fig. 1. Longitudinal profiles of land forms along the length of the Otter Creek basin.

The upper profile is for the highest surface of former low relief and is almost in the Green Mts. Its undulations are regarded as divides between tributary valleys. Note the low section where the Cheshire quartzite is absent along the mountain front. The lowland is almost closed off at South Wallingford where the profile is discontinued.
The upland surface.

Steep tributaries supply most of the Otter Creek load and are cutting back into land forms of an earlier period. These are preserved best from the main river where tributaries have not begun to widen their valley floors. This old land shows best in cross section profile viewed to southward and to southeastward from the hills near Salisbury. The profile shows a divide along the summits of the Taconic Mts. with a long incline graded westward into the Hudson valley and a shorter, steeper one eastward into the Otter Creek valley. A complementary slope on the edge of the Green Mts. forms the other side of a strath at about 1200 feet elevation near Proctor. The Otter Creek valley is notched 700 feet into it on water permeable zones. The main strath divides into tributaries. The view southeastward from West Mtn. at Proctor shows these to advantage. A conspicuous one heads near Mt. Holly; Cold River drains it; the Unaka range with Killingdon, Okemo and Stratton Peak flank it and a low coll near Ludlow separates it from a similar strath extending northwestward from the Atlantic drainage slope. A second conspicuous tributary strath heads between the monadnocks of Mt. Tabor, Mt. Aeolus and Dorset Peak. It is separated from the Hoosic River strath, feeding into the ancient Housatonic, by a narrow notched coll near North Dorset.

The highest old base level recorded in the Housatonic and Hudson regions is correlated tentatively with the Eocene surface. These straths, which are the extension of this base level into the Unaka divides, are assigned to this same period. A higher, more ancient base level has been suggested in the region but this writer has been unable to recognize it amongst the Green Mt. peaks.

Benches below the upland surface.

Numerous benches occur below the straths and may pitch up to 500 feet per mile either similarly or dissimilarly. These benches correspond to the sole of overthrusts west of Wallingford and east of Manchester, Arlington and Shaftsbury. A prominent bench northeast of South Wallingford is due to Cheshire quartzite overthrust on less weather resistant dolomite. Thus minor geomorphologic features may be due to thrust plates but the major ones appear to result from prolonged erosion, influenced by high permeability of the rocks.

THE MONTEREGIAN INTRUSIVES.

Minette, vogesite, kersantite, camptonite and diabase dikes and sills represent the Monteregian intrusives. Individual masses vary from a fraction of an inch to one
hundred feet thick. Dikes predominate, have a northeast strike and follow the more prominent joint systems of the region.

All intrusives have a chilled margin with flow lines and phenocrysts arranged in flow pattern through an altered, cryptocrystalline groundmass. Phenocrysts in the marginal chilled phase are either orthoclase and andesine-labradorite or olivine and augite but rarely both. This characteristic seems to distinguish two primary types of magma. Olivine only is changed and is altered completely to a carbonate, serpentine mixture. The amphiboles and pyroxenes are highly alkaline and are usually zoned.

The physical conditions attending intrusion caused extreme "chilling" in all sizes of intrusive. Acceleration of solidification by such changes in magma composition as loss of mineralizers or assimilation of lime, are insignificant. The fine textured margin is attributed to lowered temperature caused by contact with cool wall-rock. A large dike through West Rutland marble is neither deformed nor metamorphosed by external agencies. The white marble contains throughout, epidote, tourmaline, titanite, chlorite and actinolite and had graphite leached from it; these changes indicate temperatures ranging around 450°C and thermal gradients of magmatic regions. This thermal state must have been dissipated before intrusion since none of its effects occur in the dike or have their distribution controlled by the intrusive.

The dikes follow northeastward trending joint zones which are conspicuous discontinuities in the rocks. The metamorphism of the marble occurred under pressure far above that where discontinuities exist. Furthermore the joint zones cross the thrust planes, fault breccia, and folds alike and are much later. Vesicular centers in many dikes indicate magma pressure so low that the mineralizers could unmix and help maintain magma pressure. The rock pressure during marmorization was about 1500 kgs. per cm. so that the rapid mineralizer unmixing is indicative of great pressure reduction along a northwest-southeast axis in the vicinity of the dikes and joint zones.

Greatly reduced pressure and temperature preceded dike intrusion. This seems to indicate that mountains, formed during the earlier deformation, had been eroded already to near their present summit level, permitting reduction of both rock temperature and pressure. The Montegian intrusives are pre-tertiary, because no volcanics appear on the upland erosion surface at any place, and are post-Devonian because Oriskany limestone blocks are included in at least one intrusive. They have been assigned a Carboniferous age. If this is correct, then the region had been reduced to near the level of the Green Mt. summits by Carboniferous time.
STRUCTURE OF THE MARBLE BELT.

The structures of the marble belt fall into three categories. The most spectacular are great, low angle faults which have been overturned and thrust upon themselves. The most significant structures are the close folds on the flanks of the major basins or synclinoria. Disconformities become increasingly prominent towards the west side of the marble belt and indicate that the region bordering the Taconics was alternately above and below sea level during most of Chazy, Black River and Trenton time.

The Overthrusts.

Only one overthrust is approximately continuous; it is the Green Mt. overthrust along the mountain front. Another begins northwest of Danby and follows Tinmouth Channel northward to Boardman Hill and Pine Hill before joining the Green Mt. thrust northeast of Pittsford. No other great fault has been recognized east of the Taconic summits and only short thrusts lie between these two.

The Green Mt. thrust appears relatively simple and has minor displacement between Pittsford and Leicester. However the fault is thrust on itself at Lake Dunmore between Leicester and East Middlebury and again at the New Haven River where it bifurcates. One fork continues northward and the other swings northwestward into the Monckton Hills beyond the north end of the southern marble belt. This western fork either dies out or joins the Snake Mtn.-Lake Champlain overthrust because it looses its identity south of the Hinesburg marble region.

Details of these overthrusts and their distribution for the central region appear on the block diagram and maps. (Figures 12 and 13).

Folded structures.

The marble belt between Brandon and Dorset has two major synclinoria separated by an axial arch and flanked by two major anticlines approaching geanticlines in their general characteristics. Marble occurs in or along the flanks of the synclinoria. Quarries north of Wallingford are on the western one and all further south are on the eastern. The central region is covered through most of its length by an overthrust plate or by klippe.

The western synclinorium has numerous small folds along its flanks. Their pitch is southward along the steeply overturned eastern limb but it varies widely along the more gently dipping western side. The continuity of formations on this western margin is broken by disconformities and the marble beds are omitted completely at the north end of the West Rutland valley. The first minor
structure east of this western margin has an undulatory
crest so that Canajoharie phyllite contacts the Taconic
slate at some places and Chazy marble adjoins the Cambrian
beds at others. The resultant isolated marble areas re-
semble, either anticlines or a series of fenesters, depend-
ing upon the attitude of the observer.

The secondary structures have numerous minor folds at
West Rutland on the west side of the western synclinorium
and at Pittsford Valley on the east. These minor fold
axes pitch contrariwise to their host structure and their
axial planes make an obtuse angle with its limb; they have
been called flowage folds in contrast to drag folds which
make an acute angle with the limb of their parent struct-
ure. The pitch and dip at Pittsford Valley and at West
Rutland are contrasted in figure 2.

**PALEOZOIC SEDIMENTS OF THE MARBLE BELT.**

The Paleozoic sediments are approximately two miles
thick but only two almost adjacent horizons keep approx-
imately the same characteristics throughout the length of
Vermont. Their constancy is due to areal increase of geo-
logic units as stable equilibrium is approximated more
closely in any part. The first horizon is a small section
of limestone deposited in extremely clear water during
lower Chazy time. The other is a somewhat similar form-
ation of upper Beekmantown age. Their constancy in char-
acter is due to complete or nearly complete absence of
clastic material. This indicates a low country over the
entire land area to the east such as existed in neither
earlier nor later Paleozoic time. The upper horizon is
called the Fleury quarry beds in northern Vermont and the
Columbian marble in the south. The lower horizon is the
Sutherland Falls marble which can be recognized layer by
layer from Manchester to near Georgia. Variation in all
other parts of the series with position along the marble
belt is partly responsible for use of different formation-
al names in the marble district from those adopted in other
parts of Vermont. They are as given in the following table.

<table>
<thead>
<tr>
<th>Table of Formations.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mohawkian</strong></td>
</tr>
<tr>
<td>Canajoharie phyllite</td>
</tr>
<tr>
<td>True Blue marble</td>
</tr>
<tr>
<td><strong>Chazyan</strong></td>
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<tr>
<td>Blue marble</td>
</tr>
<tr>
<td>Main W. Rutland marble</td>
</tr>
<tr>
<td>West Blue marble</td>
</tr>
<tr>
<td>Columbian marble</td>
</tr>
<tr>
<td><strong>Beekmantown</strong></td>
</tr>
<tr>
<td>Intermediate dolomite</td>
</tr>
<tr>
<td>Sutherland Falls marble</td>
</tr>
<tr>
<td>Lower dolomite</td>
</tr>
</tbody>
</table>
The Cheshire Quartzite. The Cheshire quartzite is glassy white and contains up to 10 per cent of calcareous material. The grains are about 1/16" in diameter; however the lower 10 feet is a conglomerate with quartz pebbles up to 2" in diameter. The immediately overlying beds are crossbedded in zones up to 5 feet thick. Certain bands are argillaceous and these have large magnetite octahedra. Exact thickness is uncertain but is about 300 feet.

The Clarendon Dolomite. The lower half of the Rutland formation is exposed best in Clarendon and along Tinmouth Channel. It has a few thinly bedded siliceous bands but is composed primarily of massive, gray weathering dolomite with 5 to 10 per cent of coarse sand grains. This part is designated the Clarendon dolomite and is 2000 to 3000 feet thick. Near the top it has two cream to orange colored, 10 to 20 foot thick, marble beds separated by a green micaeous band. This zone is particularly conspicuous 1/4 mile west of Forestdale, in the eastern part of Proctor village and beside the highway at the south edge of East Dorset village.

The Florence dolomite. The Florence dolomite, overlying the Clarendon dolomite, is mainly well bedded, buff weathering, sandy dolomite with 15 per cent graywacke. Ripple marks, corrosion channels, solifluction structures and interformational breccias are characteristic. The dolomite grains are minute and elongate parallel to the bedding. Quartz, microcline, albite and muscovite are abundant, and biotite, tourmaline, zircon, garnet and titanite are not rare. Graywacke and micaeous slates, distributed through the 1000 feet of the formation, alternate along the strike of a single zone.

The Pittsford Valley Dolomite. The overlying 800 feet of Pittsford Valley dolomite has about 30 per cent of graywacke beds occurring in cyclic series. All graywacke zones are about 10 feet thick; they have buff weathering dolomite "spacers" which are thick in the lower part and thin to 10 feet in the upper portion. Quartz, orthoclase, microcline, albite and oligoclase, constituting most of the graywacke, are angular to poorly rounded.

The Crossbedded Zone. The crossbedded zone is a calcareous
Fig. 2. Block diagrams showing pitch of minor structures.
A. Pittsford Valley quarry no. 8.
B. North part of Main West Rutland deposit.
sandstone characterized by crossbedded structure throughout its 250 feet. The sand grains are dominantly well rounded quartz, microcline, albite and oligoclase. Rounded rock fragments are not uncommon and Zircon, tourmaline, and vesuvianite have been recognized.

The Lower Dolomite. The lower dolomite begins abruptly at the top of the crossbedded zone. A disconformity marks the boundary at some places. The rock has gray weathering dolomite beds averaging about 8" thick and contains little detrital matter. Total thickness is 160 to 200 feet.

The Sutherland Falls Marble. The Sutherland Falls marble is a 90 foot, cream colored band with contorted chains of dolomite grains across any surface. It has one siliceous band (the Hen Hawk layer) through the middle.

The Intermediate dolomite. The Intermediate dolomite is a thick bedded, gray dolomite containing some siderite. A silicified zone occurs near the mid section at most places. This zone is not arenaceous and the origin of the silica is uncertain. The sand content of this formation rarely exceeds 15 per cent.

The Columbian Marble. The Columbian marble is 500 to 600 feet thick. The lower 50 feet is lithologically similar to the Sutherland Falls marble but contorted forms are not conspicuous and the markings usually have a linear pattern. The entire formation weathers white but the color varies from white to dark gray. The upper part is usually light with numerous green silicate bands. Thick, buff weathering, argillaceous, gray dolomite bands mark the upper limit of the formation.

The Blue marble. The blue marble zone characteristically has a deep blue gray color but has been bleached white along zones of magmatic alteration. Brown weathering, argillaceous, gray dolomite beds are numerous and, where the blue color is lost, become green silicate veins. Argillaceous limestone bands are numerous above the disconformity at the top of the Upper West Rutland marble. (Figure 3). This marble contains abundant crinoid stems, orthocerid, Gonio-ceras, turritiforme and other gastropods and colonial corals.

The Canajoharie Phyllite. A black phyllite of indeterminate thickness overlies the blue marble. Mica flakes lie parallel to the cleavage except where they are in thick quartz albite pegmatite-like veins. Cross flakes which give the mesh structure, so characteristic of the Taconic slate are lacking.

THE PRE-CAMBRIAN SEDIMENTS.

The Pre-Cambrian sediments have not received the attention accorded the Paleozoic formations. However three
Figure 3. Disconformity between deposits at West Rutland.

Note the truncation of the Upper West Rutland marble north of the Barnes quarry.
formations have been recognized. (Figure 4).

Nickwackett Graywacke. The upper member is a bedded graywacke with numerous arkose and fine conglomerate beds. Differential weathering of beds gives many outcrops a ribbed surface. It is seen overlying the older dolomite in the syncline at the Trout Hatchery above Grangerville. Pebbles of the conglomerate are sliced badly and the rock approximates a phyllonite.

Mendon Dolomite. The Mendon dolomite underlies the graywacke and is about 400 feet thick. The upper part, below a thin gradational phase, is a blocky, buff weathering dolomite with cherty nodules. This passes down into a sandy, crossbedded, buff weathering dolomite. A rather clean, buff dolomite lies above one graywacke lens in the formation.

Occasional conglomerate lenses occur near both the top and bottom of the formation. The coarser fragments are predominantly bluish quartz but feldspars are frequent and the finer textured phases are distinctly feldspathic and strongly crossbedded.

The Lower Graywacke. A chloritic schist band occurs locally at the bottom of the dolomite and an indeterminate thickness of feldspathic sandstone and arkose make up most of the member. It is phyllonitized in most outcrops on Coxe Mtn. and east of Sugar Hollow Brook. Exposures are usually light colored but the rock becomes dark colored mylonite adjacent to the major thrusts at Coxe Mtn. and Pine Hill.

GEOLOGIC HISTORY FOR THE CAMBRO-ORDOVICIAN.

The Cheshire quartzite and the sandy phases of the Rutland formation are calcareous sandrocks with carbonates making up less than 10 per cent of the quartzite and more than 10 per cent of the Rutland formation. Both are ripple marked, crossbedded and have numerous scoured channels. Interformational breccias are not infrequent and solifluction features are common. Thus shallow water conditions prevailed during accumulation of a mile of calcareous sediments. Feldspathic sandstones are characteristic of the upper part of the Rutland formation. Their detrital material is highly abraded but slightly weathered. These are characteristic results of beach accumulation and indicate that the Rutland formation is an on-shore facies. The fine textured, clay decomposition products were carried to quietier and presumably deeper water and constitute the offshore facies.

Cross bedded structure characterizes the upper part of the Rutland formation and suggests beach bar conditions of deposition. This crossbedded zone thins southward indicating that beach bar conditions began later and lasted
Fig. 4. Geologic map and cross section of Mendon series at north end of Castleton and Rutland quadrangles. Note the nonconformable position of Cheshire quartzite on the Mendon series.
for a shorter period in the south than in the north. The lower dolomite rests disconformably upon the crossbedded zone at a few places. It has a constant thickness to east of Burlington.

The succeeding Beekmantownian, Chazyan and Mohawkian formations, with the exception of the Intermediate dolomite, have very little sand in them. Parts are dolomite and bands of slate up to 1/4 inch occur locally; elsewhere the rock has less than 1 per cent of sand particles. This records a time of clear water and complete absence of detrital material during deposition of the Columbian zone.

Disconformities, so pronounced as to indicate hills with 10 per cent slopes, separate the Chazy and Mohawkian beds in part of the West Rutland district. (See figure 2). The structure indicates a very significant elevation on the western anticline which cannot be recognized on the central arch. The middle Mohawkian beds contain numerous calcareous slates or shales and the upper part or Canajoharie phyllite is a feldspathic rock passing into an argillitic graywacke.

The entire calcareous series, instead of only a part of the Chazy beds, is absent between Whipple Hollow and the Florentine Blue quarries. Canajoharie phyllite rests directly upon Taconic slate. This represents rejuvenation of the land area to the east and also to the west and filling of the old seaway with only slightly decomposed detritus. The movements culminated in the Taconic disturbance.

It is significant that the Taconic slate fabric indicates at least two conspicuous deformations whereas only one strong deformation is recorded in the Canajoharie phyllite. Their contact is an unconformable one rather than a thrust fault type as it has been designated in most report.

PETROLOGY OF THE MARBLES.

Petrological studies of marble fall into five categories.

1. Grain size.
2. Grain form.
3. Width of openings.
5. Metamorphism.

Each is important to understanding the marble and making use of it, and has been studied in detail.

GRAIN SIZE. Finest grain occurs in the marble at Swanton, Fonda Junction, Winooski lime plant and Hinesburg. The original calcite sand grains are broken into about
300,000 crystals per cm.\(^2\). Size begins to increase through Middlebury, and reaches about 6000 per cm.\(^2\) at West Rutland. Grains average 2500 per cm.\(^2\) in the eastern synclinorium and on the eastern limb of the western synclinorium.

**GRAIN FORM.** Very fine grained marbles have approximately equidimensional crystals. Size increase beyond 6000 to 8000 per cm.\(^2\) is accompanied by dimensional elongation parallel to axial planes of the minor folds and increased irregularity of outline. Measurements show that:

\[
\frac{\text{Length of contact}}{\sqrt{\text{Number of grains}}} = 2 + .20
\]

Irregular outlines give a high coefficient (above 2) and equidimensional regular grains have a coefficient considerably below 2.

**WIDTH OF OPENINGS.** The porosity of a rock is the product of area of openings and the width of openings where the spaces have an irregular sheet-like form as in most metamorphic types. The area of openings in a given volume can be determined from length of openings in a given area by a simple calculation; porosity can be determined by direct measurement; the width of opening is estimated by division of the first into the second. Width varies from \(2 \times 10^{-6}\) to \(10 \times 10^{-7}\) cms.

Petrofabric Studies in Marble.

The petrofabric studies fall into four general divisions as follows:
1. Orientation surfaces.
2. Susceptibility of minerals to orientation.
3. Areal distribution of orientation types.

The marbles are composed essentially of calcite; Pittsford Valley varieties contain up to 8 per cent of dolomite and the West Rutland and Danby marbles carry considerable mica, chlorite and epidote. Dolomite orientation has been studied but the flaky minerals have not been examined in detail.

**ORIENTATION SURFACES.**

The orientation surfaces in carbonates at West Rutland are \(01\bar{1}2\) and \(0001\). The \(0001\) orientation is pronounced at Pittsford Valley but has not been recognized at Danby. Type of orientation surface seems to be directly related to intensity of folding. (Figure 5). (Figure 6). The \(0001\) orientation almost disappears away from sharp folds and even the \(01\bar{1}2\) twin surfaces become less abundant in the regular stretches between fold axes. Thus areal distribution is limited sharply.

The \(01\bar{1}2\) orientation is interpreted as mechanical glid-
Calcite orientation in the West Rutland deposit is illustrated by the diagram for Double Belt marble, (Fig. 7) from the S.W. corner of pillar 43 in the Main quarry. (See figure 6). This location is close to a small anticline and shows some features of all types of orientation. The rock sections were cut perpendicular to the "b" or tectonic axis. The principal axes of all grains show an extremely random orientation. (Fig. 7a). The twin grains form an indistinct girdle about the "b" axis; (fig. 7c); this girdle is developed better in most other parts of the deposit. Poles of normals to the 0112 plane are grouped on either side of the axial plane of the nearby fold. (Fig. 7b). Poles of the principal axes of untwinned grains show distribution similar to poles of normals to the 0112 plane; (figure 7d). A high pole density in the untwinned grain pattern occurs along the "b" axis and is even more conspicuous in slightly deformed sections of the deeper quarry levels. The diagrams show two definite orientations related to axial planes of folds; they are poles to the 0112 surface of twinned grains and principal axes of untwinned grains and both types are normal or subnormal to axial planes of folds.

Principal axes of twinned and untwinned calcite are arranged perpendicular to the axial planes of minor folds at Pittsford Valley, (Figure 8), simulating the untwinned grains at West Rutland. The principal axes of all grains form a girdle about the "b" axis in Danby marble (figure 9) simulating the the twinned grains at West Rutland.

SUSCEPTIBILITY TO ORIENTATION.
Calcite is the most susceptible mineral in marble. The flaky minerals have not been studied statistically and quartz has not been found in sufficient abundance to undertake an investigation of its behavior. The principal axes of dolomite form a girdle about the "b" axis at Pittsford Valley, (Figure 8d), even although calcite in the same rock
has its principal axes perpendicular to the axial plane of the minor folds.

**AREAL DISTRIBUTION OF ORIENTATION. TYPES.**

Relative abundance of grains with *c* axes oriented normal to axial plane directions was recognized as related to the folds. A series of determinations along the sharp fold at 180 feet depth showed uniformly high orientation (figure 10 a, c, e) and this was duplicated to some degree on each minor fold. Other series in the regular intervening parts of the quarry showed lower degree of orientation (figure 10 b, d, f). The variation in degree shows up particularly strong in the aggregate of the principal axes and remains about constant in principal axes of untwinned grains.

The degree of tectonic deformation is very uniform at Pittsford Valley and orientation is equally constant throughout the deposit. (Figure 8). The same is true in the Danby deposit although the orientation follows a different rule.

**ORIGIN OF ORIENTATION.**

The orientation of the O1T2 gliding planes parallel to the axes of minor folds is regarded as a simple mechanical process. It has been explained so often in books on petrofabrics that no further comment will be made. The orientation of the vertical crystallographic axes disregards surfaces of greatest ease of movement and is a new type. Also marbles with crystallographic orientation have grain elongation parallel to the base.

The vertical crystallographic axis is the most compressible direction in calcite and the most resistant to solution effects. Alignment according to either the elastic or the chemical stability of the minerals, suggests that one or both of these two processes influenced the orientation.

Simple compression could elongate the crystals parallel to the base but would diminish their thickness as the length increased. Actually the grain size in poorly oriented simple fabric marbles at West Rutland is from 5000 to 7000 per cm. and in some highly oriented varieties diminishes to 2500 to 3500 per cm.2. The minimum dimension remains the same, indicating that compression is insignificant. Statistical studies of the untwinned grains shows that they are present in almost all parts of the West Rutland deposit but that their relative abundance increases with grain size up to about 4000 grains per cm.2. Increase in abundance and increase in dimension parallel to the base without diminution in thickness, are attributed to accretion of some less favorably oriented grains upon the more favored ones. The recry-
stallization is extremely local, causes a dimensional elongation, and preserves the favorably oriented grains.

The axis orientation in the West Blue and the Pittsford Valley deposit is believed to originate in this fashion. Twinning, characteristic of marble in these deposits, is regarded as due to minor later stress, converted to strain. The Danby orientation is a girdle fabric like the early fabric at West Rutland but is regarded as a third stage superimposed upon an axis orientation like that at Pittsford Valley. Paratectonic magmatic solutions, almost lacking in the Pittsford Valley and West Blue deposits, and only moderately abundant in the West Rutland Main deposit, penetrated the Danby marble and caused many mineral transformations. Experimental work shows that solutions affect the elastic properties of these marbles by lowering the stress necessary to cause intergranular deformation. The magmatic solutions may be responsible for the different fabric in the Danby deposit through their effect on the elastic qualities of the stone.

The fabric diagrams for an augen-like structure, in some West Rutland marble, are presented for consideration. The rock seems to show what happens to fabric, grain size, and grain form when a marble is deformed in the presence of magmatic solutions. Opportunity to study the rock will be afforded during the excursion.

Metamorphism.

All Cambro-Ordovician rocks of the marble belt have been subjected to both tectonic and magmatic metamorphism, but the degree has varied widely. The white, cream or gray rocks of the Rutland formation have essentially the same composition as the red sandrock between Monkton and Swanton. Difference in appearance is due to change of ferric hydrate and ferric oxide in the northern rocks to magnetite and iron carbonate in the southern region. The same transition occurs along all mineral veins as far north as Swanton so that it is not altogether unexpected in the more intensely changed southern section. Change in color is due to deoxidation, dehydration and high temperature carbonatization of the ferric compounds.

Color changes are not limited to the Rutland formation. The marble is primarily gray due to minute graphite particles but is decolorized adjacent to fractured dolomite beds and silicated bands. The silicate bands are predominantly chlorite but contain also abundant mica, epidote, actinolite, tourmaline, titanite, quartz and occasional pyrite. This mineral assemblage is indicative of high temperature, hydrothermal action.

The white marble occurs usually in sharply folded sections and the same stone becomes dark gray where the
structure becomes regular. This is illustrated by the large body of light marble in the gently pitching, highly folded structure at West Rutland. Most of this is gray where the structure becomes regular at the McGarry quarry up the dip from the Green Mtn. Company's test hole in the West Rutland meadow, and down the dip at the bottom of the Sherman quarry. A large body of light colored marble appears in a sharp fold in the "L" bed at the north wall of Pittsford Valley quarry no. 2. Not all folds have light marble but if light marble occurs in a normally gray band it is on such a structure.

The light colored marbles of Vermont have more equi-dimensional grains than the gray types. The difference is attributed to increased mobility of material in proportion to increased volume of magmatic solutions.

The chlorite-mica bands are formed usually by change of dolomite beds. The best cases at West Rutland are the inferior part of the Hard Layer and the green stripe of the Rutland Italian which become dolomite in the less metamorphosed parts.

BIBLIOGRAPHY.

The writer does not recognize requisite accuracy in many preceding maps of the region nor does he concur with many opinions expressed in earlier reports, including some of his own. Certain maps in the XVI International Geological Congress guidebook no. 1 confuse the Sutherland Falls marble, the Columbian marble and white deposits in the blue marble zone and so give a poor basis for independent structural study. However a representative bibliography is appended so that each excursionist may be able to evaluate the numerous opinions expressed on this key region.

PHYSIOGRAPHY. - GEOMORPHOLOGY.


Stratigraphy.


METAMORPHISM.

G. W. Bain, Calcite marble. Econ. geol., 29, 121-139, 1934.

GENERAL.

ITINERARY.

STRUCTURAL PETROLOGY EXCURSION. October 14, 1938.

ASSEMBLE. West Rutland office, Vermont Marble Company. 2 P. M.

EXCURSION 1. Visit the Main quarry and examine sites of specimens used in making petrofabric diagrams.

EXCURSION 2. Leave West Rutland office at 4 P. M. for visit to Pittsford Valley quarries and to examine site of specimens used in making petrofabric diagrams. Return to Rutland via Proctor and examine augen-like structure in blocks of West Rutland marble. Arrive Rutland 6:15 P. M.

EVENING PROGRAM. October 14, 1938.

Leave Rutland 7:15 P.M. for marble exhibit, Vermont Marble Company, Proctor, Vt. Educational and architectural specimens, and vertical and horizontal cores across the West Rutland structure will be set out in addition to the regular displays. The group will have an opportunity to see the 80 ton blocks being carved for the Oregon State capital. Moving pictures showing different operations in the marble industry will be run. Return to Rutland (6 miles) for the night.

MAIN EXCURSION. October 15, 1938.

MORNING. Leave Rutland 8:30 A.M. for Pittsford. Follow route U.S. 7 to Pittsford. Take first right north of bridge at Pittsford village. Continue on dirt road straight through four corners at Grangerville to Mt. Nickwackett. Examine section of Mendon series. 9:45 Leave Nickwackett locality for Florence via the Trout Hatchery. Note Nickwackett graywacke overlying Mendon dolomite on the right (north) as the road follows the brook toward Grangerville. Note bedded dolomite (Rutland) in brook bed below bridge at entrance to Grangerville. At four corners, turn right, then left; this road is over phyllonitized graywacke and arkose below the Mendon dolomite. Cross Sugar Hollow Brook and pass the Sugar Hollow road on the right. Take next right to U. S. 7. Note Cheshire quartzite at west base of Coxe Mtn. Turn right on U. S. 7 and take first left to Florence. Note Clarendon dolomite near Otter Creek bridge and Rutland R.R. Turn right on Florence Road and then left to Pittsford Valley quarries. PARK CARS. Examine ripple marks, solifluction, and other shallow water structures in Florence dolomite. 10:45 A.M. Proceed to quarries. Park cars and return for short distance along road to study section from base of Pittsford Valley dolomite to Blue Marble. Visit Pittsford Valley quarry no. 8/. LUNCH AT THE CARS. 12:30.

AFTERNOON. Leave at 1:15. Turn right on Florence road. Note Florence dolomite on right. Continue due south. Note flood levels marked on ledge near covered bridge about 1 mile south of Florence mill. Note syncline of
Sutherland Falls marble on right at Proctor town line. Columbian marble begins at base of "crooked hill". Canajoharie phyllites begin east of C. & P. R.R. tracks at top of hill. Pass through Proctor via marble bridge turning right after crossing it. Riverside quarry is at first cross road to west; on Columbian marble; cut by augite porphyrite dike. Flint and Johnson quarries east of road at this place are on Sutherland Falls deposit. Continue to Center Rutland and turn right on concrete. Note thinned Columbian-Blue zone in small valley at Rutland town line. Canajoharie phyllite immediately to the west. Proceed to West Rutland office, Vermont Marble Co. (2:00 P.M.).

Visit underground and see Monteregian dike at south end of Covered quarry. (This quarry is 200 feet deep; those not wishing to walk the stairs may collect fossils from Mohawkian beds east of the quarry). Note the blue marble changed to white along certain silicified bands in the roof of the Main quarry.

3:00 P.M. Leave for McGarry and Hyde quarries on west side of West Rutland. Collect Chazyan gastropods and see Monteregian dikes. Dikes cause some control of metamorphism at this place; induce cream color in marble.

3:30 P.M. Leave for Clarendon Springs by route 3. Keep to the left after leaving West Rutland. Turn sharp left uphill at 1/4 mile south of Green Mtn. Co's mill and quarry at Clarendon. Continue to hill top; road crosses Clarendon dolomite to Canajoharie phyllite. Take private road at hill-top and turn right where it joins Boardman Hill road. PARK CARS. See Mendon series overthrust on Canajoharie phyllite at 500 feet east.

5:00 P.M. Continue south along west base of overthrust to Chippenhook. Road follows near marble dolomite contact. Turn left at Chippenhook. Road crosses Cheshire quartzite and Mendon series to Otter Creek valley. Turn right and continue south to first fields. PARK CARS. Rutland formation and Mendon series overthrust on marble at 800 feet west of road. Thrust plane and breccia exposed.

5:40 Return to Rutland. Arrive about 6:15.

Alternate trips.

October 15, MORNING. Visit to Danby quarries. The pillar plan in these quarries illustrates the type of support in a modern quarry operating on almost horizontal deposits. Quarrying and hoisting machinery will be explained.

AFTERNOON. Visit West Rutland quarries. The pillar plan differs from the Danby scheme. Quarrying is in progress on both vertical and gently inclined beds.

Fig. 6. Map of Main quarry, West Rutland, Vt. showing location of specimens used in orientation study. Distribution of fabrics is shown in appropriate patterns.

Fig. 7. Orientation diagrams for West Rutland marbles, showing orientation surfaces. A to D. Diagrams for Double Belt marble from pillar 43, Main quarry, West Rutland, Vt. All sections are cut perpendicular to the "b" or tectonic axis. The line across the diagrams is vertical in all cases.
A. Diagram for poles of all vertical crystallographic axes.
B. Diagram for poles of normals to 0112.
C. Diagram for poles of vertical crystallographic axes of twinned grains.
D. Diagram for poles of vertical crystallographic axes of untwinned grains.
E. Diagram for poles of all vertical crystallographic axes in West Blue marble. Specimen W.B. 1. Quarry
F. Diagram for poles of all vertical crystallographic axes in upper West Rutland deposit. Barnes quarry.

Fig. 8. Orientation diagrams for Pittsford Valley marble.
A. Diagram for poles of all vertical crystallographic axes for calcite grains in spec. P.V. #2. Quarry no. 8, west pillar.
B. Same specimen as A but diagram is for dolomite.
C. Diagram for poles of all vertical crystallographic axes for calcite grains in spec. P.V. #4. Quarry no. 6, east pillar.
D. Same specimen as C but diagram is for dolomite.
F. Same as E but for spec. P.V. #6a, quarry no.1 entrance, "A" layer.

Fig. 9. Orientation diagrams for Danby marble. All specimens are from top of Brook deposit.
A. Diagram for poles of vertical crystallographic axes of all grains in spec. B-2, from flat beds at south side of Brook quarry no. 2.
B. Same as A but slightly to west where beds are vertical.
C. Same but from face of gently dipping beds, New York quarry.
D. Same from middle opening above New York quarry.
E. Same from old opening on north side of Dorset Mtn.
F. Diagram using all untwinned grains in specimens for diagrams A to E. Poles of vertical crystallographic axes referred to vertical line through "b" axis.

Fig. 10. Orientation diagrams to contrast regular and highly deformed parts of West Rutland main deposit.
A., C & E are for specimen #5 from deformed section of Rutland Italian layer.
B., D, & F are for specimen R.I.M. #85 from the undeformed part of the Average layer.
C & D. Diagrams for poles of vertical crystallographic axes of all grains.

Fig. 11. Orientation diagrams for Rutland Italian marble with augen-like structure.
A, C & E are for augen-like masses.
B, D & F are for matrix of augen.
C & D. Diagrams for poles of vertical crystallographic axes of untwinned grains.

Fig. 12. Block diagram for the southern marble belt.

Fig. 13. Map for the central part of the southern marble belt.
Fig. 12.

[Diagram showing geologic formations and markers including:
- Phyllite
- Marble
- Rutland Form
- Cheshire Qtz.
- Taconic Slate
- Mendon Series]