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GUIDEBOOK 1 - - - EXCURSION A–1

EASTERN NEW YORK

AND

WESTERN NEW ENGLAND

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Guidebook 1: Excursion A–1

EASTERN NEW YORK
AND
WESTERN NEW ENGLAND

Prepared under the direction of

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EASTERN NEW YORK AND WESTERN NEW ENGLAND

Prepared under the direction of
Chester R. Longwell[1]

ABSTRACT

The region traversed by excursion A–1 has great diversity of topography and geology but consists of three major units. (1) The Hudson Valley and the Champlain Lowland together constitute a long, narrow belt of low altitude, underlain by disturbed strata of early Paleozoic age. This belt is continuous with the folded Appalachians of Pennsylvania but contains no formations younger than the Devonian. Much of the deformation occurred near the end of the Ordovician period; the part played by the Appalachian revolution of Permian time has not been determined quantitatively for most of the belt. (2) The Adirondack Mountains form a rugged highland west of the Champlain Lowland. A great complex of pre-Cambrian igneous rocks, both acidic and basic, is intruded into metamorphosed sedimentary formations. The most conspicuous rock unit is a mass of anorthosite, which is associated with gabbros on the one hand and syenitic rocks on the other. There are numerous unsolved problems relating to the origin and the structure of this great complex. (3) Western New England consists in large part of metamorphic formations, many of which have not been dated. The Taconic Range and the Green Mountains, with an intervening belt of metamorphosed limestones, present difficult but fascinating structural problems. In central Massachusetts and Connecticut a narrow belt is occupied by Triassic sedimentary rocks with included basic lavas and intrusive bodies. These rocks have been faulted and tilted but not appreciably altered.

The resistant rocks of the entire region preserve remnants of an old peneplain, elevated, tilted, and greatly dissected. Lower and less extensive surfaces are developed on weaker rocks. The region was glaciated during Pleistocene time, and characteristic glacial débris mantles much of the surface.

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[1] In addition to the collaborators whose names appear in this guidebook, Prof. Charles Schuchert, Dr. E. B. Knopf, and Mr. L. M. Prindle helped generously in assembling and preparing much of the material.

INTRODUCTION

By Chester R. Longwell

Scope and purpose.—More than 90 years ago the Paleozoic strata of the Hudson Valley and the Champlain Lowland were studied by the newly organized New York Geological Survey; and the term "Champlain group" was proposed for a series of strata now included in the Ordovician system. At the same time the first study of the Adirondack region was begun, and attempts were made to unravel the difficult stratigraphy and structure on the west slope of the Taconic Range. The names of W. W. Mather, James Hall, and Ebenezer Emmons are conspicuously associated with these early projects. Charles Hitchcock did pioneer work on the marbles and other metamorphic rocks of northern Vermont, and Sir William Logan extended his remarkable structural studies to the region of Lake Champlain. It is nearly a century since Edward Hitchcock described as "bird footmarks" the dinosaur footprints in the "New Red" (Triassic) sandstone of Massachusetts. James D. Dana studied many of the geologic problems and also the mineralogy of the region.

The route to be followed in excursion A-1 is indicated on Figure 1. In the Hudson Valley the Paleozoic stratigraphy will be reviewed briefly, and evidence of two notable disturbances will be examined. In the Adirondack Mountains the results of recent field studies will be used in considering the form of the great anorthosite mass, the mechanics of its intrusion, and the differentiation of the magma into various rock types. The complex belt of folds, thrusts, and schistosity in western Vermont and Massachusetts still holds numerous major problems of stratigraphy and structure; these will be pointed out during examination of the results of recent detailed work. Old erosion surfaces are particularly well displayed in western New England. They will be pointed out, and their bearing on the late geologic history will be discussed. In the Connecticut Valley the composition, structure, and fossil content of the Triassic rocks will be studied, and the problem of the original extent of the Triassic strata will be considered. In this area features that prove widespread stagnation of the last ice sheet are especially well developed.

Several museums in the region have rich paleontologic and geologic collections, which will be utilized to supplement the field examinations.

Geography.—The region has large variations in topographic relief. In the coastal belt the land is low and the streams are drowned; tides reach up the Hudson River to Albany, 150 miles (241 kilometers) inland. Numerous points in the Adirondack

Mountains are from 3,000 to 5,000 feet (914 to 1,524 meters) above sea level, and altitudes in the Green Mountains are comparable.

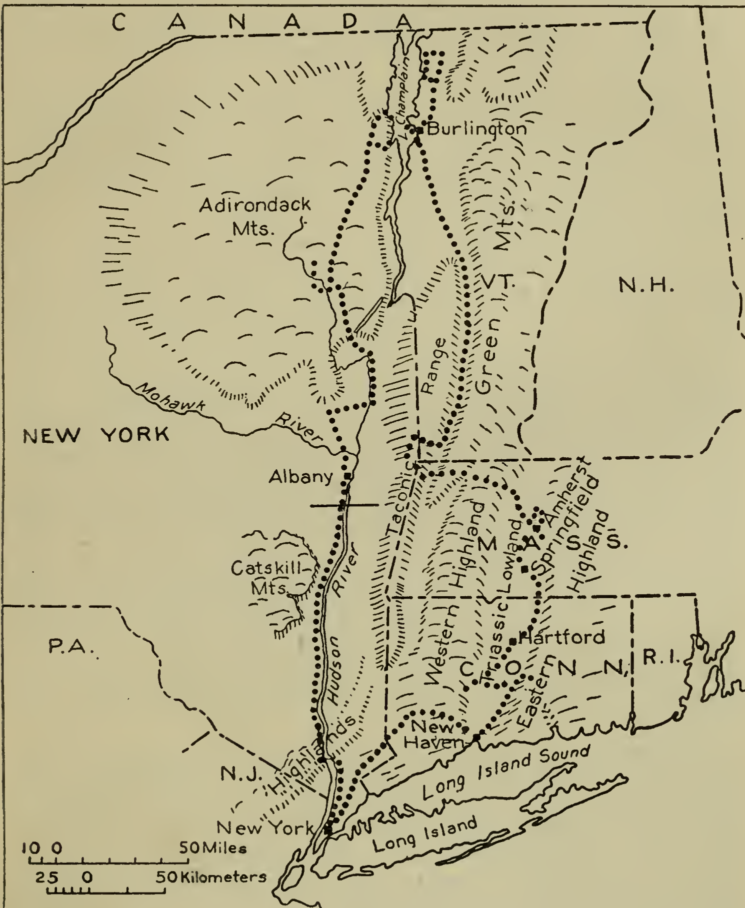


FIGURE 1.—Index map of eastern New York and western New England. The line south of Albany indicates the position of the structure section in Figure 3. Heavy dotted line shows route of excursion.

Local climate is controlled appreciably by the relief, but even more by distance from the coast. Near Long Island Sound the influence of the Gulf Stream is strong, and therefore the winters are comparatively mild for the latitude. Farther inland the mean temperatures are considerably lower, even in the lowland belts; and in the mountain districts the winters are rigorous. The entire region is in the belt of cyclonic storms and has a mean annual rainfall in excess of 40 inches (102 centimeters). Therefore conditions are favorable for agriculture wherever the soil is suitable. In large areas, however, the surface is rugged and the soil is stony and thin. The Hudson Valley and Champlain Lowland belt and the Triassic Lowland have large continuous tracts of good farm land. Fruit growing and general farming are practiced extensively in both these areas. In addition the Triassic belt produces large quantities of tobacco, although it is far north of the latitude at which this crop is grown generally in the eastern United States.

Early history.—In 1609 Henry Hudson arrived at the mouth of the river that bears his name, and Samuel Champlain reached Lake Champlain from the St. Lawrence Valley. Shortly after this date the Dutch colonized Manhattan Island, where they founded New Amsterdam, and gradually extended their settlements up the Hudson Valley; many of the place names in the region are reminiscent of this early Dutch invasion. The French established some settlements in the Champlain Lowland. In the meantime the English were founding colonies along the east coast, starting with eastern Massachusetts in 1620 and spreading inland. Late in the century British rule superseded the Dutch in the Hudson Valley, and in 1763 the territory held by the French also passed into the hands of Great Britain. Soon afterward began the revolt of the British colonies, which culminated in the War of Independence in 1775. Many activities of the war centered about New York, and the British used Lake Champlain and the Hudson Valley as a military route from Canada. Some of the battle fields lie along the route of the excursion.

Population and industries.—The coastal belt and the valleys of the larger streams are occupied by populous industrial centers. As New York is the largest port in the country it is naturally an important manufacturing center. Abundant water power invited the establishment of mills and factories in New England at an early date. As a result this region has a large immigrant population, derived in considerable part from the countries of southeastern Europe but including also numerous French Canadians. During the past few years a considerable part of the country's textile manufacturing has been shifted from New England to various Southern States.

Geology.—The route of the excursion traverses several districts that differ greatly in stratigraphy, structure, and geologic history, and therefore it is best to present the discussion of the geology of each district separately as the excursion proceeds.

A general outline of the geologic history is given here, however, to make clear the relationships of the different districts.

The Adirondack mass appears to have been a positive unit since pre-Cambrian time. East of it the early Paleozoic seas spread through the Champlain Lowland and Hudson Valley belt, which was part of the Appalachian geosyncline, connecting the St. Lawrence Valley with the seas to the south. This segment of the geosyncline was not a simple trough but was made up of several irregular basins in which were deposited contemporaneous sequences of strata with strikingly different lithology. Sediments were supplied in part by the Adirondack land mass but also in considerable quantities by highlands to the east, where the Green Mountain axis seems to have been persistently emergent. The geosyncline as a whole was considerably wider than the present lowland belt, in which close folds and thrust faults represent many miles of shortening.

Sedimentation in the trough was not continuous. Near the end of the Ordovician period the strata from the St. Lawrence Valley to Pennsylvania were intensely deformed, and a long interval of erosion followed. In the Hudson Valley the next strata deposited are late Silurian. These are followed by Devonian limestones and shales; but it is not known how far any of these formations extended northward, as they do not now exist in the valley as far north as Albany. Since Devonian time the region has been entirely emergent, so far as can be judged from sedimentary evidence. During the late Devonian western New England was uplifted strongly and shed large volumes of sediment to the west. Probably this uplift was part of the Acadian movement, which was especially severe in southeastern Canada.

The Appalachian movement near the end of the Paleozoic era deformed the Devonian strata in the southern part of the Hudson Valley; but farther north the results of this movement, if they exist, have not yet been differentiated from those of the older deformations. In late Triassic time, after erosion had reduced the region to subdued relief, thick deposits accumulated in a series of inland basins, some of which probably were formed by faulting. (See fig. 21.) Intrusion and extrusion of basic magma accompanied the sedimentation. At the end of the Triassic period or early in the Jurassic there was strong upwarping in southwestern Massachusetts and western Connecticut, accompanied by intensive faulting on the east and west flanks of the uplift. Probably these movements affected much of New England, but their results are seen directly only in the areas of Triassic rocks, which are broken and tilted. (See pl. 15, figs. 23, 33.) After this disturbance erosion continued unhindered until the entire region had been reduced to a nearly even surface of low altitude.

It is possible that during the Cretaceous period a belt of country along the Atlantic coast was submerged and a veneer of coastal-plain sediments reached far inland on the peneplained surface. Although no remnants of such sediments remain in southern New England, during Tertiary time the major streams became superposed across belts of resistant rock. It is difficult to explain such superposition without assuming that the streams were let down from a sedimentary cover.

Probably the Tertiary uplift was of long duration and occurred in several stages. It was strongest in the northern part of the region, and therefore the peneplain was tilted toward the south and southeast. In northern Massachusetts and in Vermont wide remnants of the old surface now range in altitude from 1,600 to 2,000 feet (488 to 610 meters). In Connecticut the surface slopes visibly to the south and disappears beneath Long Island Sound. The superior resistance of the New England bedrock is responsible for the persistence of these large remnants; in eastern New York the Hudson River and its tributaries have cut away the weak sedimentary formations, and only the Catskill Mountains remain as a record of the once extensive plateau.

Pleistocene glaciation changed details of the topography more by deposition than by erosion. Lakes formed by temporary ice dams left extensive deposits, and locallv imoortant changes in drainage were effected.

GEOLOGY OF THE HUDSON VALLEY

By Chester R. Longwell

The Hudson River has its headwaters on the resistant pre-Cambrian rocks of the Adirondacks, but to the south it flows through a wide lowland developed on the weak Paleozoic sedimentary formations. The lowland is 15 to 20 miles (24 to 32 kilometers) in width; it is bounded on the west by the Catskill Mountains and the Helderberg Plateau, on the east by the Taconic Range and the Rensselaer Plateau. (See pl. 1.) North of Albany, where the Mohawk River comes in from the west, the lowland widens enormously. Adjacent to the inner valley is a conspicuous terrace, 150 to 200 feet (46 to 61 meters) in height, which records a notable uplift of the region. The most recent record is one of depression; a long stretch of the stream course has been drowned, and the rock floor of the inner valley has been buried under a thick deposit of silt. (See fig. 2.)

For a long distance the stream flows on weak Ordovician shales. About 60 miles (97 kilometers) above its mouth the river abruptly leaves the Paleozoic belt and enters a narrow gorge cut into granite and other ancient rocks in a southwestward extension of the New England highlands. South of the highland belt the valley widens at the expense of weak Triassic rocks along the west side.

Stratigraphy.—In the belt of Paleozoic rocks north of the Highlands of the Hudson (pl. 1) the oldest rocks (Lower Cambrian) are on the east side of the Hudson lowland, where they are exposed on the west flank of the Taconic Range. These formations are of particular interest because they were included in the Taconic system of Emmons. Some of the strata are exposed above the Bald Mountain thrust, north of Albany. (See fig. 7.)

The Ordovician formations of the valley are of two contemporaneous sequences, whose differences are explained by assuming separate basins of deposition. The eastern sequence has been

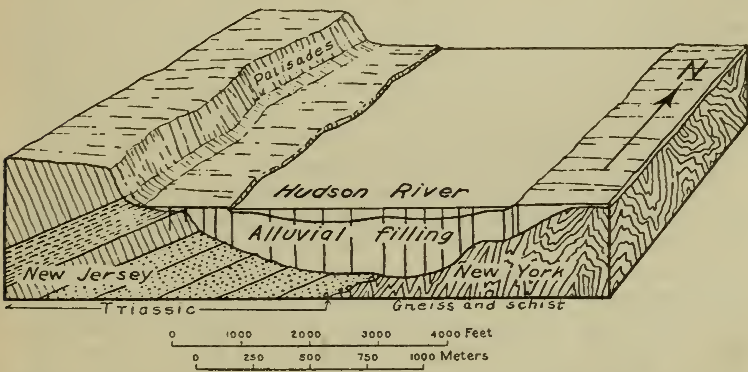


FIGURE 2.—Section across the Hudson River near New York City. Depth of rock floor shown to true scale. Vertical lines represent borings. Profile and structure modified from D. W. Johnson.

thrust partially over the western, hence the original relationship is obscured. The principal formations, with Ruedemann's interpretation of their correlation, are represented in Figure 6.

The Silurian limestones of the region represent a very late stage of the period. A considerable thickness of Devonian strata is present. Most of the formations vary in character from south to north, and some have only local development. No strata younger than the Middle Devonian are preserved in the valley. Later formations lie in the upper part of the Catskill Mountains.

Structure.—The Ordovician formations are closely folded and are cut by several thrust faults. On the east side of the valley slaty cleavage is developed in some of the shales. The late Silurian limestone lies on these deformed beds with strong angular unconformity. However, the Silurian and Devonian formations also are severely folded and faulted. Thus two distinct disturbances are recorded.

NEW YORK TO ALBANY, NEW YORK

By Chester R. Longwell

New York to the Bear Mountain Bridge (45 miles, or 72 kilometers).—Leaving the low surface of Manhattan Island the route passes into a region of rounded hills, the altitude increasing gradually northward. This topography is developed on old metamorphic and plutonic igneous rocks, most of which presumably are of pre-Cambrian age. The west side of the Hudson Valley, visible from many points on the road, is marked by a high bluff formed of columnar dolerite (diabase), the edge of a great sill intruded into Triassic arkose and shale which dip westward at a moderate angle. The river marks the contact between the Triassic and the older formations for many miles (pl. 1), and it is easy to recognize the presence of the Triassic from the nearly continuous bluff with its conspicuous columns—the "Palisades of the Hudson."

The rocks along the route consist of complex gneisses, intruded and injected by granites; belts of limestone and schist are infolded with the more resistant rocks. The major structural axes trend north-northeast; they are strongly reflected in the general arrangement of ridges and valleys. Along the lower part of the river—for example, in the vicinity of Yonkers—the trend is about N. 20° E. and is parallel with the river itself. A few miles above Yonkers the structural trend gradually becomes more easterly, whereas the course of the river is more nearly due south and hence is discordant with the structure.

The river is almost without a flood plain; its valley walls descend steeply from the rolling upland surface, and the tidal stream extends from wall to wall. Between Dobbs Ferry and New York the width is very uniform and is slightly over a mile (1.6 kilometers); north of Dobbs Ferry the width of the valley increases rather abruptly, and above Irvington the stream is fully 2½ miles (4 kilometers) wide. For a distance of more than 12 miles (19 kilometers) to the north the river, with its quiet sea-level surface, resembles a lake; in fact, this exceptionally wide portion is known as the Tappan Sea. Overlooking this stretch of water from the eastern upland are many magnificent country estates, especially in the vicinity of Tarrytown.

Sing Sing, a famous State prison, is located at Ossining. Two miles (3.2 kilometers) north of Ossining, above the mouth of the Croton River, a prominent peninsula known as Croton Point projects into the Hudson. It is built partly of moraine and partly of stream deposits, and its flat top, 80 feet (24 meters) above sea level, is a fragment of an alluvial terrace. Directly across the river the edge of the Palisades sill curves away from the river, reflecting strong warping of the Triassic rocks.

Above Peekskill the highway enters the Highlands of the Hudson, which rise 1,000 feet (305 meters) or more above sea level. The south side of the Highlands is marked by a notable fault, which on the west side of the river drops the Triassic strata against the crystalline rocks. In its course through the resistant rocks of the Highlands the Hudson Valley is narrow and deep. The road has been cut into the granite and gneiss of Anthony's Nose, and at many points there are excellent exposures of the fresh bedrock. Both ends of the Bear Mountain Bridge are anchored in the old crystalline rocks. The crossing gives a fine view up and down a stretch of the river that was of strategic importance during the War of Independence (1775–1781). Several strong fortifications commanded the natural gateway through the Highlands.

Bear Mountain Bridge to Newburgh (16 miles, or 26 kilometers).—In the Highlands the Hudson fills the bottom of the valley from one steep wall to the other. The road, however, follows a distinct bench about 150 feet (46 meters) above the stream. This terrace, cut across gneiss and other crystalline rocks, follows both sides of the river but is better developed at some localities than at others; presumably it represents an older, wider valley, perhaps of Tertiary age, below which the present inner valley was cut as a result of uplift. The gorge would appear formidable indeed if its full depth were exposed. Submergence in late geologic time has caused deposition of sediment hundreds of feet thick. Borings near Storm King, where an aqueduct tunnel crosses at a depth of 1,100 feet (335 meters), failed to strike bedrock under the stream bed 765 feet (233 meters) below the present water level.

North of Highland Falls the West Point Military Academy, where officers for the United States Army are trained, is built on an unusually wide stretch of the high terrace. In the river opposite this locality is Constitution Island, one of several bedrock islands scattered along the valley in the Highlands; these islands seem to indicate at least one submergence, followed by uplift, after excavation of the inner gorge began. Sedimentation as a result of submergence filled the inner valley. When uplift occurred the stream in general cut down again into the trench it formerly occupied; but in a few places its new course was slightly to one side, and knobs of bedrock were left between the old gorge and the new.

About 3 miles (4.8 kilometers) northwest of West Point the Hudson gorge cuts through the highest ridge in the Highlands, made of massive granite. In this portal there is no trace of the high terrace, presumably because the superior resistance of the rock prevented its development. The highway is cut into bedrock along the side of Storm King, the part of the high ridge west of the river. The north side of this ridge is the northern limit of the Highlands; from the highway as it rounds the high point the view northward shows a lowland developed by the Hudson and its tributaries on the comparatively weak Paleozoic sedimentary formations. At the north base of Storm King the Highland rocks are thrust to the northwest over these sedimentary rocks. The fault, as exposed in the aqueduct tunnel passing under the river at this locality, dips 45° SE. Newburgh is built on folded and metamorphosed Ordovician formations.

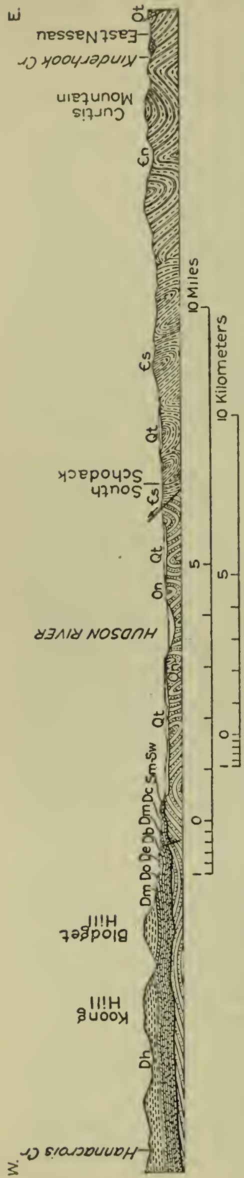
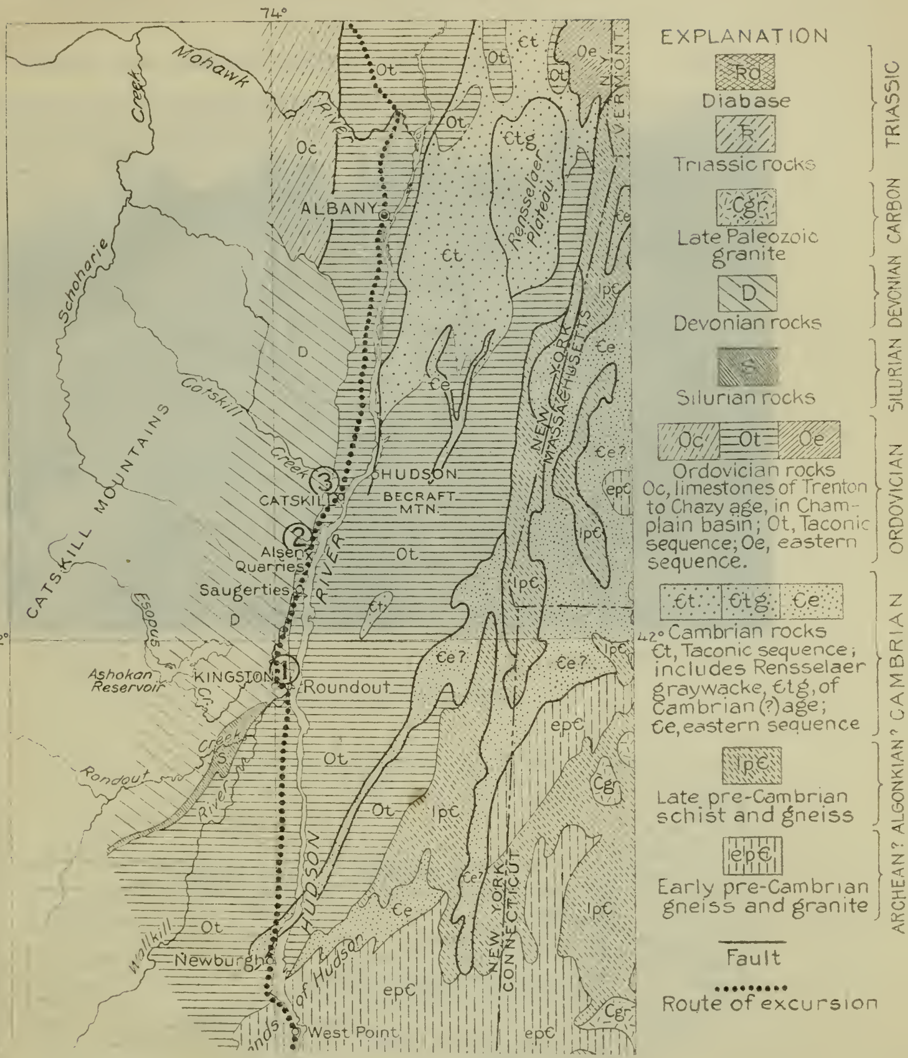
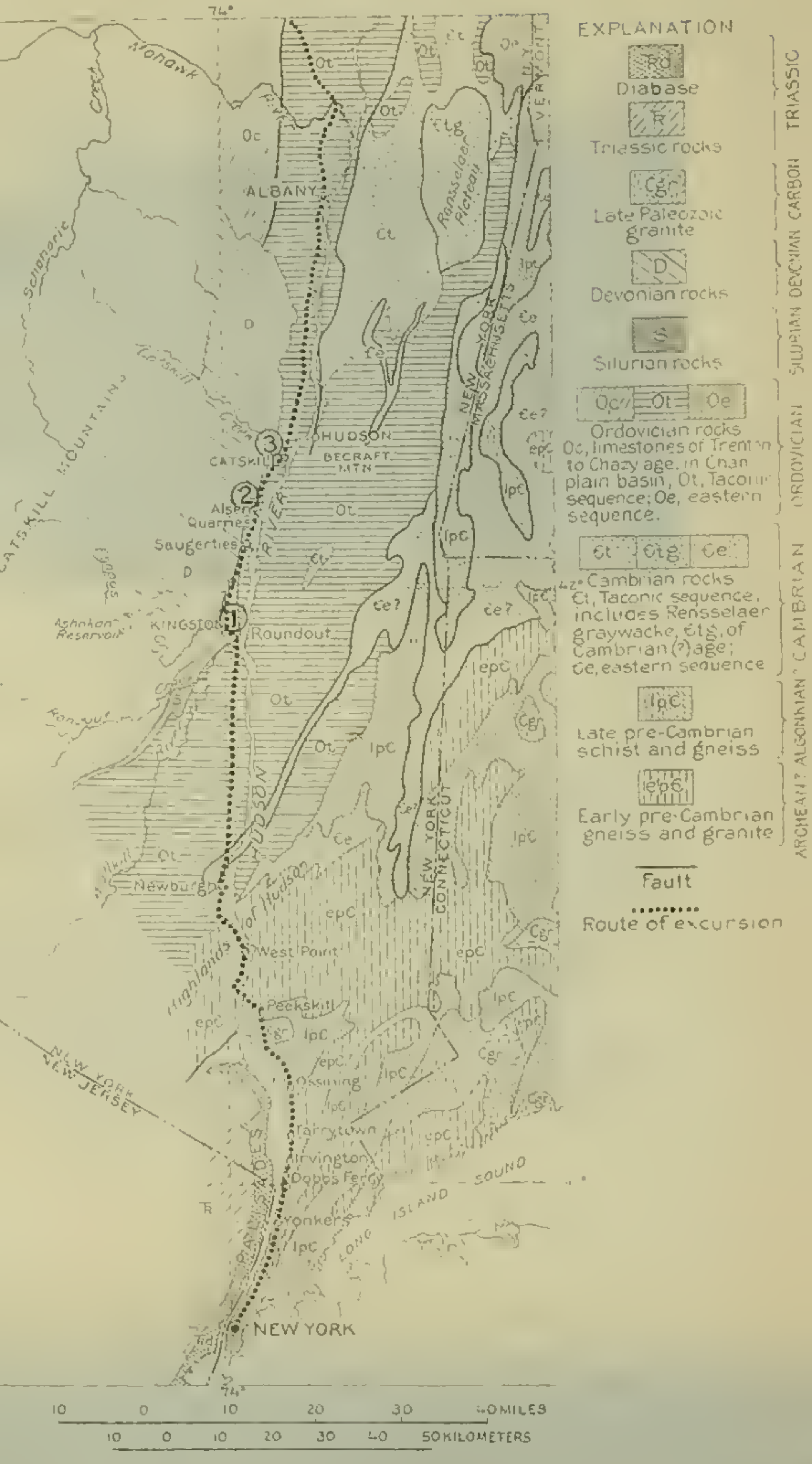


FIGURE 3.—Structure section across the Hudson Valley (see fig. 1) showing the unconformity between the Ordovician and younger formations. The line of the section is about 10 miles (16 kilometers) south of Albany, with the Helderberg Plateau on the left; but the same general structure is found also much farther south, where the formations of the plateau make the higher Catskill Mountains. Length of section, 25 miles (40 kilometers). By Rudolf Ruedemann, New York State Museum. Qt, Pleistocene till; Dh, Dm, Do, De, Db, Dm, Dc, Devonian formations; Sm, Sw, late Silurian formations; Ot, On, Ordovician formations; Ꞓs, Ꞓn, Cambrian formations

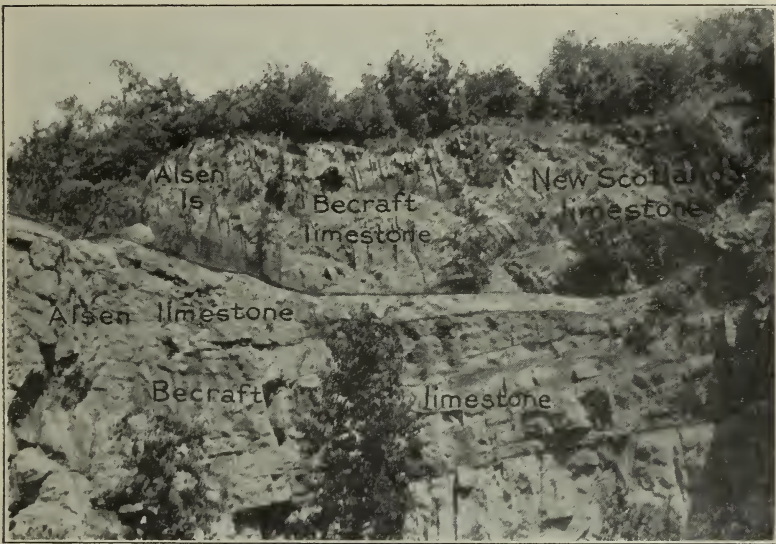
Newburgh to Rondout (32 miles, or 51 kilometers).—From Newburgh northward the Hudson has a narrow inner valley, but the country bordering it is generally low and rolling, broken by somewhat higher ridges made of the more resistant formations. These ridges have a general northeastward trend; they reflect the fold axes of the Paleozoic formations. Between the ridges the weaker formations are reduced to a surface which, near the river, ranges from 100 to 300 feet (30 to 91 meters) in height.

To the left of the route the Catskill Mountains come prominently into view before Rondout is reached. These mountains


74°
42°
Mohawk
Creek
Schoharie
Catskill
Creek
CATSKILL MOUNTAINS
Esopus
Ashokan Reservoir
Rondout
Creek
Wallkill
River
ALBANY
HUDSON
BECRAFT MTN.
CATSKILL
Alsen Quarries
Saugerties
KINGSTON
Roundout
Newburgh
West Point
HUDSON RIVER
Hudson
Rensselaer Plateau
NEW YORK
MASSACHUSETTS
VERMONT
NEW YORK
CONNECTICUT
EXPLANATION
Diabase
Triassic rocks
Late Paleozoic granite
Devonian rocks
Silurian rocks
Ordovician rocks
Oc, limestones of Trenton to Chazy age, in Champlain basin; Ot, Taconic sequence; Oe, eastern sequence.
Cambrian rocks
Ɛt, Taconic sequence; includes Rensselaer graywacke, Ɛtg, of Cambrian (?) age; Ɛe, eastern sequence
Late pre-Cambrian schist and gneiss
Early pre-Cambrian gneiss and granite
Fault
Route of excursion
TRIASSIC
CARBON
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
ALGONKIAN?
ARCHEAN?

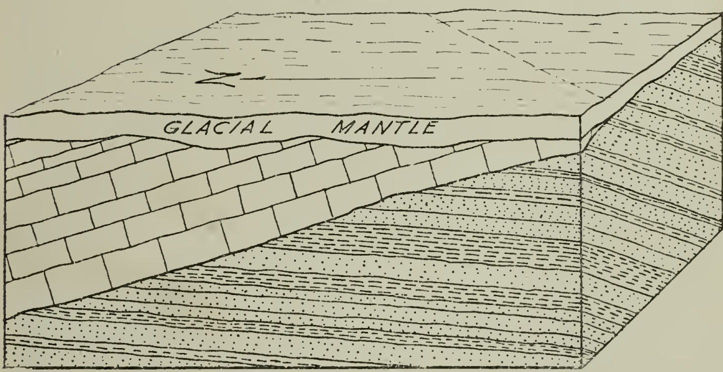


ROUTE MAP, NEW YORK TO ALBANY
Numbers in circles indicate localities mentioned in the text



A. THRUST IN DEVONIAN LIMESTONES AT ALSEN, NEW YORK

North end of Lehigh quarries.



B. BLOCK DIAGRAM SHOWING ANGULAR UNCONFORMITY BETWEEN ORDOVICIAN CLASTIC STRATA AND UPPER SILURIAN LIMESTONE WEST OF ALSEN

Western Lehigh quarry.

SECTIONS OF CRYPTOZOON PROLIFERUM ON THE GLACIATED SURFACE AT LESTER PARK, NEW YORK are erosion remnants of Upper Devonian clastic formations which are nearly horizontal. Presumably these strata extended eastward across the Hudson Valley, but after folding and uplift they were stripped back to their present position. (See fig. 3.)

[1][1] At Rondout, in the hill known as the Vlightberg, there are numerous old limestone quarries. The upper Silurian in particular contains a member long known as the "water lime," which is valuable as cement rock. One quarry exposes the angular unconformity between Ordovician sandstone and Silurian limestone. The Ordovician strata strike N. 30° W. and dip 50° NE.; [1a] the Silurian strike N. 50° E. and dip 70°–80° NW. (See fig. 4.) Folding of the Ordovician strata occurred during the Taconian disturbance near the end of the period; presumably the Silurian and Devonian strata in this region were folded during the Appalachian revolution, in Permian time. In most parts of the region the structural axes in the Ordovician formations trend nearly north, or slightly east of north; therefore the strike of the older rocks at Rondout is somewhat exceptional.

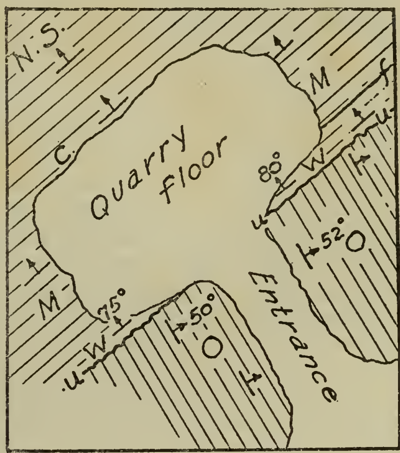


FIGURE 4.—Sketch geologic map of old quarry on the east side of the Vlightberg, at Rondout, New York. O, Ordovician; W, Wilbur limestone; M, Manlius limestone; C, Coeymans limestone; N. S., New Scotland limestone; u–u, unconformable contact between the Ordovician and Silurian; f, small bedding fault

Stratigraphic relations at Rondout

	Feet	Meters
Lower Devonian:		
Oriskany sandstone and conglomerate.		
Port Ewen shaly limestone	110–200	34–61
Becraft limestone	40	12
New Scotland shaly limestone	100	30
Coeymans limestone	50	15
Late Silurian:		
Manlius limestone	40–45	12–14
Basal limestone, including cement rock	30±	9±
Angular unconformity.		
Ordovician: Normanskill sandstone with interbedded shale	1,000±	305±

[1] Numbers in brackets refer to corresponding numbers on route maps and geologic maps. See Plate 1 for Nos. 1–3.

[1a] Recent work has shown that these strata were overturned from the northeast through 130° and now lie in inverted order.

Rondout to Alsen (15 miles, or 24 kilometers).—On the way north from Rondout and Kingston the Catskill Mountains are in full view on the left. To the northeast are the Berkshire Hills, in western Massachusetts, and the southern part of the Taconic Range, near the State line.

Devonian strata are well exposed at several points on the route, especially north of Glenerie, in the valley of Esopus Creek. The stream runs along the strike of the Esopus shale (Middle Devonian); beside the highway is the underlying Glenerie limestone, richly fossiliferous. Near Saugerties, 10 miles (16 kilometers) north of Kingston, remnants of a flat thrust in the Devonian make conspicuous hills.

[2] Four miles (6.4 kilometers) farther along, near West Camp, the Alsen cement quarries give extensive exposures of the Lower Devonian limestones. The Manlius (late Silurian) and Coeymans (lowest Devonian) form the eastern slope of the hill; but in the quarries to be visited the principal formations are the New Scotland shaly limestone and two higher units—the Becraft, a rather thick-bedded pure limestone, and the Alsen, a thin-bedded limestone. All these formations have abundant fossils; the New Scotland fauna is particularly large, but some of the common brachiopods are *Rhipidomella oblata*, *Leptaena rhomboidalis*, *Leptostrophia becki*, *Strophonella punctulifera*, *Orthotetes woolworthanus*, *Atrypa reticularis*, *Atrypina imbricata*, *Spirifer cyclopterus*, and *S. macropleurus;* and of trilobites, *Dalmanites micrurus* and *Phacops logani*.

The entire section is severely folded on axes trending east of north, and there is considerable local crumpling of the thin-bedded shaly units beneath stronger members that have yielded only on a larger scale. Thrust faults of considerable magnitude also complicate the section; the flat thrust represented in Plate 2, *A*, is exposed at the north end of the quarries. The full extent of this fault is not known, as the overthrust mass is only an erosion remnant on the top and the east flank of the hill.

A long tunnel leads westward through the ridge to another quarry beyond; there the upper Silurian limestone rests with strong angular discordance on the Ordovician shaly sandstone, as at Rondout. The Ordovician strata here have their normal regional strike, a few degrees east of north, and dip steeply eastward; the Silurian beds strike northeast (as at Rondout) and dip northwest. (See pl. 2, *B*.)

Alsen to Catskill (8 miles, or 13 kilometers).—There are many good outcrops along the road, on the left, showing the strong angular discordance between the Ordovician and Silurian. Numerous graptolites found at Catskill fix the date of the Ordovician sandstone and shale; the species, all European, are *Dicel-*

lograptus gurleyi, *Climacograptus bicornis* var. *peltifer*, and *Cryptograptus tricornis*. The same locality has yielded the following genera of small eurypterids: *Eurypterus*, *Eusarcus*, *Dolichopteris*, *Stylonurus*, and *Pterygotus*.

[3] In Austin Glen, on Catskill Creek, a short distance west of the town, *Climacograptus bicornis peltifer* occurs in typical graywacke. At this locality the angular unconformity can be seen in the stream bed if the water is sufficiently low, but the discordance is less striking than at the localities farther south. On the north side of the creek the Ordovician strata are folded on axes trending northeastward, and the Silurian appears to be nearly if not quite accordant. Thin laminae in the Manlius limestone at this locality have been studied by W. H. Bradley, of the United States Geological Survey, who finds a regular sequence of thin layers (average 0.018 millimeter) that contain abundant organic matter, alternating with thicker layers (average 0.139 millimeter) that consist chiefly of carbonate granules. He considers that these couplets represent a seasonal cycle, although the sediments are marine. Among the characteristic fossils in the formation are *Tentaculites gyrocanthus*, *Spirifer vanuxemi*, and *Leperditia alta*.

The road between Austin Glen and Catskill passes over a terrace formed by deposits in glacial Lake Albany.

Catskill to Albany (35 miles, or 56 kilometers).—The post-Ordovician rocks do not occur along the highway north of Catskill. East of the river near Hudson a synclinal outlier of the Silurian and Devonian strata forms Becraft Mountain. West of the river erosion has removed these formations from the valley belt, but they form the Helderberg Plateau along the north side of the Catskill Mountains. (See fig. 3.) There are numerous outcrops of the Ordovician rocks along the route. About a mile (1.6 kilometers) south of Albany a quarry shows an excellent section of the Normanskill black shales. This locality is on Normans Kill, from which the formation takes its name.

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ALBANY TO LAKE GEORGE, NEW YORK

By Rudolf Ruedemann

Albany to Lester Park (40 miles, or 64 kilometers).—Albany stands on a clay plain that rises from 200 feet (61 meters) above the river at the capitol to more than 300 feet (91 meters) farther west and north. The clay has excellent varve structure, which can be seen in a clay pit passed on the northern outskirts of the city. It was deposited in glacial Lake Albany, which according to Woodworth extended from the neighborhood of Kingston beyond Schenectady and Saratoga. Cook considers that the lake resulted from obstruction of the drainage by stagnant ice tongues in the river valley. The road passes over the lake deposits until the hills above the Mohawk River opposite Crescent are reached; there the grit of the Normanskill shale appears on both sides. The beds dip steeply to the east; they were intensely folded by the Taconian (late Ordovician) disturbance, the effects of which die out a few miles to the west.

South and north of Clifton Park the road passes through an extensive region of sand dunes which were formed after the draining of Lake Albany, at the end of the Pleistocene epoch, when enormous quantities of sand brought down from the Adirondacks were blown over the lake beds. There are many bare areas, especially south of Clifton Park, where the sod has been stripped off and molding sand is dug out. The sand, forming layers averaging about 2 to 3 feet (0.6 to 0.9 meter) in thickness, is used for the finer kinds of castings and for this purpose is shipped as far as the Pacific coast. The amount of this sand shipped each year is about 500,000 tons, at $2.50 a ton. The sand has the proper grade of cohesion by the weathering of admixed shale particles, which produce a binding film of clay.

From Clifton Park north the road passes over Snake Hill shale, mostly hidden by drift. From several points there are excellent views of the mountain ranges east of the Hudson River. In front are the Taconic foothills; in the background the Taconic Range, and north of it the Green Mountains. The straight sky line of the Rensselaer Plateau is farther south. The rocks in this belt of highlands are intensely folded, and in the Taconic and Green Mountains they are much metamorphosed. The folding and in some degree the metamorphism extend westward across the Hudson Valley, but the deformation is much less intense on the west side.

Round Lake is a great kettle hole, produced by a large block of dead ice left in an ancient valley. At its north end the road passes Anthony Creek, which in this locality furnishes a section of the Snake Hill shale over 2,000 feet (610 meters) thick.

Continuing north, the route passes over more deposits of Lake Albany in the Malta Plain.

[4] [2] The first stop on the Paleozoic formations is at the Hoyt "*Cryptozoon* State Park" (Lester Park), 4 miles (6.4 kilometers) west of Saratoga Springs. The Hoyt limestone is a calcareous,

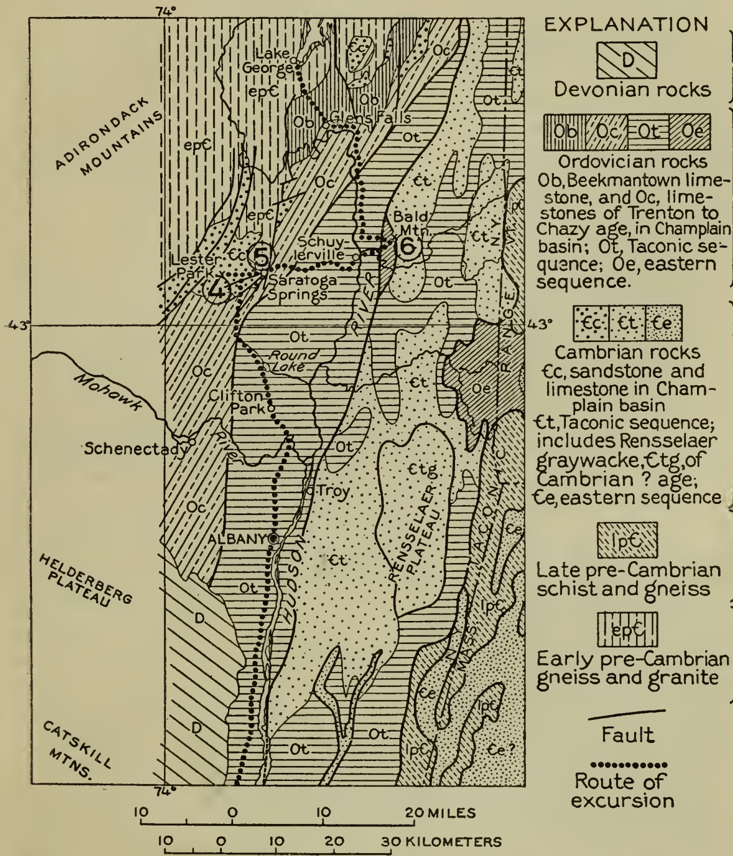

FIGURE 5.—Route map, Albany to Lake George. Numbers in circles indicate localities mentioned in the text

off-shore facies of the Theresa formation which, consisting of alternating sandstone, limestone, and dolomite, forms a transition from the Potsdam sandstone to the Little Falls dolomite (all Upper Cambrian; see fig. 6). At the park a glacially

[2] See fig. 5 for Nos. 4 to 6.

smoothed surface is covered with sections of *Cryptozoon proliferum*, a calcareous alga that formed large reefs. (See pl. 3.)

Lester Park to Bald Mountain (18 miles, or 29 kilometers).—[5] Saratoga Springs is one of the most noted health and sport resorts of the United States. It owes its prominence to a series of springs and wells that are characterized by an abundance of carbon dioxide, sodium chloride, and calcium, magnesium, and sodium bicarbonates; by the presence of bromides and iodides; and by an almost entire lack of sulphates. Both the springs and the drilled wells are on the downthrown side of a large fault, known as the Saratoga fault, which is a branch of the McGregor fault, farther north. According to Cushing the McGregor fault, separating the pre-Cambrian and Middle Ordovician rocks at the border of the Adirondacks, has a throw of at least 1,400 feet (427 meters) and probably much more. The Saratoga fault, the scarp of which is seen in High Rock Spring Park, has the Upper Cambrian Little Falls dolomite (with fault breccia) on the west (upthrown) side. The bedrock on the east side (not exposed) is Canajoharie shale (Middle Ordovician). The throw of the fault is altogether not more than 160 feet (49 meters) (6).[3] The famous Hathorn Well has a depth of 1,006 feet (307 meters). The source of the gases and the mineral matter in the water has been a subject of dispute. Earlier geologists (as Kemp and Clarke) thought a volcanic origin most probable; certain objections raised against this view by Cushing (6) caused the writer to suggest that metamorphic processes generated the gases, and especially that the carbon dioxide was produced by the metamorphism of limestone deep below the mountains to the east. More recently Doctor Ant, the chemist of the Spring Commission, from a long study of the waters reached the conclusion (not yet published) that the constituents of the water are derived by chemical change in the thick cover of Canajoharie shale. The water is stored in a large basin, extending to the east, north, and south in the Little Falls dolomite, and it reaches this basin, according to Doctor Ant, from the overlying shale.

In the vicinity of Saratoga the southern border of the Adirondack Mountains is plainly visible; there the Paleozoic formations end abruptly against pre-Cambrian rocks. From Saratoga the route leads eastward over a plain formed largely by Albany Lake deposits but underlain in order from west to east by Canajoharie shale, Snake Hill shale, and (about Schuylerville) Normanskill shale. The Canajoharie and Snake Hill shales are both of lower Trenton age and essentially equivalent, but although the Canajoharie shale rests upon (lowest) Trenton limestone, the Snake Hill shale overlies Normanskill shale of Chazy age. The

[3] Numbers in parentheses refer to bibliography, p. 20.

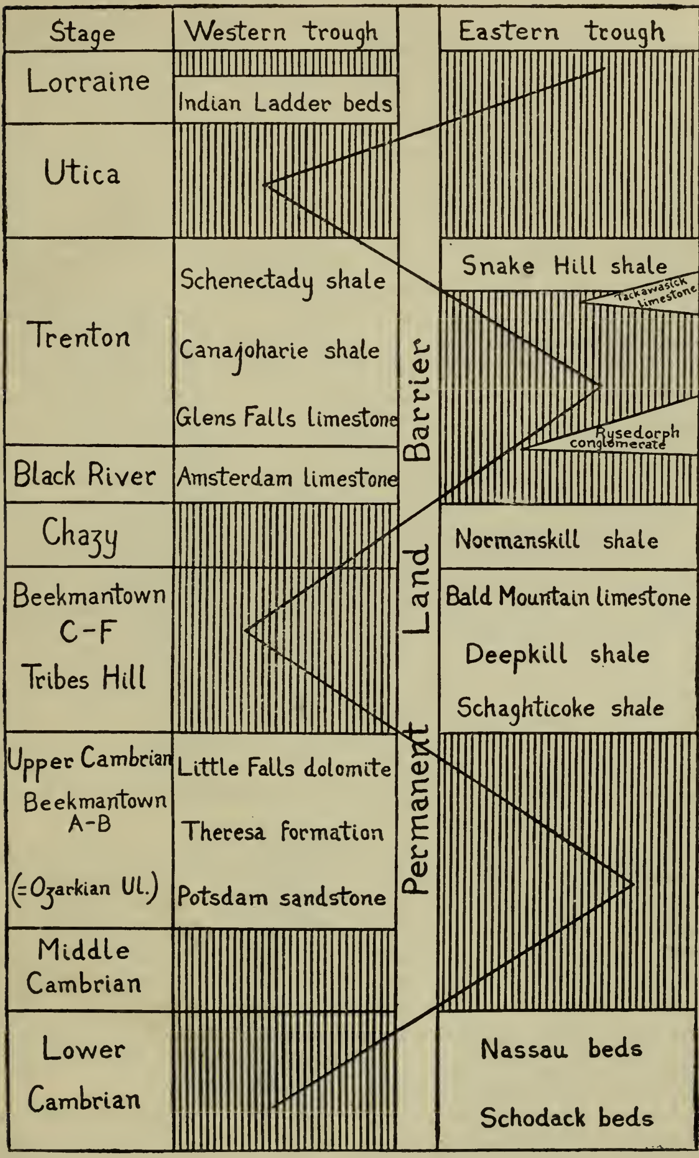

FIGURE 6.—Diagrammatic representation of emergences and submergences in the Husdon Valley during Cambrian and Ordovician time, according to Ruedemann. Lined intervals represent emergence; the zigzag line shows the alternation of movement between the eastern and western portions of the geosyncline

two formations are members of two entirely different sets of formations and must be considered as deposits of two different basins. Figure 6 shows the two sets of formations deposited in the two basins and also the oscillating emergence of the two basins, as a result of which the formations in the two troughs are fairly regularly alternating. The zigzag line indicates the shifting of the alternate movement from one trough to the other.

The two sets of formations have been brought into contact by extensive overthrusts of the Taconic revolution that have completely overridden the barrier that once separated the basins.

Before the excursion reaches Schuylerville, on top of the terrace on the right is seen the obelisk that commemorates the surrender of Burgoyne's army to the American Revolutionary forces in 1777, at Schuylerville (then Saratoga). Eastward there is a magnificent view of the Hudson Valley with its clay banks and of the mountain ranges to the east. These are all parts of the Taconic-Green Mountain fold system. In clear weather both the Taconic Mountains in Massachusetts (at the southeast) and the Green Mountains in Vermont (at the northeast) are visible.

At Schuylerville the road turns north, following the Hudson River Valley past the Marshall house (a hospital during the siege of 1777); farther on are an inlier of Normanskill shale with fossils, and Stark's Knob, locally known as the "volcano," a diabase boss of unknown age and relations. The river banks are formed on both sides by high cliffs (more than 100 feet, or 30 meters) of clay, the deposits of glacial Lake Albany. In the immediate neighborhood of the mouth of the Batten Kill a large delta was built into the lake by that stream. The road climbs the bank to the top of a flat terrace, then leads over a series of postglacial terraces to the westernmost of the ridges of the Taconic fold system.

[6] At the foot of the ridge is the Bald Mountain quarry, where a remarkable thrust, probably continuous with the Champlain thrust or "Logan's line," is well exposed. This locality is of considerable interest in the history of American geology; it is the type locality of Ebenezer Emmons's "Taconic system," which he considered the oldest system of fossil-bearing rocks. Emmons based his view as to the age of the strata on fossils now recognized as Lower Cambrian found near the top of the mountain (See fig. 7.) He knew nothing of the thrust and therefore believed that the strata were in normal sequence.

At the base of the mountain is the blue-gray Ordovician limestone, of Beekmantown age (Lower Ordovician or Canadian system). The extremely jagged top of this limestone is broken into steep needles, which project into an overlying black shale mass that is of very unequal thickness, lacking in some plac and 30 feet (9 meters) thick at the east end of the quarry. This is a comminuted fault breccia. Above the fault breccia masses of olive-green grit weathering reddish brown and of black and

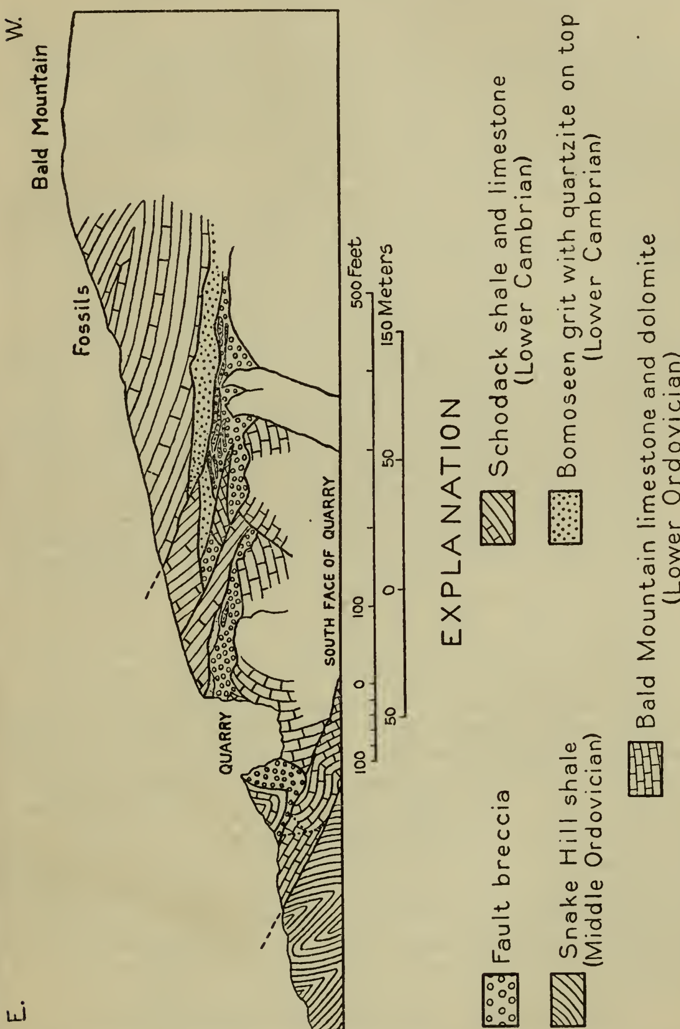

FIGURE 7.—Section through thrust zone at Bald Mountain, New York. Note the large development of finely comminuted fault breccia. See Figure 6 for normal relation of formations

green shale alternating with thin-bedded limestone are seen, more or less mixed. Both of these formations belong to the Lower Cambrian (Waucoban, formerly Georgian). They compose the bulk of the whole mountain. Fossils can be found in the Cambrian limestone on the mountain and more sparsely in the Ordovician limestone. The fault breccia contains fossils in pebbles of various ages, up to Trenton. Close by are outcrops of Rysedorph conglomerate, which are very fossiliferous.

Of especial significance is the southern part of the quarry, which extends eastward and gives a section at right angles to the front view of the quarry. Here (fig. 7) the broken and overturned Ordovician limestone is overlain by fault breccia, followed upward by grit, shale, and limestone in the order named. It is evident in this exposure that instead of one fault there is a series of thrusts, forming a thrust zone.

The limestone is separated by another thrust from the Trenton formation below. This plane is well exposed below the Batten Kill bridge at Middle Falls, 2 miles (3.2 kilometers) south of Bald Mountain. It is thus apparent that a whole series of thrusts is present (schuppen or shingle structure).

Bald Mountain to Lake George[3a] (31 miles or 50 kilometers).—The road leads along the east side of the Hudson River, with the Taconic Range in view on the right and the Adirondacks ahead. Hudson Falls is the beginning of the general southerly course maintained by the river from this point to its mouth; above Hudson Falls the stream is smaller and swifter and has a devious course from its source in the mountains. (See pl. 4.)

At 5½ miles (8.8 kilometers) north of Glens Falls the road crosses one of the border faults on the east side of the Adirondacks, along which the Paleozoic sediments are downfaulted, and the drift-filled valley followed by the road is underlain by pre-Cambrian rocks. (See pl. 4.) Forward to the right is French Mountain, a block of pre-Cambrian syenite and granite with inclusions of Grenville sediments, surrounded on the east and west by narrow belts of downfaulted Paleozoic sediments.

The Pleistocene deposits in the valley form the local divide between the drainage areas of the Hudson River and the St. Lawrence River. Lake George was originally connected with the Hudson, and a powerful stream flowed through a broad valley on the east side of French Mountain.

Lake George is 4 miles (6.4 kilometers) north of the fault. This beautiful body of water follows a graben of Paleozoic sediments, and the lake shores coincide approximately with the faults along which the younger formations have been dropped into the pre-Cambrian rocks that rise on both sides of the lake.

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[3a] By Robert Balk.

THE ADIRONDACK MOUNTAINS

By Robert Balk

LOCATION

The fertile plains in which the cities of Albany, Schenectady, and Troy are located come to an abrupt end 2 miles (3.2 kilometers) northwest of Saratoga Springs, and with a bold escarpment, crowned by somber woods of spruce and fir, the Adirondack Mountains make their appearance. They extend over 150 miles (241 kilometers) to the north and northwest, nearly all the way to the St. Lawrence River. (See pl. 4.)

The Adirondacks constitute a nearly circular mass with an area of some 17,000 square miles (44,000 square kilometers), which occupies the territory between Lake Ontario on the west, Lake Champlain on the east, the St. Lawrence lowland on the north, and the Mohawk Valley on the south. The northwestern part of the Adirondacks is a rolling upland of gentle relief and a mean altitude of about 1,000 feet (305 meters) above sea level, whereas the southeastern part is a rugged mountain mass. Individual ridges rise as much as 3,000 feet (914 meters) above the nearest valley floors, and the highest peak, Mount Marcy, stands 5,344 feet (1,629 meters) above the sea. Geologic work in the southeastern mountains is difficult on account of the dense forest. Roads and settlements are much fewer here than in the northwestern part of the region.

GENERAL GEOLOGY

The Adirondacks are composed mainly of pre-Cambrian rocks. The region has been uplifted in post-Ordovician time, and the Cambrian Potsdam sandstone and Cambro-Ordovician limestones and dolomites dip away from the pre-Cambrian core at gentle angles. The unconformity between pre-Cambrian and Paleozoic rocks is exposed in numerous places, although in the southeast the primary relations are somewhat blurred by post-Ordovician faults along which the Adirondacks have been elevated with reference to the surrounding younger rocks. One of these faults passes through Saratoga; another one forms the escarpment northwest of the town and is followed by the road from Saratoga to Glens Falls for many miles. Escarpments near Lakes George and Champlain are due to additional border faults along the eastern margin of the Adirondacks.

The pre-Cambrian sedimentary rocks of the Adirondacks appear to be identical with rocks of the same general age in the Provinces of Quebec and Ontario, so that the whole region is to be regarded as an outlier of the Canadian shield.

The principal sedimentary formation of early pre-Cambrian age, known as the Grenville series, consists in large part of marble, intermixed with schistose gneisses, amphibolites, and quartzites.

These sediments were intruded later in pre-Cambrian time by at least two generations of igneous rocks. In the northwestern area Cushing (11)[4] thought he recognized an older granite and a later series of syenites and granites; in the southeastern Adirondacks the older granite is hard to identify, and the younger intrusive rocks predominate in bulk and areal extension over all other rocks.

The oldest of the younger intrusives is anorthosite, which covers the central eastern part of the Adirondacks (approximately 1,200 square miles, or 3,108 square kilometers). Of nearly the same age, and surrounding the anorthosite in the form of a peripheral belt of variable width, is the so-called syenite series.

In addition, there are in both parts of the Adirondacks gabbroic rocks of various ages. Some are perhaps early Laurentian, others belong in the anorthosite-syenite series, and those gabbros which crop out within the anorthosite are probably as old as the anorthosite or even somewhat older, and consequently older than the syenite series. But there are gabbros within the syenite belt which may be younger than the syenite.

The youngest igneous rocks are basic dikes, mostly diabasic in texture, but some basalt and lamprophyre dikes are also known.

The following pages refer chiefly to the southeastern Adirondacks.

THE ROCKS

GRENVILLE METAMORPHOSED SEDIMENTS

Marble.—The coarse-grained rock is composed of calcite which includes or is interlocked with quartz, diopside, garnet, phlogopite, graphite, pyrrhotite, and pyrite. Common accessories are tourmaline, chondrodite, scapolite, apatite, tremolite, hornblende, and chalcopyrite. Layering of the rock due to accumulation of graphite or quartz along subparallel planes is common, and the layers can be identified in many places as limbs of isoclinal folds.

Quartzite.—Narrow and thin lenses of quartzite occur in Grenville marble. Only in the North Creek quadrangle do quartzites cover more continuous areas (12). In addition to quartz, graphite is almost invariably present, and in the southeastern Adirondacks its amount increases to such an extent that it is being mined. Other accessory minerals are microcline,

[4] Numbers in parentheses refer to bibliography, p. 36.

orthoclase, albite, and mica. Through the addition of diopside, the quartzites grade into lime-silicate rocks, which in turn pass into Grenville marble.

Amphibolite.—Hardly any exposure of Grenville marble fails to show layers, lenses, or oddly twisted and folded fragments of dark-green amphibolite, "floating," so to speak, in the surrounding calcareous rock. In so far as the amphibolite contains cores of pyroxene, or the amphibolites are composed of uralite, they may represent metamorphosed basic igneous rocks. There are other amphibolites, however, without any pyroxene, and these rocks probably represent metamorphosed marly layers of the sediments. Just how far the formation of amphibole and amphibolite in Grenville marble is a result of diffusion due to granitic injection of the sediments is not yet definitely known.

Schistose gneisses.—The schistose gneisses cover areas of appreciable size in the northwestern Adirondacks and are rare in the southeastern region. Wherever they occur they are intimately injected or "soaked" by an acidic granite, carrying, in addition to the biotite, microcline, quartz, and a sodic plagioclase. These schists and injected gneisses weather to a rusty brown, owing to the oxidation of finely distributed pyrite.

Garnet gneisses.—The garnet gneisses are also more common in the western Adirondacks. They occur in frequent association with the schistose gneisses, and the quantitative proportions of garnet, biotite, sillimanite, feldspar, and quartz vary.

OLDER GRANITES

Wherever the age relations between the older and the younger intrusive rocks can be determined, it seems to be the older, granitic magma which has "soaked" the Grenville sediments; the younger intrusions, as a rule, have confined themselves to disrupting, scattering, and contorting these previously metamorphosed rocks. Certain oval, concordant masses of gneissoid granite in the northwestern Adirondacks are correlated tentatively with the Laurentian granite of Canada (11, p. 38; 12, pp. 10, 38). Although an older siliceous granite has been found locally as inclusions in the syenite series of the eastern Adirondacks, it is doubtful whether the older granite forms bodies of large size in this part of the region.

YOUNGER INTRUSIVE ROCKS

Anorthosite.—The principal mineral is a sodic labradorite ranging from An_{45} to An_{55}. This mineral occurs as large crystals, half an inch to 3 inches (1.3 to 7.6 centimeters) in length, and also as small crushed fragments between the phenocrysts, surrounding them as a light-colored groundmass. Accessory minerals are augite, hypersthene, iron ore, garnet, quartz, and potash feldspar. In the center of the massif the anorthosite is dark dove-blue and massive, the labradorite phenocrysts making up about one-third or one-half of the volume. This is the so-called "Marcy type." In the northern half of the anorthosite and in many places along the borders of the anorthosite massif the rock is foliated, the phenocrysts of labradorite decrease while crushed labradorite and the accessory minerals increase in proportion, and a sodic plagioclase of about An_{25} makes its appearance. Rocks of this variable composition have been termed "Whiteface type anorthosite." This second variety of anorthosite weathers grayish white; the more crushed labradorite there is, the lighter in general the weathering color. The two types of rock grade into each other.

Syenite series.—The syenite group of rocks is extremely variable in composition, ranging from gabbro-dioritic to siliceous granitic phases. These contrasting types grade into one another. The plagioclase in the syenite series ranges from a sodic andesine to albite, and an oligoclase of 25 per cent anorthite is most common (8). Perthitic feldspars are the most abundant minerals of the syenite series, in which the same oligoclase occurs as spindles, droplets, and rows of small dots. The potash and soda-lime feldspars occur in approximately equal proportions, and the local departures from this equilibrium justify the great number of petrographic names that have been given to local phases of the rock (16, 23). Quartz is found in practically all varieties. Amphibole and augite are the principal ferromagnesian constituents, occurring either separately or jointly in specimens but decreasing in the more siliceous types in proportion as biotite increases. Amphibole predominates over augite in the granitic varieties. Garnet is common in all phases of the syenite series.

The ferromagnesian minerals in the syenite series appear commonly with parallel orientation or arranged in more or less concentrated layers, lenses, or streaks, which range in thickness from a fraction of an inch to a foot (0.3 meter) or even more and attain a length of more than 100 feet (30 meters).

Gabbros.—The so-called "basic" gabbros within the anorthosite are composed of a calcic labradorite or bytownite, hypersthene, augite, garnet, and iron ore. Olivine and some quartz are common, though in small quantities only. The calcic plagioclase is so filled with minute inclusions of pyroxene(?) that its exact composition is difficult to determine. In thin sections the mineral looks almost black, in hand specimens dull green. Augite forms scattered clusters, resembling Vogt's "synneusis structure." In some clusters the mineral grains are identically oriented, suggesting recrystallization after clustering.

A special feature of the gabbros consists of reaction rims (13, 15). Crystals of olivine or augite and also of labradorite are surrounded by shells of garnet, quartz, and sodic plagioclase. A more siliceous magma, corresponding to end-stage juices, is believed to have attacked the early precipitated minerals, giving rise to the concentric shells.

Borders of gabbro-amphibolite surround almost every large mass of "basic" gabbro, and small bodies are almost entirely amphibolitized. The amphibolitic shells grade imperceptibly into the gabbroic core, and all stages of uralitization are represented.

Basic dikes.—Most of the dike rocks show a diabasic texture. Olivine is commonly but not invariably present, and some of the diabase dikes carry large phenocrysts of labradorite. Basalt dikes and true lamprophyres have been described by Kemp (14, 15).

STRUCTURAL GEOLOGY

NORTHWESTERN ADIRONDACKS

The pre-Cambrian rocks, both sedimentary and igneous, strike generally northeast. (See pl. 4.) In the Alexandria Bay, Gouverneur, and Russell quadrangles the dip is commonly to the northwest, at angles of 45° or slightly less, although belts of steeper dip occur.

SOUTHEASTERN ADIRONDACKS

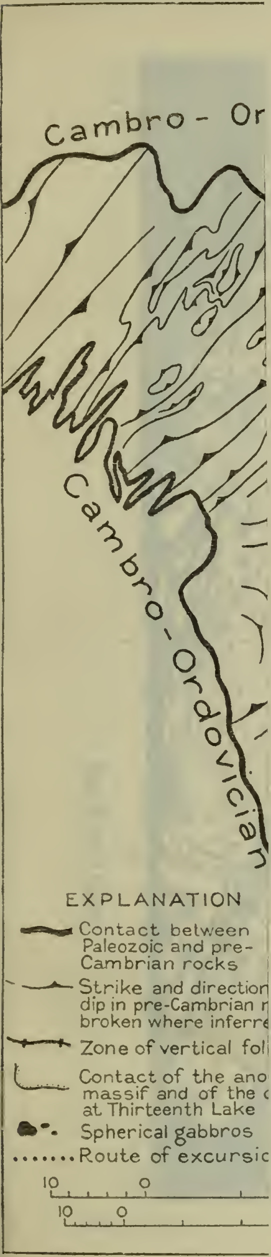
A poorly inhabited and partly swampy belt, some 30 miles (48 kilometers) wide and 60 miles (97 kilometers) long, separates the region mentioned above from the mountains of the southeastern Adirondacks. Little is known about the geology in this intervening area, but the regional northeasterly strike of the rocks probably veers to the east and east-southeast in the southern part, while the same rocks retain their northeast strike in the northern part. Thus the general strike seems to diverge, leaving a wedge-shaped area to the east. In this wedgelike section the great mass of anorthosite with its border of syenitic rocks makes its appearance. This intrusive massif extends all the way to Lake Champlain, where it ends along the border faults mentioned above, and on the downthrown east side the Paleozoic sediments conceal the continuation of the pre-Cambrian rocks.

FORM OF THE INTRUSIVES

The anorthosite massif that forms the nucleus of the region is believed to be of lenticular shape, inclined gently (about 15° or 20°) to the northeast and north. (See fig. 8.) The evidence is as follows: (1) The easternmost exposures of anorthosite along the shore of Lake Champlain between Willsboro and Port Douglas (see pp. 46-49) are visibly underlain in many places by Grenville marble, which dips at gentle angles (25°–0°) under the anorthosite. (2) North-northwest of Port Henry, farther south along the eastern border of the anorthosite area, the igneous rock rests on a nearly horizontal floor of Grenville quartzite and marble. Farther west the intrusive mass dips to the west. (3) In the vicinity of Tupper Lake, on the southwestern contact, the marginal foliation of the anorthosite dips gently to the northeast, and syenite sills farther to the south and west dip in the same direction, apparently into the anorthosite. (4) Over the entire northern half of the anorthosite massif the primary flow planes and flow lines dip at gentle angles to the north or northeast. (See fig. 8.) (5) South and southwest of the anorthosite a belt of foliated syenite and concordant Grenville sediments extends from northwest to southeast.

Along the central axis of this belt the foliation stands vertical; in the northeastern half, which approaches the anorthosite, it dips to the south and southwest; and in the southwestern half it dips to the north and northeast. (See fig. 8.) This fan-shaped structure is believed to be a mechanically necessary arrangement of the foliation where a large intrusive mass advances over a gently dipping floor. The southwestern area, with an abundance of Grenville sediments and an average dip of about 15° NE., is regarded as the exposed part of the general floor on which, farther northeast, the anorthosite rests; the intervening section of syenite is interpreted as the filling with magma of the wedge-shaped space between the floor and the curved front of the anorthosite lens. The syenite itself, as set forth below, is regarded as the residue of a parent magma from which the labradorite crystals have separated. Figure 9 shows exactly the same arrangement of flow planes, on a smaller scale but due to just such a play of forces. The parent magma, in all probability, was introduced from the northeast or north, moving obliquely upward to the south and southwest. The thickness of the lens of anorthosite is estimated to be 10 or 12 miles (16 to 19 kilometers), or possibly less.

The gabbros that crop out within the anorthosite are of spherical, torpedolike, or spheroidal shape. The floors, in particular, are visible in many places. Thus the gabbro of Peaked Hill (pp. 40-41) rests on a saucer-shaped floor of schistose anorthosite. (See fig. 10.) This gabbro lens measures about 1 mile (1.6 kilometers) from northwest to southeast, and a little less at right angles. The large gabbro mass of Jay Mountain, near the northern contact of the anorthosite massif, is 3 miles (4.8 kilometers) long and 1½ miles (2.4 kilometers) wide and may



ST

After Alling, Balk, Buddingt
in the text. SSp, Sara
Creek; M, Minerva; SI
LP, Lake Placid; AF, A

STRUCTURE MAP OF THE PRE-CAMBRIAN ROCKS OF THE ADIRONDACKS

After Alling, Balk, Buddington, Cushing, Kemp, Martin, Miller, Newland, Ogilvie, and Smyth. Numbers in circles indicate localities mentioned in the text. SSp, Saratoga Springs; GF, Glens Falls; LG, Lake George; W, Warrensburg; Ch, Chestertown; R, Riparius; NC, North Creek; M, Minerva; SL, Schroon Lake; N, Newcomb; U, Underwood; SRF, Split Rock Falls; NR, New Russia; E, Elizabethtown; LP, Lake Placid; AF, Ausable Forks; K, Keeseville; Pl, Plattsburg.

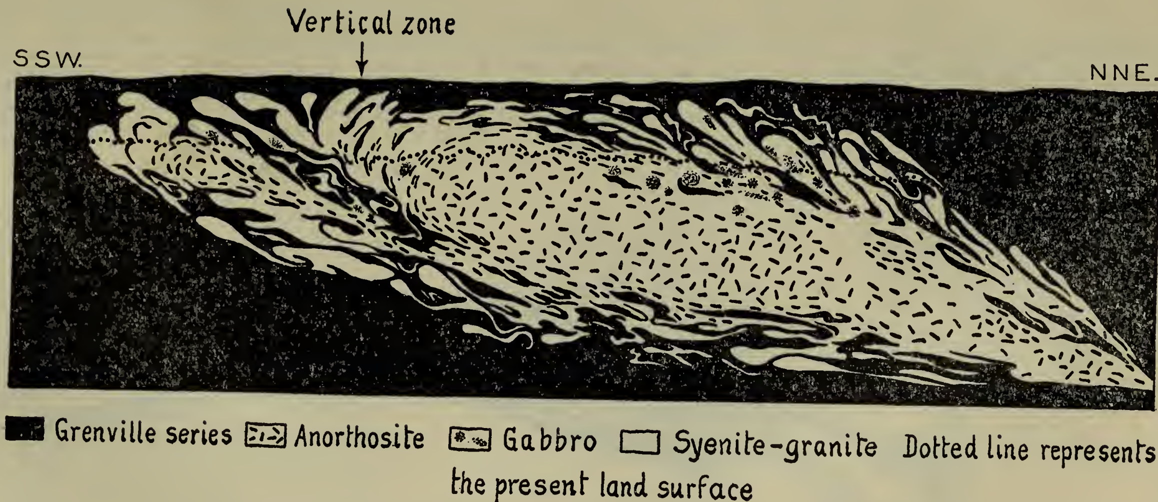


FIGURE 8.—Generalized cross section through the eastern Adirondacks. Details near the present land surface (dotted line) are observed; upward and downward extensions are hypothetical. The detached mass of anorthosite in the south-southwest is the outlier near Thirteenth Lake. Compare this figure with Figure 9

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FIGURE 9.—Assimilated inclusions of schist and schlieren of anorthosite in a ledge southwest of Willsboro, New York. Note the flow structure near the line A–B. Here a mass of magma has pushed to the northwest, and the friction along the base causes a curvature of the foliation which, if considered truncated by a plane A–B, gives a cross section essentially similar to that which is observed along the present land surface in the Adirondacks and shown in Figure 8. Approximate length of exposure, 30 feet (9 meters)

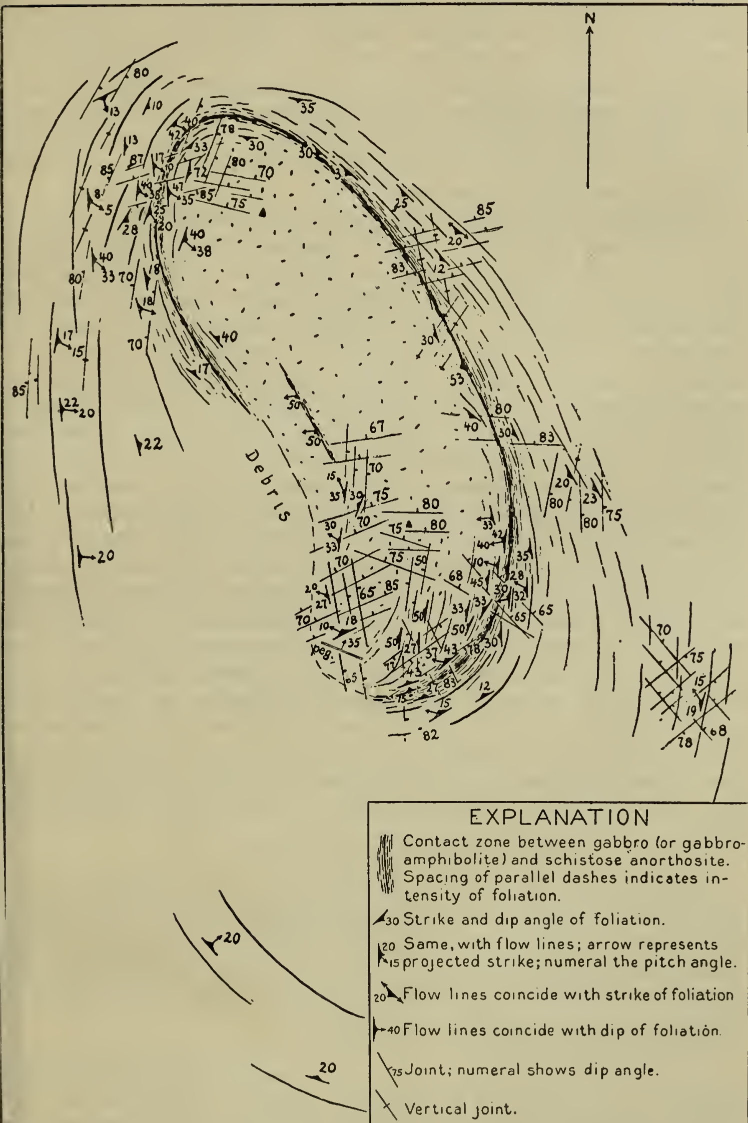

Figure 10.—Structure map of the spherical gabbro of Peaked Hill, New York. The gabbro is synclinally underlain by schistose anorthosite. Length of the gabbro, approximately 1 mile (1.6 kilometers)

be about 1½ miles thick. Most other gabbros are smaller, and few exceed 1 mile in length. (See pl. 5, *A*.) It is particularly interesting that the gabbros rest on schistose anorthosite or syenite, whereas the flanks and the upper cover, where exposed, are not intensely schistose. For gabbro masses that are small, or tabular and thin, no schistose floors have been observed. The bearing of these observations on the problem of crystal settling is pointed out on page 33.

The largest continuous mass of syenite is wedgelike, its northeast limb leaning on the southwest border of the anorthosite and its southwest limb resting on Grenville sediments. (See fig. 8.) Away from the anorthosite, many syenite bodies are encountered. All are concordantly inserted into Grenville sediments and may be called sills or phacoliths. Some are straight; others are curved. Some are single units; others seem to be composed of a number of allied lenticular bodies, arranged either as a string or as a series of irregular sills on top of one another. Most syenite bodies southwest of the anorthosite dip gently to the northeast or northwest—that is, toward the anorthosite. Those along the southeastern border seem to dip predominantly to the northwest, but data are scarce here. Large syenite sills on the north side of the anorthosite dip gently to the north, northeast, or northwest, resting, as it were, on the anorthosite massif. Some syenite masses crop out within the anorthosite, especially in the northern and eastern portions of the massif; they dip in general also to the north and northeast. Finally, there are small and odd-shaped bodies of syenite and granite in the contact zones between gabbros and anorthosite. They prefer, as it seems, the irregular-shaped reentrants and interstices between closely adjacent gabbros, notably in the Iron Mountain and Cobble Hill area, southwest of Elizabethtown.

RELATIONS BETWEEN THE IGNEOUS ROCKS

Two facts are of fundamental importance for the interpretation of the relations between anorthosite, gabbro, and syenite: (1) All rocks are foliated or linearly drawn out, and along contact zones the foliation planes or lines of flowage of the two rock masses involved are parallel; (2) all three kinds of rock exhibit gradational zones from one to another.

Because of the absence of crosscutting contacts on a large scale and because of the persistent parallel orientation of the primary flow structures in the three principal igneous rocks and the gradational zones, it is believed that anorthosite, gabbro, and syenite-granite are derivatives of the same parent magma; that gabbro and anorthosite have developed as accumulations of solid suspended crystals that were floating in the parent magma;

and that the syenitic rocks represent the residual mother liquor from the parent magma. This assumption is based on a number of field observations:

1. Although none of the three igneous rocks break through the flow structure of their sister rocks, some of them deflect the structure of others. All large spherical masses of gabbro, for instance, are underlain by synclines of schistose anorthosite or strongly foliated syenite, whereas the same rocks are but gently foliated or even massive above and along the lateral parts of such gabbro spheres or some distance below their contacts. The writer is of the opinion that these gabbros existed as potentially solid bodies during a stage when both the anorthosite and the syenite contained so much interstitial liquid that they were capable of flow movements. It is not claimed that a rock which so deflected the flowage of an adjacent igneous rock was completely solidified; but it is claimed that the deflecting mass behaved as a relatively rigid body. Probably the potentially solid body contained a larger percentage of solid crystals per unit volume than the surrounding relatively liquid material. Thus the existence of many large, spherical gabbro bodies indicates that the ferromagnesian minerals clustered earlier than the other constituents in the parent magma. On the other hand, there are many ill-defined gabbroic schlieren and basic phases of anorthosite. These are believed to represent gabbros "in statu nascendi," ferromagnesian segregations in the making, which were overtaken by the final consolidation of the magma chamber. These less concentrated gabbroic rocks are not underlain by schistose floors.

As schistose floors are restricted to the large spherical gabbros, and as the schistosity is a purely local phenomenon and, of course, an expression of local strong deformation, it is believed that the spheres of gabbro have sagged downward with reference to the simultaneous motion of the surrounding anorthosite and syenite. In this modified manner, we have an example of "crystal settling." But as the tabular and less concentrated gabbroic schlieren are not underlain by schistose floors, it is thought that the surrounding melt was so viscous that the smaller and impure basic schlieren could be carried along with the concomitant current of the magma. Only after a cluster of basic minerals of appreciable bulk and concentration had developed did the settling motion begin.

2. A number of gabbros, including large spherical bodies, carry augen of labradorite like those in the anorthosite. They are found especially in the marginal amphibolitic zones.

3. Some gabbros, including the largest mass (Jay Mountain), enclose schlieren of foliated anorthosite, always conformable to

the foliation of the surrounding gabbro. Here the two rocks grade again imperceptibly into each other. The writer does not know of any locality where a block of anorthosite lies in gabbro with its foliation running athwart the flow structure of the surrounding rock and with sharp contacts, nor of a locality where anorthosite cuts gabbro.

4. Many syenite bodies within or near the contact zones of the anorthosite carry augen of labradorite. An example is exposed in the quarry northwest of Minerva (p. 39). The chief plagioclase of the syenite, with 25 per cent of anorthite, forms the main constituent of the medium-grained rock, and the augen, of precisely the same composition as the labradorite in the anorthosite, reach 4 inches (10 centimeters) in length. They are surrounded by crushed rims. This quarry is 4 miles (6.4 kilometers) from the general contact of the anorthosite massif.

5. As Plate 4 shows, the contact of the anorthosite massif is not everywhere sharp. South of Elizabethtown, for instance, also northwest of Schroon Lake and at two other localities it is possible to pass from anorthosite through a mixed zone into normal syenite. These transitional zones afford no evidence of intrusive relations between the two principal rocks. Instead, the number of labradorite phenocrysts decreases gradually in proportion as the more sodic oligoclase makes its appearance. Others have expressed the opinion that these transitions between anorthosite and syenite are caused, at least in part, by an assimilating effect of the syenite on the anorthosite and Grenville sediments.

6. The northeastern half of the anorthosite massif, in which the rock is more generally foliated and in which concordant syenite lenses occur, contains acidic "shear zones." (See pl. 5, *B*.) These are intensely foliated and stretched intercalations in the anorthosite, which grade into the surrounding rock through outer zones of decreasing schistosity. The centers may be true mylonites; the outer edges scarcely foliated anorthosite. The central layers are rich in microcline and perthite and carry quartz and comminuted fragments of labradorite and a few augen of augite and garnet. A number of these shear zones are connected marginally with very thin quartz-microcline-albite-garnet veinlets, which fade out into the surrounding anorthosite. As these shear zones are rarely over a foot thick (0.3 meter), are not associated with postanorthositic disturbances, and are nowhere intrusive (crosscutting) into the surrounding anorthosite, they are regarded as the remnants of channels along which a siliceous liquid has passed through the congealing anorthosite, and it is believed that this residual liquid is the mother liquor of the magma chamber.

MODE OF CRYSTAL SEPARATION

The parent magma from which anorthosite, gabbro, and syenite were derived is believed to have advanced from northeast obliquely to the southwest. In all probability this parent magma already carried in suspension abundant solid ferromagnesian minerals and labradorite. The mechanism by which the three principal igneous rocks differentiated out of this magma is obviously the most important problem.

The present writer believes that purely gravitative movements have played at most an auxiliary part, and he doubts whether the wall rocks have been assimilated on a large scale. On the other hand, a large number of field exposures show that suspended solid crystal grains that float in the magma have the tendency to cluster or to form streaks or layers, if the moving magma strikes against or flows along an obstruction that is either stationary (the main contact) or moves more slowly than the magma ("autoliths" and "xenoliths"). Certain blocks of anorthosite, for instance, which appear to be early formed autoliths in the anorthosite massif, are surrounded by rims of augite, iron ore, amphibole, and garnet. The larger the proportion of available solid crystals and the exposed surface, the greater the stimulus for the separation of these early precipitates. A number of spherical and tabular schlierenlike gabbros are associated with Grenville xenoliths, which may well have acted as friction-exerting obstructions. The chemical composition of such xenoliths is irrelevant. Gabbros are associated with marble (Jay Mountain), with quartzite (northeast of Keene), and with amphibolite (Pulpit Mountain, northeast of Lake Placid). As the marble-gabbro contacts are sharp it is unlikely that gabbros of large volume are the result of reactions between magma and Grenville marble.

While the parent magma was moving through the chamber now occupied by the igneous rocks it seems to have been deprived of a large amount of its ferromagnesian minerals, because they were retarded and kept behind by the friction along the innumerable contact walls and xenolith surfaces. From small and insignificant schlieren and clusters these mineral accumulations are believed to have grown into large and more concentrated spheres. The largest ones became so heavy that the magma could no longer carry them along with the regional upward current; they slowly sagged downward and greatly deformed the underlying material, giving rise to the synclinal floors of schistose anorthosite and syenite. Not all gabbros are pure; some of them still contain phenocrysts such as make up the anorthosite, or even large schlieren of true anorthosite. The gabbro clusters kept forming until the magma chamber finally consolidated. All stages in the concentration of the ferromagnesian minerals are exposed.

The evolution of the anorthosite massif, although to some extent analogous to that of the gabbros, is nevertheless recorded by different features in the field. As "block structure" the writer has described the peculiar appearance, in the anorthosite, of angular or round blocks of anorthosite of a sufficiently different hue or average grain size to be clearly recognizable. Some of these blocks grade on one side into the surrounding anorthosite, and their longest axes may be subparallel, even drawn out into long and thin slabs. As a rule, these elongated blocks are parallel with the surrounding foliation in the anorthosite. Thus it seems that groups of labradorite crystals began to form in the magma chamber during a very early stage; they were deformed or drawn out locally in the same directions in which the entire rock mass was elongated (foliated). The interstitial liquid that acted as a lubricant is probably identical with the siliceous filling of the innumerable shear zones in the anorthosite. The shear zones now visible are thought to represent those channels along which the last of the mother liquor was expelled from an increasingly compacted and compressed labradorite mass. In the light of this interpretation, the flow structure which is common in the anorthosite is entirely compatible with the failure of the anorthosite to inject or intrude other rocks on a large scale. The syenitic mother liquor often carried individual labradorite phenocrysts with it, beyond the confines of the main crystal-filled central chamber. And wherever such peripheral phenocryst-bearing offshoots had to pass through narrows, the crystals would again cluster and be left behind. In this manner, local dikelets of anorthosite originated. If sufficiently well exposed, they are found to be connected with more siliceous material.

The anorthosite mass now exposed probably resulted from the accumulation of many thousands of small labradorite clusters. As it took a long time before enough of them had coalesced to build up the present large mass of anorthosite, we can not expect to find the boundaries of all of the component units in the field, but it is believed that some of the last ones to form constitute the "block structure," just as the shear zones represent only the last channels of mother liquor, whereas thousands of others, older ones, have been blotted out by the subsequent compaction of the entire mass.

This explanation of the mode of formation is corroborated by the protoclastic structure of the anorthosite, so well known that it need not be stressed. It may be emphasized, however, that the large massif of anorthosite with its intensely crushed labradorite fragments is surrounded by uncrushed syenite. The crushing can not be due to subsequent diastrophism, for if it were, the minerals of the syenite series would have been comminuted also.

Ferromagnesian minerals and labradorite crystals probably formed clusters throughout the same long period of time. But undoubtedly there was many times more labradorite in the parent magma than ferromagnesian minerals. At any rate, there is no compelling evidence that a large basal zone of gabbro exists along the floor of the anorthosite mass. Wherever this floor is exposed the immediately overlying rock is anorthosite, with or without gabbroic layers and schlieren, or even syenite (northwest of Port Henry).

The mother liquor, now represented by the syenitic and granitic rocks, has moved far beyond the limits of the crystal-filled central chamber. Although anorthosite and syenite locally grade into each other, the syenite in the peripheral belt that surrounds the anorthosite is a fairly uniform rock in which no labradorite phenocrysts appear. The farthest distance to which such augen or xenocrysts of labradorite are known to have been transported is 7 miles (11 kilometers) from the contact of the anorthosite. While mother liquor was being ejected from the anorthosite, the central chamber continued to expand, owing to the further intrusion of parent magma from the chamber entrance. Thus the continuous expansion of the "older" anorthosite dragged the foliation of the surrounding "younger" syenite sills upward, especially along the southwestern contact.

The quantitative relation of syenite, anorthosite, and gabbro can not yet be correctly estimated, and we are therefore ignorant of the precise composition of the parent magma, but it was probably more silicic than gabbro.

JOINTS AND DIKES

The southeastern Adirondacks are traversed by thousands of steep joints of northeasterly strike. In view of the general motion of the magma from northeast to southwest, these crevices must be regarded as the regional tension joints. The northeast set, however, was formed at a relatively late stage and disregarded the orientation of the local flow structure in the igneous rocks. On the other hand, these joints have been occupied by a large number of diabase dikes. Practically every one of them strikes northeast.

The northeast joints appear in almost every cliff of syenite. Diabase dikes with northeasterly strike can be seen on the road from Schroon Lake to Elizabethtown, especially between Underwood and New Russia (p. 42.) The joints and the diabase dikes along the Lake Champlain front, along the eastern contact of the anorthosite (pp. 46–47), are exceptional in their orientation. One major set runs east, and a second one north-northwest.

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LAKE GEORGE TO AUSABLE CHASM, NEW YORK

By Robert Balk

Lake George to North Creek (29 miles, or 47 kilometers).—As soon as Lake George is left behind, mountains close in on both sides, and the road leads through pre-Cambrian rocks for the remainder of the day. The most prominent igneous rock in this section of the Adirondacks is a medium-grained syenite with granitic phases, in which small oval or circular masses of gabbro are irregularly scattered. Some 12 gabbro masses have been observed by Miller in the hills to the left of the road, south of Warrensburg. All the igneous rocks here belong to the so-called "younger" intrusions of the Adirondacks and are genetically related to the anorthosite.

Six miles (9.6 kilometers) northwest of Lake George is Warrensburg, on a flat-topped terrace of gravel and sand, the result of deposition in a glacial lake that extended from Corinth, 16 miles (26 kilometers) south of Warrensburg, northward along the present valleys of the Schroon and Hudson Rivers. Almost every larger stream of the Adirondacks exhibits along its course flat-topped gravel terraces; the outlets of many of the glacial lakes in which these deposits formed have been determined, but no regional study of the genesis of these late glacial lakes has yet been undertaken in the Adirondacks. The available evidence points to a condition of ice stagnation very much like that in Connecticut which has been studied by Flint.[5]

From Warrensburg, the road pursues a northerly direction, paralleling the general strike of the pre-Cambrian rocks in this section. Halfway to Chestertown is Tripp Pond, from which a glimpse may be had of a large area of Grenville quartzite, which crops out to the east, on the west slope of Bull Rock Mountain. In the southeastern Adirondacks quartzites are prominent among the Grenville sediments, and the rocks are in places sufficiently rich in graphite to be mined. The largest mining center is the so-called Faxon & Dixon property, at Graphite and Hague, about 15 miles (24 kilometers) northeast of Chestertown. The geology of the graphite mines has been described by Alling in Bulletin 199 of the State Museum.

In the vicinity of Chestertown the general strike of the pre-Cambrian rocks diverges; an easterly branch continues northward and forms the east flank of the Adirondack anorthosite; the second branch veers to the west, the dip being predominantly to the north. This belt surrounds the anorthosite and syenite on the south, and in so far as Grenville sediments are involved, they are regarded by the writer as the exposed part of the general floor on which the large compound intrusion is resting. (See pl. 4 and fig. 8.)

From Chestertown the road turns to the west. After passing Loon Lake on the right the highway descends, and soon the Hudson River is crossed at Riverside (Riparius on map of North Creek quadrangle). Here as elsewhere in the Adirondack Mountains the Hudson is a shallow stream and can be forded at numerous places. The course of the river, before it emerges from the mountains at Glens Falls, is due south for the most part. The springs at the source are a short distance to the southwest of Mount Marcy, the highest peak in the Adirondacks and in New York State.

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[5] Flint, R. F., The glacial geology of Connecticut: Connecticut Geol. and Nat. Hist. Survey Bull. 47, 1930.

Along the river between Riverside and North Creek flat-topped gravel bars and terraces are again developed. A small glacial lake seems to have extended 2 or 3 miles (3.2 to 4.8 kilometers) east of North Creek. Five miles (8 kilometers) northwest of Riverside North Creek is reached, and the Hudson is crossed again.

North Creek to quarry northwest of Minerva and back (26 miles or 42 kilometers).—This section of the trip leads through the southern portion of the Adirondack intrusives. The bedrock consists of Grenville sediments with many sills and phacoliths of syenite and granite. Small circular gabbro masses are common, as between Lake George and Chestertown. The general dip of all the rocks is northerly, toward the anorthosite massif, whose southern border is only 4 miles (6.4 kilometers) north of the quarry to be visited. (See pl. 4.) The syenite sills in the Grenville sediments are regarded by the writer as the more distant offshoots of the anorthosite-syenite intrusion, and it is believed that they have been pushed obliquely to the south and southwest. (See fig. 8.)

As the road rises above the drift-covered lowland along the river, Moxham Mountain appears forward to the left, 5 miles (8 kilometers) north of North Creek. This is a conspicuous sill of granitic syenite resting on Grenville marble on the south, dipping at gentle angles to the northeast. The resistant rock is undermined on the south by decomposition of the marble, and a long escarpment has resulted. As the ridge is approached the gentle dip of the foliation can be made out. The contact at the base is not visible from the road, but low hills in the foreground are composed of marble. At the east end of the ridge the igneous rock is exfoliating on a large scale. The shells conform to the contour of the mountain and disregard the northward dip of the foliation.

The highway continues through rolling hills underlain for the most part by Grenville sediments, the deeply eroded cover of the Moxham Mountain sill, but exposures are scarce; gravelly moraine and swampy muck predominate on the surface. Four miles (6.4 kilometers) north of Moxham Mountain is Minerva, in the Schroon Lake quadrangle. Beyond the lowland to the right are Wilson Mountain and Oliver Hill, composed of syenite-granite. Farther away is Texas Ridge, the second largest gabbro mass in the Adirondacks, located along the southwest contact of the anorthosite massif. North of Minerva the Grenville sediments are better exposed. Graphite-bearing marble is most common; it contains black fragments of amphibolite, oddly twisted and contorted.

[7] [6] As the road ascends the hill north of Calahan Pond, a long exposure of marble with light-brown graphite-bearing quartzite beds is passed. The strata dip gently to the northwest and west, and the more resistant constituents are isoclinally folded and linearly elongated. The last outcrop of Grenville marble is 3½ miles (5.6 kilometers) beyond Minerva; the layers dip 35° N., and about 1,000 feet (305 meters) farther north the main mass of syenite begins. This occupies the space between the northward-dipping Grenville floor and the southern contact of the anorthosite. The syenite also dips to the north.

[8] At the quarry a mile (1.6 kilometers) farther north the rock is typical Adirondack syenite, dark green, strongly gneissic, composed of perthite, oligoclase (An_{25}), quartz, augite, hornblende, and biotite. In this syenitic rock many large augen of labradorite (An_{45}) are surrounded by crushed rims. This quarry is 4 miles (6.4 kilometers) southwest of the general contact of the anorthosite massif. It is believed that the syenite has been expelled from the congealing anorthosite, and that it has carried these augen of labradorite over from the crystal-filled chamber of anorthosite. In the hills between the quarry and the anorthosite contact the syenitic rocks carry many such xenocrysts of the calcic plagioclase. It is noteworthy that the labradorite is found in individual crystals, that blocks of anorthosite, suggesting ordinary inclusions in the syenite, are practically unknown, and that the augen are not corroded by the surrounding syenite.

Joint sets in the syenite are well displayed just south of the quarry. The syenite has been elongated to the west-northwest, and the flow lines lie subhorizontal. The associated tension joints run north and south and stand vertical. A second vertical joint set runs east and west.

North Creek to Peaked Hill (54 miles, or 87 kilometers).—From North Creek the road leads back to Loon Lake and north toward Schroon Lake.[6a] Three miles (4.8 kilometers) northeast of Loon Lake the road crosses a wide belt of Grenville sediments. A large mass of quartzite in this belt forms the slopes of Loon Lake Mountain, on the right. To the left of the road and east of Loon Lake Mountain the marble is deeply weathered, but the outcrops show the rock dipping to the north, under the sills of syenite and granite that lie to the right of the road east of Pottersville. The sediments form the eastward continuation of the marble belt traversed north of Minerva, and here too they appear in the position of a floor of the intrusions farther north. There are several road cuts in these intrusive rocks, 1 to 2 miles (1.6 to 3.2 kilometers) north of Pottersville. From here to

[6] See Plate 4 for Nos. 7 to 11.

[6a] If roads are dry, the excursion will probably follow a shorter route from Minerva to Schroon Lake.

Schroon Lake exposures are scarce. To the left in the distance are extensive masses of syenite-granite, and across Schroon Lake, forward to the right, Pharaoh Mountain, a prominent landmark in the Paradox quadrangle, comes into view. It is composed of granite, and the great scarp on its southwest side resembles that of Moxham Mountain.

Schroon Lake village lies on a small outlier of late Cambrian (Little Falls) dolomite, along the west shore of the lake. North of the village, across the drift-covered plains on the left, Severance Hill introduces the anorthosite massif. On the south slope the rock is extremely schistose and resembles in places a dense and splintery mylonite. The mineral fragments are smeared out into long streaks that pitch with the foliation to the south. On the right side of the road the anorthosite contact makes a reentrant for some 2 miles (3.2 kilometers), possibly owing to a fault. The border of the anorthosite is everywhere schistose and recrystallized, and in many places it is rich in microcline. The flow lines pitch in the direction of the dip of the schistosity, and there is reason to believe that the schistose border developed as a result of the long-continued expansion of the anorthosite mass, which was due to the continuous intrusion of parent magma from the chamber entrance in the northeast.

Four miles (6.4 kilometers) northwest of Severance Hill, to the left, is the densely forested Blue Ridge, with Hoffman Mountain, composed of massive anorthosite.

Nine miles (14 kilometers) north of Schroon Lake village, at the settlement of Schroon River, the route leaves the main highway and turns to the right, up a small hill, 4½ miles (7.2 kilometers) eastward, past Jackson Pond, to the north foot of Peaked Hill. Many ledges of anorthosite are seen along the road. To the left in the distance are the bold escarpments of Old Pate and Bald Pate.

[9] At Peaked Hill the contact relations between a spherical gabbro and the anorthosite are exposed. On the southern slopes of the mountain the sequence of rocks from bottom to top is massive anorthosite, foliated anorthosite, schistose anorthosite, gabbro-amphibolite with local crosscutting pegmatites and syenite lenses, and massive medium-grained gabbro. These rocks are all synclinally arranged, the massive gabbro forming at once the structural center and the top of Peaked Hill. (See fig. 10.) The hill is ascended from the north, where the bedrock is concealed by drift. The first outcrops are near the top and show schistose anorthosite dipping toward the top of the mountain—that is, under the gabbro. Augen of labradorite and large single crystals of augite and garnet are common. Ledges of this rock continue all along the southern slope; the

dip angles range between 55° and 10°. Some 200 feet (61 meters) to the northeast the contact zone of the gabbro is reached. The rock at the lowest horizon is schistose amphibolite, but higher up the rock grows massive. The most schistose portions of the amphibolite and anorthosite have been worn down to make a shoulder along the flank of the mountain, which can be recognized from the top of Peaked Hill. The crest of the mountain affords a fine view over many of the highest peaks of the Adirondacks. To the west, Mount Dix, Spotted Mountain, the Wolf's Jaws, the Rocky Peak Ridge, and Giant Mountain are seen. To the south lies Paradox Lake, which follows a belt of marble along the southeast contact of the anorthosite massif. A climb down the southern front of the cliff leads to another good exposure of the contact zone, where fresh specimens of practically all rocks can be obtained.

It is believed that the synclinal, saucer-shaped arrangement of the gabbro border is due to the sagging of the heavy sphere of gabbro amidst the congealing plastic anorthosite, whereby the labradorite crystals below were crushed. Both the border of gabbro-amphibolite and the underlying schistose anorthosite are linearly deformed. The flow lines strike almost everywhere west-northwest, irrespective of the strike and dip of the foliation; they coincide either with the dip or with the strike or appear as oblique lines on the planes of schistosity. The west-northwest direction is the prevalent elongation of this part of the anorthosite massif, and while the gabbro sphere dragged the plastic anorthosite down, the expansion of the entire anorthosite mass elongated the floor of the gabbro in the same direction.

Peaked Hill to Elizabethtown (27 miles, or 43 kilometers).—From Peaked Hill the journey to Elizabethtown leads through one of the most beautiful parts of the Adirondack Mountains. Practically every exposure that comes into view is anorthosite, but the valley of the Schroon River, which the road follows, is filled with Pleistocene deposits, and outcrops near the road are rare.

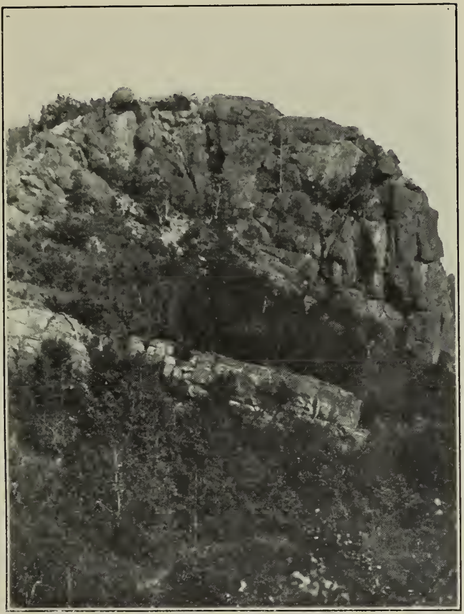
On the left the rocky slopes of Nippletop, Far, Saunders, and Spotted Mountains border the valley and give a good impression of the topography in the center of the anorthosite area.

About 7½ miles (12 kilometers) beyond the point where the trip along the highway is resumed, a quarry is passed on the right that exposes a gabbroic phase of syenite, rich in orthoclase, augite, and amphibole, which carries augen of labradorite and is about intermediate between all three of the principal intrusive rocks of the region.

Immediately beyond the quarry the road crosses Schroon River. About 3½ miles (5.6 kilometers) north is the Underwood Club, and in the anorthosite cliffs beyond several diabase dikes may be recognized. They strike northeast, parallel to the regional tension joints. The high mountain mass that appears on the left side of the road is the Rocky Peak Ridge, with Noble Mountain, and Giant farther back. The rugged slopes, which drop fully 3,000 feet (914 meters) to the valley of the Bouquet River, afford excellent and continuous outcrops of massive or slightly foliated anorthosite, with hundreds of shear zones, local gabbroic lenses, and a few scattered inclusions of Grenville quartzite. In contrast to the high relief on the left side, the hills to the right of the road are fully 2,000 feet (610 meters) lower; the rocks on the left side are anorthosite, whereas on the opposite side syenitic rocks and gabbros predominate. Xenocrysts of labradorite, however, are so profusely scattered through all phases that the writer is of the opinion that in this zone, which extends over 10 miles (16 kilometers) from north to south, the separation of labradorite crystals from the parent magma had not been completed when the rocks finally consolidated. It is thought that here a great mass of magma welled up obliquely from the west, in which the differentiation into gabbro, anorthosite, and syenite was still actively going on at the time of consolidation.

One mile (1.6 kilometers) northwest of Underwood a road turns to the left to St. Hubert, passing Chapel Pond, a beautiful lake high up on a divide. The main highway turns to the northeast. Soon an abandoned quarry is passed on the right which exposes a great fault and crush zone. This is one of the few zones of disturbance in the anorthosite that are well exposed. The fault strikes northeast and traverses the valley of the Bouquet River at an acute angle. Three miles (4.8 kilometers) farther on, Split Rock Falls of the Bouquet River is passed. The gorge is cut into impure anorthosite with basic gabbroic phases, and blocks of light-colored anorthosite appear within the darker variety. Back of the gorge, on the right, the great dip slope of Split Rock Mountain is visible, composed of syenite with augen of labradorite.

Three miles (4.8 kilometers) north of Split Rock Falls is New Russia, beyond which the rocky slopes of Iron Mountain and Oak Hill appear on the left. These and several adjacent mountains are capped by basic spherical gabbros, like that of Peaked Hill, and are underlain also by schistose anorthosite or, more commonly, by syenite. One of these gabbro spheres is shown in Plate 5, *A*.



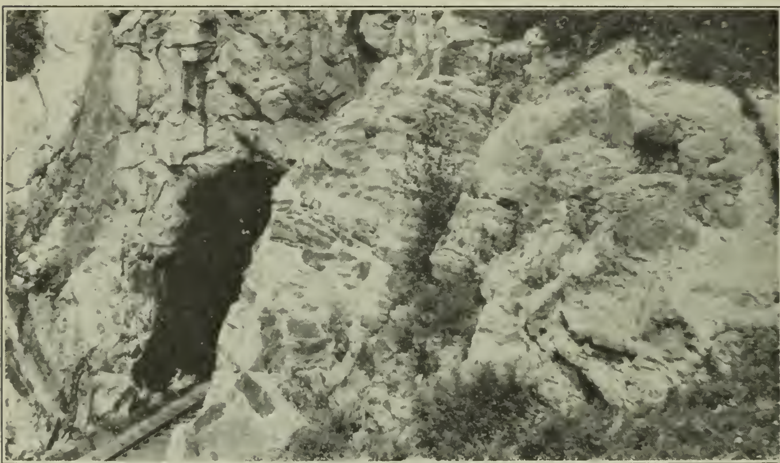
A. SMALL SPHERICAL GABBRO BETWEEN IRON MOUNTAIN AND GREEN MOUNTAIN, NEW YORK

The ledge in the center of the picture is schistose anorthosite, which underlies the gabbro.

B. SHEARED ZONE OF SCHISTOSE ANORTHOSITE IN MASSIVE ANORTHOSITE 1½ MILES (2.4 KILOMETERS) NORTH OF ELIZABETHTOWN, NEW YORK

Blocks of the massive rock are drawn out in the foliated zone.

A



B

GRENVILLE MARBLE IN RAILROAD CUT NORTHWEST OF WILLSBORO, NEW YORK

A. Marble (white) in the position of a floor under foliated anorthosite, dipping southwest; *B*, marble with disrupted blocks of schist and quartzite.

Five miles (8 kilometers) north of New Russia is a road-metal quarry on the left. The rocks here consist of syenite and a mixed rock with labradorite at the north end. Several outcrops of anorthosite follow along the road. Elizabethtown, which stands on a flat-topped gravel terrace, is 2 miles (3.2 kilometers) farther on.

Elizabethtown to Pokamoonshine Mountain (15 miles, or 24 kilometers).—A short distance from Elizabethtown the road ascends the embankment of the Bouquet River, and 5 miles (8 kilometers) to the north it reaches Lewis. To the right, across the river valley, Raven Hill and Little Raven Hill are in view for some time, two anorthosite hills amidst drift-covered plains. Forward to the right are Rattlesnake Mountain and Discovery Hill, composed of foliated anorthosite. Here the flow lines pitch gently to the north, and the associated cross joints dip steeply to the south, giving rise to a prominent escarpment.

On the left side is seen the even sky line of a group of mountains which extend from Hurricane Mountain northward to Limekiln Mountain and several unnamed ridges. The even surface here is due to the almost horizontal attitude of the foliation. The rock ranges from typical massive anorthosite to granitic syenite. The flow lines strike north, and the steeply tilted cross joints cause steep scarps on the south sides of the mountains, which, however, are not easily visible from the road.

From the flat plains north of Lewis another great mountain mass appears on the left—the Jay Mountains, with Saddleback Mountain and, nearer by, Fay Mountain. The higher portions of all these peaks are composed of gabbro; while the lower slopes are underlain by anorthosite, syenite, or Grenville quartzite and marble. The gabbro of Jay Mountain is 3 miles (4.8 kilometers) long and 1½ miles (2.4 kilometers) wide and is the largest mass of this rock in the Adirondacks. Near the top this gabbro mass carries a large schliere of anorthosite, and the surrounding anorthosite in turn contains several schlieren of gabbro near the contact. The peculiar silhouette of Saddleback Mountain is due to a depression between two parallel ridges of foliated gabbro. The eastern spur of Jay Mountain (summit 3334, Ausable quadrangle) exhibits a long and continuous escarpment of white anorthosite, and even from the distance the gentle dip of the foliation to the north can be recognized.

The mountains that follow to the left are all capped by lenses of gabbro, which rest on westward-dipping syenite or anorthosite. Beyond the western slopes of these hills the anorthosite massif comes to an end, and a large syncline of Grenville sedi-

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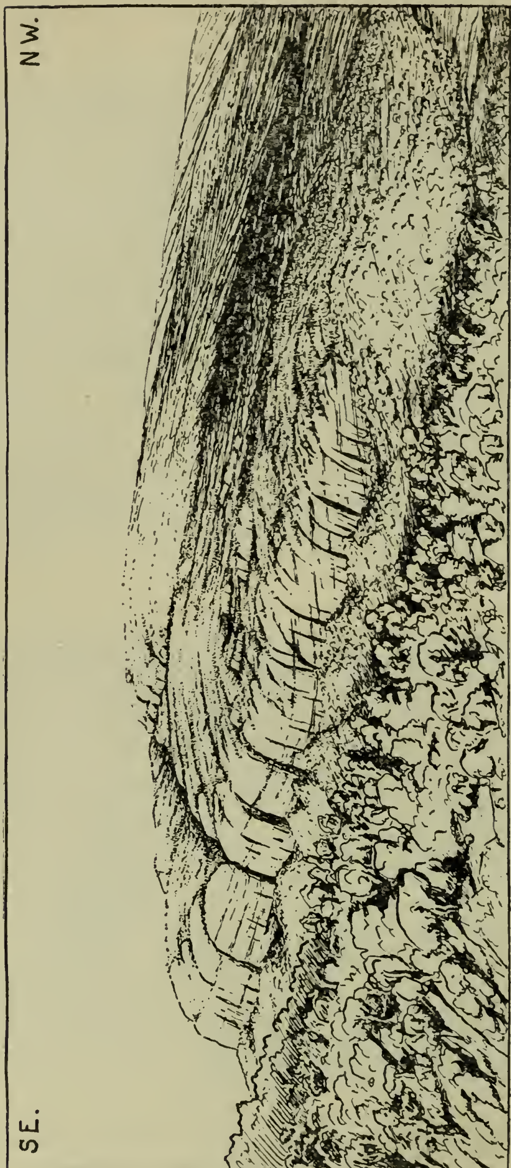


FIGURE 11.—Field sketch of Pokamoonshine Mountain, New York, showing the gentle westward dip and slightly synclinal structure of the syenite-granite. The bottom of the valley is composed of foliated anorthosite and inclusions of Grenville marble

ments ("Ausable Forks-Grenville syncline") causes a considerable indentation in the northern contact of the intrusive. The syncline pitches gently to the north, and all the igneous rocks plunge under the sedimentary rocks. The persistent gentle slope of the anorthosite massif to the north, the gentle pitch of the flow lines in the same direction, the frequent appearance of poorly differentiated rock types in the north half of the intrusive body, and many other criteria point to the north and northeast as the most probable directions whence the parent magma of the anorthosite was intruded.

The anorthosite continues to crop out on the right side of the road, forming a long and broad salient of the massif to the northeast. The Ausable Forks syncline forms the western cover of it; Grenville marble, which dips under it from the east, will be seen along the railroad track northwest of Willsboro. The whole projection of anorthosite may be regarded, therefore, as a sill-like mass.

[10] Six miles (9.6 kilometers) north of Lewis, Deerfield Mountain appears in the distance, and to the right the great escarpment of Pokamoonshine Mountain comes into view. The intrusive rocks that constitute these two mountains are a part of the northeastern salient of the anorthosite massif, which is characterized by a great diversity of the constituent rocks. The top of Pokamoonshine Mountain and the higher portions of the great escarpment are made up of syenite and granite which dip gently to the west (fig. 11); the base of the cliff and the rocks along the road are anorthosite, rich in garnet and augite, as seen at a road-metal quarry in this basal anorthosite. The strongly foliated rock dips at gentle angles toward the escarpment, and as the cliff is examined it will be found that the proportion of labradorite crystals rapidly decreases upward and that the rock takes on the appearance of a syenite, but that sporadic lenses and schlieren rich in labradorite continue to occur. No crosscutting contacts between the syenite-granite and anorthosite have been noted, and both rocks are regarded by the writer as comagmatic parts of the same sill. Interesting inclusions of Grenville marble occur a short distance south in the cliff. The deep valley between Pokamoonshine Mountain and the opposite ridge on the east side is probably due to the rapid decomposition of the marble rather than to a fault.

Farther north along the highway the synclinal cross section of the sill can be recognized; this structure is brought out by the conspicuous weathering of ferromagnesian layers in the syenite. (See fig. 11.)

Pokamoonshine Mountain to railroad cut northwest of Willsboro (11 miles, or 17.7 kilometers).—On both sides of the road the ridges are composed of foliated anorthosite with irregular intercalations of syenite and scattered inclusions of Grenville marble. Where the road turns sharply to the right Mount Bigelow is seen ahead, one of the most northerly ridges of anorthosite. Finely layered anorthosite, the layers lying nearly horizontal, is passed in a cliff 1 mile (1.6 kilometers) south of the road intersection. After passing several lakes, some of which are located in Grenville inclusions, others formed by barriers of moraine, the highway descends and Lake Champlain comes into view, with the serrated chain of the Green Mountains of Vermont forming a pleasing background. The characteristic outline of Camel's Hump is easily made out. Champlain in his descriptions of the lake called the mountain "lion couché."

Along the base of the slope the pre-Cambrian rocks of the Adirondacks are cut off by a long fault of north-south strike. The plains of the Champlain lowland are underlain by the same Cambro-Ordovician sediments that were last seen at Glens Falls. The border fault itself is exposed a few miles south of Willsboro; the plane stands vertical or nearly so.

[11] A walk along the track of the Delaware & Hudson Railroad leads to one of the longest and most instructive exposures of the anorthosite; it extends uninterruptedly to Brown Point, over 5 miles (8 kilometers) to the north. Foliated anorthosite forms the first cliff. The layers dip gently to the west, and about 300 feet (91 meters) to the north thin layers of Grenville marble appear at the foot of the track. They increase in length and thickness, and some 1,000 feet (305 meters) to the north the floor of the anorthosite rises above the level of the railroad track. (See pl. 6, *A*.) Farther north anorthosite crops out again, and the marble dips to the southwest. The layers of igneous rock show considerable variability in composition, ranging from white anorthosite to gabbro; the dip is likewise irregular but nowhere steep. Farther along the track this belt of anorthositic rocks is in turn underlain by marble, and several additional sill-like offshoots of gabbroic anorthosite between marble layers follow.

The common occurrence of Grenville marble in the position of a concordant floor of the anorthosite leads the writer to the opinion that this salient of the Adirondack anorthosite rests as a whole on such a floor. It must be borne in mind that the Pleistocene deposits almost everywhere tend to conceal the weak Grenville strata, and that the vertical range of the section (less than 1,000 feet, or 305 meters) is small in comparison with the dimensions of the intrusive mass.

Diabase dikes are extremely abundant in the railroad cut. Two sets can be distinguished, one striking east, the other north-northwest. These directions are anomalous for the Adirondacks and show that the available fissures during the diabase injection (probably late in pre-Cambrian time) followed independent directions along the eastern border of the Adirondacks. This is regarded as evidence that the present Lake Champlain fault marks the primary eastern boundary of the Adirondack intrusion.

About a mile (1.6 kilometers) from the starting point large cliffs along the lake front show layering of the anorthosite on a large scale. White anorthositic layers and dark-green layers rich in augite and amphibole alternate, and the gradation from one to the other rock can be studied to good advantage. A local anticline of the foliation affords a complete cross section of a long lens of gabbroic composition. At 400 feet (122 meters) south of the tunnel another cliff shows the incipient concentration of ferromagnesian minerals in layers in the anorthosite.

At the southern entrance of the tunnel a small lens of gabbro on the west side is in contact with marble. The contact is sharp, and the marble breaks locally through the gabbro; such pseudo-intrusive marble has been observed and described at many places in the Adirondacks. The entrance of the tunnel is a fine exposure of marble in which blocks of quartzite and schist are suspended, illustrative of the plasticity of the marble during the time of the igneous invasion and the greater brittleness of the quartzose rocks. These blocks too, however, have been isoclinally folded and linearly stretched. (See pl. 6, *B*.)

On the return trip along the railroad the blocks of gray limestone that protect the track on the east side will attract attention. They are replete with the large gastropod *Maclurites magna* and with corals, bryozoans, and brachiopods of the Lower Ordovician (Chazy) and probably are from the limestone quarries at Valcour Island, in the northern part of Lake Champlain.

Railroad track near Willsboro to Ausable Chasm (15 miles, or 24 kilometers).—The route leads back to the road intersection north of Pokamoonshine Mountain and continues north past the west spur of Bigelow Mountain. Ahead to the left is Fordway Mountain, a prominent peak, the northernmost outcrop of anorthosite. The layers of rock dip to the west, under the Ausable Forks syncline, like the igneous rocks of Deerfield, Pokamoonshine, and Baldface Mountains, farther south. The isolated hill on the right, Prospect Hill, marks the last exposure of anorthosite on this side of the road. The northern contact of the pre-Cambrian rocks is not seen, because of Pleistocene cover. In the bed of the Ausable River at Keeseville the first exposure of the Cambrian Potsdam sandstone is seen on the left side, while crossing the stream. Ausable Chasm, 1½ miles (2.4

kilometers) north of Keeseville, is a picturesque canyon carved into the Potsdam sandstone by the Ausable River.

OUTLINE OF THE STRUCTURE AND STRATIGRAPHY OF NORTHWESTERN VERMONT

By Arthur Keith [7]

INTRODUCTION

As the traveler comes out from the rugged ranges of the Adirondack Mountains of New York, he sees spread before him a smooth and fertile valley. Far in the eastern distance are the faint profiles of the Green Mountains of Vermont, blue with haze and reaching to the north and south as far as the eye can reach. This is the Champlain Valley, famed in history and the scene of conflict, from the early days of settlement by the Europeans back into the traditions of the Indians.

Along the middle of this valley lies Lake Champlain, a broad silver sheet whose waters flow northward into Canada and the mighty St. Lawrence River. On its bosom the Indians in their war canoes fought their battles and launched their expeditions in stealth. Near Burlington a lonely island, Rock Dunder, was finally agreed upon as the boundary between tribes.

Down the lake came French voyageurs led by Champlain, and later fleets of voyageurs pressed far to the south the limit of French occupation. The Dutch, coming up the Hudson, pushed their sphere of influence to the southern part of the Champlain Valley, and in later days the British followed the same route. French and British forces fought their battles in our colonial days, aided by the willing Indians, and the lake was their highway and battleground. Later yet the new American forces contended with the British for supremacy, and one of the decisive battles of the Revolution took place near Ticonderoga, at the south end of the lake. Further but more peaceful struggles centered around the proposed extension of New York State across the lake into what is now Vermont.

A century later conflict still flourished around the lake, and scientists disputed about the age and order of the rocks of the Champlain Valley. The conflict was bloodless but none the less bitter, and the questions at issue are not yet settled in their entirety. The crux of the difficulty was the Taconic system of Emmons, which was later found to include two of our modern

[7] This discussion appears as an independent section because Mr. Keith was unable to prepare it until the rest of the manuscript was ready for publication. A more detailed discussion by Mr. Keith has appeared in the Journal of the Washington Academy of Sciences, vol. 22, Nos. 13 and 14, pp. 357–379, 393–406, 1932.

systems. Since his day the complications due to thrust faulting have been discovered, and work in very recent years has disclosed the presence of extensive overthrusts, on which great groups of formations were borne for miles across other groups.

GENERAL GEOGRAPHY AND GEOLOGY

Geography.—The Champlain Valley lies partly in New York and partly in New England. In the largest view it is bounded on the east by the Green Mountains and on the west by the Adirondack Mountains, and at the south it is split by a minor group of mountains—the Taconic Range. A large part of the valley is occupied by Lake Champlain, the surface of which is 100 feet (30 meters) above sea level and the bottom is below sea level. The valley passes northward into Canada and curves northeastward, merging into the St. Lawrence Valley.

The Champlain Valley is 20 miles (32 kilometers) wide where it is first seen by the excursionists, and it extends southward for 80 miles (129 kilometers) from the Canadian border to the Taconic Range. The valley is there divided by the range into two parts—a western part, which is continuous into the Hudson Valley of New York, and an eastern part, which extends as the western valley of New England nearly to Long Island Sound. This part of the valley also has several names for individual sections, such as the Rutland Valley, in Vermont, and the Stockbridge Valley, in Massachusetts. It will be followed by the excursion from Brandon, Vermont, to Massachusetts. The east side of the Champlain Valley is sharply marked by the abrupt rise of the Green Mountain front, which trends nearly north and south. The west side of the valley is also clearly marked by the bold slopes of the Adirondack Mountains, in New York. Near the south end of Lake Champlain these mountains come to the shore of the lake.

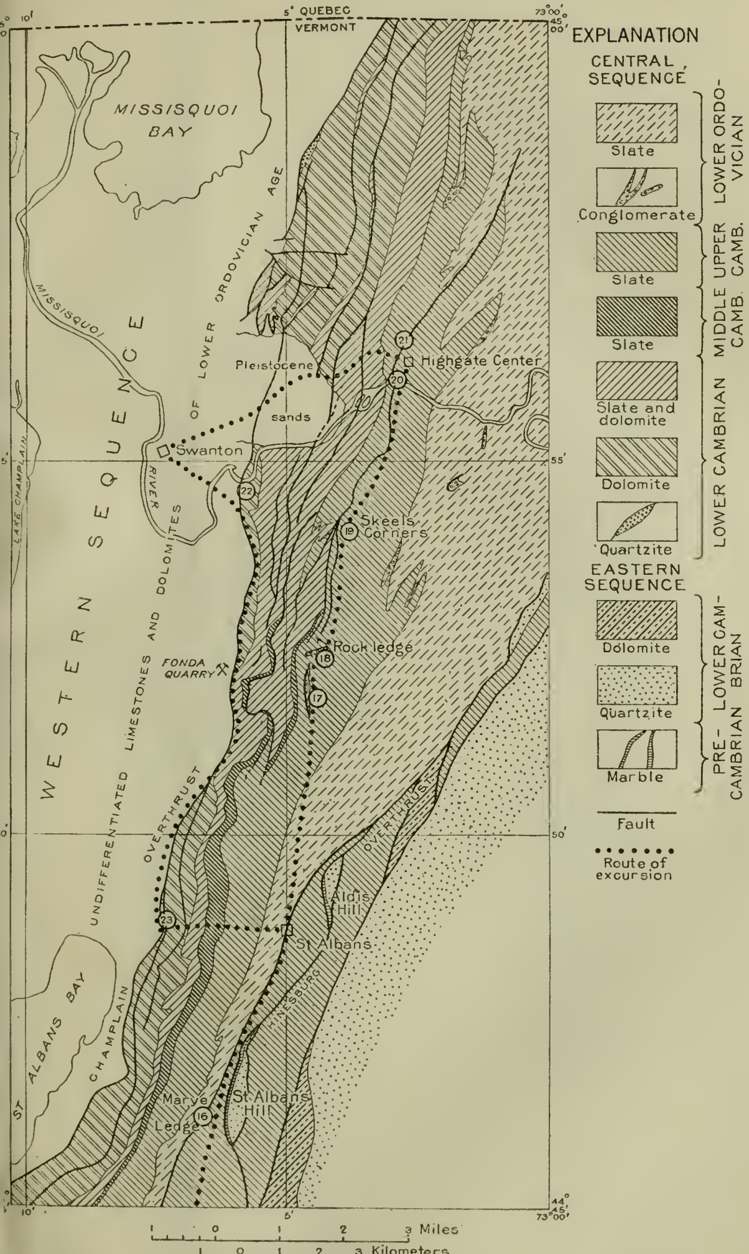
Stratigraphy.—The valley and its southern branches are floored by Paleozoic limestone, dolomite, marble, shale, and slate, with a few belts of quartzite. All these rocks except the quartzite are rather easily eroded, and their surface is well worn down toward sea level. They range from Lower Cambrian to Middle Ordovician in age, and the older formations show mainly in the eastern part of the valley and the younger ones in the western part. The west half of the valley and its extension southward into the Hudson Valley is floored mainly by a few formations of Ordovician shale and limestone; the east half is underlain by many formations of Cambrian limestone, dolomite, marble, and quartzite. These two groups are separated by the Champlain overthrust. The Cambrian formations also underlie nearly all of the western valley of New England. Thus, in a broad way, older and older rocks appear successively to the traveler from west to east. As a result of this general progression the eastern margin of the valley and the front of the Green Mountains are formed by the lowest Cambrian quartzites and by lower formations of Algonkian age. Still older formations are the granites and gneisses in the heart of the Green Mountains.

A marked departure from this plan is seen in the Taconic Range. There the carbonate rocks that characterize the valley disappear, and nearly all the formations are of slate. One thin quartzite formation and one very thin limestone together form perhaps 5 per cent of the total section. There are three slate formations of Middle Ordovician age and six of Lower Cambrian age. No Middle or Upper Cambrian is present and no Lower Ordovician. The Lower Cambrian of the Taconic Range lies on or beside the Lower Cambrian of the valleys, and the two groups have no features in common except that of age. One group makes the mountains; the other forms the valleys. Similarly, most of the Ordovician formations of the Taconic Range differ widely from the Ordovician of the surrounding valleys.

Other discrepancies of this sort are found in the Champlain Valley, so that in all there are three major tracts in the valley and a fourth in the Taconic Range, which differ strikingly from one another in the formations present and in their metamorphic condition. Each of these natural groups is called a sequence, and each is separated from the others by a major fault, as shown in Figure 12. These sequences are called western, central, eastern, and Taconic sequences, in order to show where they are best developed. The Champlain overthrust separates the western from the central sequence; the Monkton overthrust is the boundary between the central and eastern sequences; and the Taconic overthrust separates the Taconic sequence from the others.

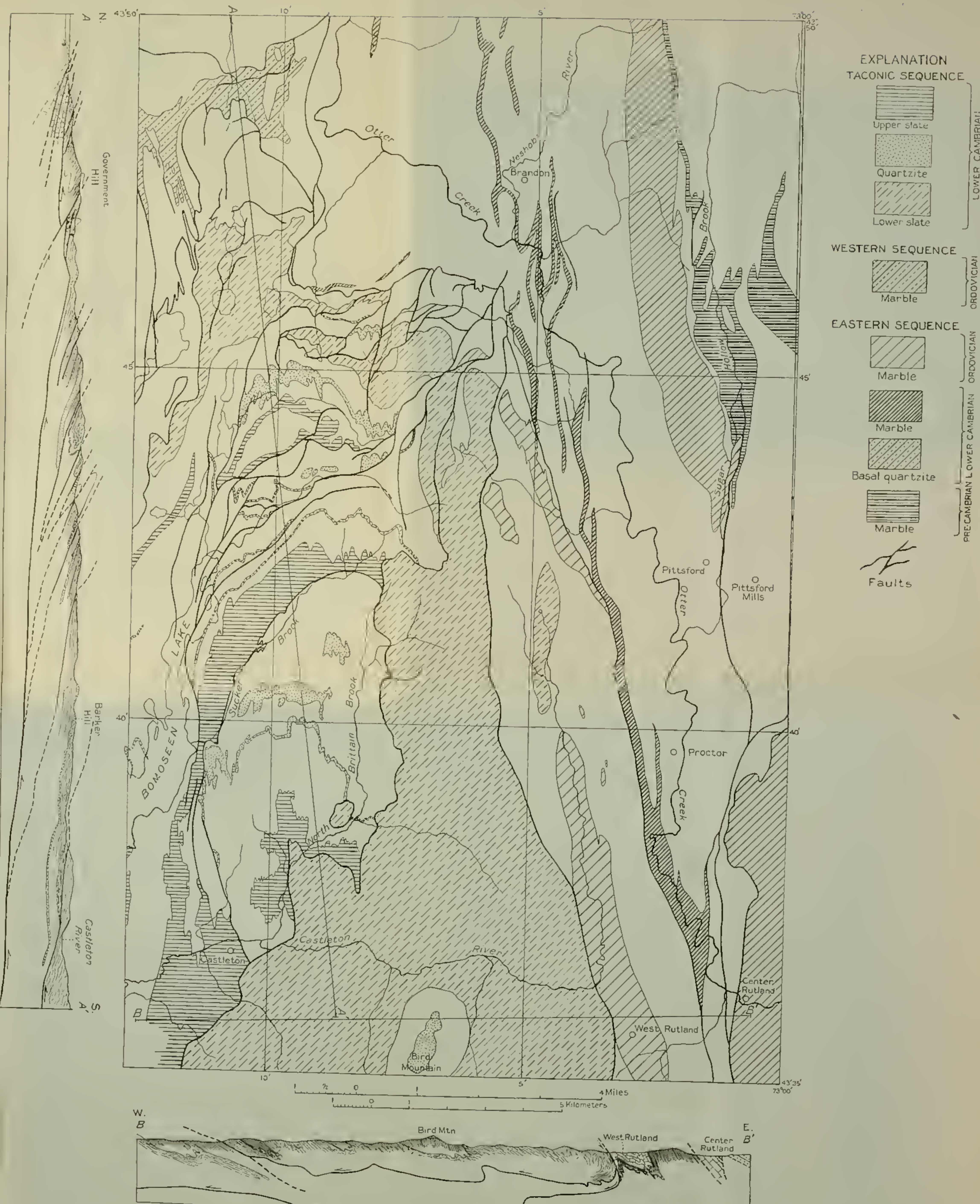
Structure.—The geologic structure of the Champlain Valley consists of long, narrow folds overturned toward the northwest and split by numerous faults. Other faults (the great overthrusts mentioned above) are more than usually numerous, and because they bring the extremes of sedimentation together they greatly complicate the structure of the region. The rock formations have the same north-south trend as the structural features except here and there where they are shoved aside by the great overthrusts.

Because of differences between the various formations in respect to ease of erosion the valley is very plainly defined from the mountains, and the weaker formations of the valley are separated by the minor ridges of the harder formations, such as the Monkton Hills.



GEOLOGIC MAP OF THE ST. ALBANS REGION, VERMONT

By Arthur Keith. Numbers in circles indicate localities mentioned in the text.



GEOLOGIC MAP AND SECTIONS OF THE NORTH END OF THE TACONIC RANGE

By Arthur Keith. Only a few key formations are shown by conventional patterns.

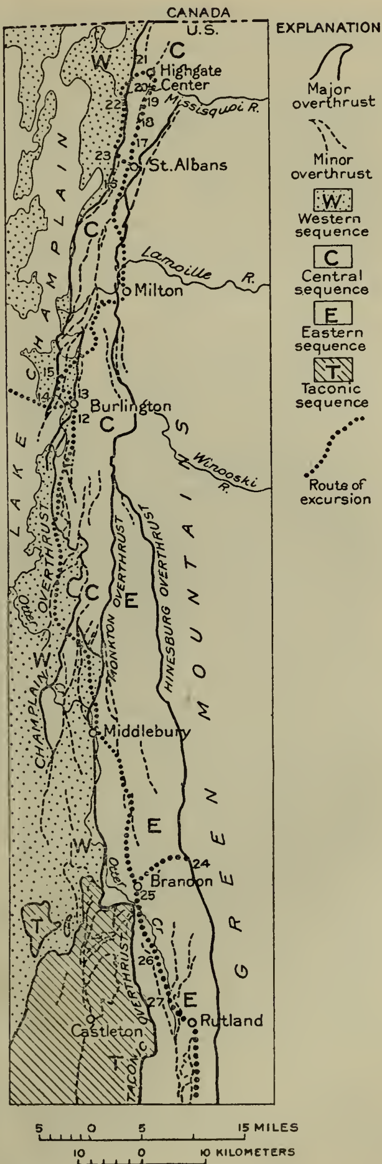


FIGURE 12.—Map showing major thrusts and the stratigraphic sequences in northwestern Vermont. By Arthur Keith

This region is at one of the great salients of the Appalachian system where the rocks of the earth's crust have been pushed farther west than in adjoining regions. The axis of the salient crosses the valley and mountains in the St. Albans district (see pl. 7), where the structural trends change from northerly to northeasterly. Farther south, in the Rutland district, the folds have lagged behind those of the St. Albans district and even trend to the west of north. This is the only place in the Appalachian system where such a general trend is seen. The lag is due to the massive buttress of pre-Cambrian rocks in the Adirondack Mountains, which checked the westward advance of the folds.

The rocks of this region show the results of extreme compression and exhibit a great variety of folds, faults, and metamorphism. First came the group of great overthrusts, the Champlain earliest, followed by the Monkton and Hinesburg thrusts, with the Taconic as a climax. Each of these was marked by more or less horizontal movement, but the Taconic overthrust was much greater than the others. Its roots lie far to the east in the Green Mountains, nearly 20 miles (32 kilometers) away. The Taconic overthrust mass was forced completely over the other thrust masses and is now to be seen overriding two of them, the Monkton and the Champlain, at the north end of the Taconic Range. (See pl. 8.) On each overthrust there were brought together groups of formations of the same age but of very different nature and formed originally many miles apart.

Apparently the overthrusting reached a deadlock, being stopped by friction and piling up of the masses. The pressure was still being applied, however, and the rocks were still more folded and mashed. With them were folded the overthrust planes and masses until in places they were turned upside down, as is to be seen along the east side of the Taconic Range. Still further compression split many folds and formed minor thrusts and faults. Some of these—for instance, the Castleton fault—sliced through the great overthrust masses and dislocated them into separate blocks. Such results are well seen in the vicinity of Burlington and Middlebury, where the Champlain overthrust was dissected. A far finer example of this secondary slicing is seen in the northern part of the Taconic Range, where a dozen secondary thrust faults have cut the overthrust mass into slices.

The process of compression went on until in some sections, notably near St. Albans, scarcely a vestige of folding remains, all being swallowed up in a succession of slices. The planes of the great overthrusts dipped originally at low angles toward the east; they still do so in some places but are overturned in others. The lesser faults dip as a rule less than 45° E.

In many places the overthrust masses were raised so high on the secondary structures that erosion has revealed the under-

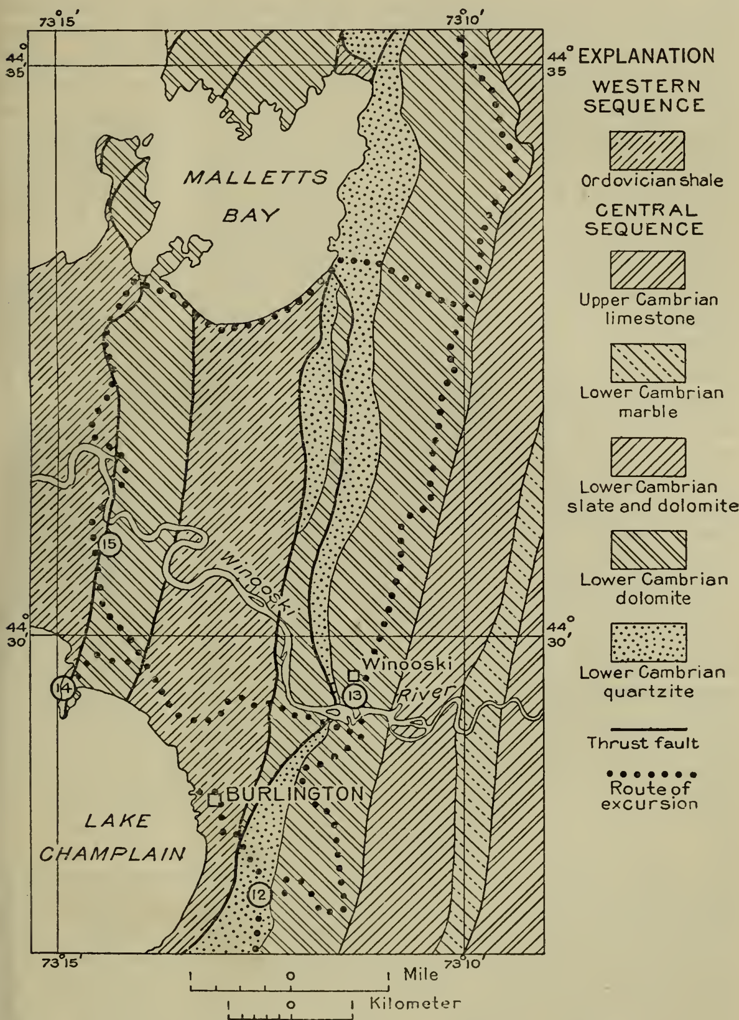


FIGURE 13.—Geologic map of Burlington, Vermont, and vicinity. By Arthur Keith

lying rocks in fensters. The largest of these appears a few miles west of Middlebury and east of Snake Mountain, where the limestones of the Western sequence are exposed in a tract covering many square miles. This is indicated in Figure 12. Smaller structures of the same sort are to be seen in the vicinity of Burlington (fig. 13) on the same overthrust, which is there close to the water front. Of the same nature, but enormously greater in scale, is the region east of the Taconic Range and including the western part of the Green Mountains. All of this was brought above the erosion plane by folding and faulting subsequent to the Taconic overthrust. The outcrop of this overthrust now forms an enormous flattened Z, the middle line of which reaches from the north end of the Taconic Range into Massachusetts, where it turns back to the northeast.

A far different arrangement is seen west of the Champlain overthrust, where the western sequence of formations prevails. Folding is at a minimum and is expressed mainly by tilting at angles which are rarely as great as 30°. The tilting was accomplished mainly by normal faults, which trend in a great variety of directions and of which the throw is commonly small. A very few faults of this kind are known to cross the Champlain overthrust into the region of the central sequence. The rocks of this sequence exhibit practically no metamorphism except some slaty cleavage near the Champlain overthrust, and the whole system of structure differs so widely from that east of the Champlain fault that they obviously belong in different provinces.

Hand in hand with the movements of folding and faulting was deformation by metamorphism. This was least in the western sequence, so that shales were barely transformed into slates, and fossils were scarcely deformed. At the east, however, the changes were extreme; no rocks escaped entirely, and some were mashed almost out of recognition. Interbedded limestones and dolomites were transformed into strings of blocks of ruptured dolomite, between which was forced calcite marble, as shown in Plate 9, *A*. Such metamorphism was accomplished not only by physical rupture and separation but by chemical recrystallization. The details of this differ widely between marbles, slates, quartzites, graywacke, and granites. The difference in aspect produced by these chemical changes is greatest in rocks that originally contained alumina in the form of clay or feldspar. In such rocks the development of micas proceeded to great lengths, so that new structure planes—schistosity—were produced in them, and rocks of different original composition approach one another closely in appearance. In these rocks lithologic composition is of little value in fixing their age, and phyllites of Ordovician and pre-Cambrian age may be identical in appearance.

Between the extremes of metamorphism there are many intermediate grades. The western margin of readily noticeable metamorphism is not far west of the Taconic overthrust at the south and of the Champlain overthrust at the north. The metamorphism is substantially limited to the region covered by overthrusts and doubtless is due to the combination of intense lateral pressure with the greatly added overburden of the overthrust mass. It is because of this intense recrystallization of the limestone and dolomite, and the changes of bulk, color, and pattern that went with it, that this region has the largest body of fine marble in the United States.

INDIVIDUAL FORMATIONS

The general character of the formations exhibited in this region has been mentioned briefly in the foregoing general descriptions. The outcrops of rock are very good in some parts of the district, such as the northern part of the Taconic Range and the upper slopes of the hills and ridges throughout the region. All the ledges have been scraped and polished by the Pleistocene glaciers, and the decomposed rock has almost everywhere been removed. On the other hand, exposures are very poor in the low ground, which is largely floored by glacial drift. The lower levels of the valley are usually filled with glacial clay deposited in the glacial lakes at various stages. This clay conceals everything over great areas near Lake Champlain. In the eastern and higher tracts there are numerous sand plains and terraces ranging from 200 to 1,600 feet (61 to 488 meters) in altitude. These are particularly clustered around the points where the rivers come out of the mountains, and they cover all kinds of the bedrock, so that in places it is impossible to tell precisely how the formations connect from side to side of a delta. In the Green Mountains boulder clay conceals most of the rock, which only here and there projects through it or is uncovered by the down-cutting streams.

CENTRAL SEQUENCE

The central sequence is exhibited in two general areas—one in the vicinity of Burlington, the other near St. Albans. The lower formations are the same for each area, but the higher units differ materially. Some differences are due to unconformity and overlap that produced Middle and Upper Cambrian beds found only in the St. Albans region. Also, in the St. Albans region there are two Ordovician formations which doubtless have been eroded from the Burlington region, owing to the greater depth of erosion there. The section passes from a quartzite base through dolomites and marbles and into slates at the top.

Lower Cambrian quartzite.—The sequence begins with quartzite of Lower Cambrian age. This is one of the best key rocks of the region. The original thickness is not known nor what beds precede it, because the base is cut off by the Champlain overthrust. The formation appears on several faults and folds in the township of Monkton, 17 miles (27 kilometers) nearly south of Burlington, but nowhere is anything lower exposed. In that town the Lower Cambrian quartzite of the Eastern sequence is brought into contact with the quartzite of the Central sequence by a thrust which there separates the two sequences.

The formation in the central sequence consists very largely of a dense, fine-grained quartzite whose notable feature is its red color. The top of the formation has interbedded layers of a tough, fine dolomitic marble, also rather highly colored with red or pink. These beds are of the same composition as those of the overlying dolomite and make a transition between the two formations. A few Lower Cambrian fossils have been found in the uppermost layers of the quartzite but are rarely to be seen until the thin slabs have been exposed to the weather for a considerable period, thus leaching out a calcareous cement and permitting the interior structures to be exposed. Cross-bedding, ripple marks, and trails of animals are numerous in the formation, showing that it was deposited in shallow waters.

The quartzite is eroded very slowly, so that it forms mountains or high hills, by which its course may be readily traced. It is considerably dissected by faults, so that the quartzite forms few continuous ridges but rather a lot of irregular, elevated tracts. This relation is very well seen around Mount Philo, in Charlotte, 14 miles (23 kilometers) south of Burlington. The most notable of the mountains made of this quartzite is Snake Mountain, 6 miles (9.6 kilometers) northwest of Middlebury, which is a remnant of the Champlain overthrust plate, lying on Ordovician shale. West of this lie the low limestones and shales of the western sequence, and east of it are other limestones of the same sequence, appearing through a great fenster in the overthrust.

Lower Cambrian dolomites.—These rocks are exposed in the bluffs around Mallett Bay, northwest of Burlington. At the base is a colored ornamental marble, well exposed in Winooski Gorge and in several quarries. There is a transition upward into beds of massive light or dark gray dolomite. With this are interbedded seams and layers of dolomitic sandstone, which in the northern part of the region expand to form quartzite beds as much as 10 feet (3 meters) thick. A few fossils of Lower Cambrian age have been found in this formation, mostly in slabby layers in its upper part.

Lower Cambrian slate.— This formation contains large numbers of Lower Cambrian fossils. It consists mainly of slaty shale of a dark-gray or slightly banded color and containing considerable original mica. This mica permits the splitting of the layers along the bedding rather than along the cleavage, so that there is an especially good opportunity to uncover the fossils. A notable feature in the slate appears about 7 miles (11 kilometers) north of St. Albans in the form of massive, blunt lenses of blue limestone surrounded by the slate. These have the same form and relations as limestone reefs in the Upper Cambrian slate.

The formation represents a sharp change in lithology from the preceding dolomites, and no interbedding has been noted. The top of the formation, however, is marked by a decided unconformity, by which the formation is reduced to almost nothing from a maximum thickness of perhaps 100 feet (30 meters). Locally the basal part of the overlying dolomite consists of dolomite conglomerate containing large boulders of dolomite and slabs and pebbles of the fossiliferous slate.

Lower Cambrian dolomite.—This dolomite is one of the most variable formations in this region. It varies in thickness, from perhaps 700 feet (213 meters) down to 8 or 10 feet (2.4 to 3 meters), and it varies in character, from massive gray dolomite, fine and coarse grained, thick bedded and slabby, through sandy dolomite and quartzite to a coarse dolomite conglomerate. In the upper part of the formation, and only where it is thick, considerable black chert is found in the dolomite.

The rocks just mentioned are those which are usually exposed, but there is another component of the formation which is very rarely visible—a series of slate layers interbedded with the other rocks. They have thus far been found in full only in the section below Highgate Falls. At extreme low stages of the river a considerable section is exposed which is not ordinarily visible, and in this are found numerous layers of slate. These layers have the same characteristics as those in the underlying slate, and a few fossils were found in them, the age of which has not yet been determined. Numerous minor unconformities were brought out between the slates and the conglomerates and sandstones, which emphasize clearly the torrential nature of this part of the formation. This general conglomeratic nature is characteristic in practically all of this area and is most prominent from the latitude of Milton northward to Canada. In some places these dolomite conglomerates consist of angular fragments of all the kinds of rock which appear as layers in the formation and thus may be properly classified as intraformational. The coarse basal conglomerates, however, which carry boulders 3 or 4 feet

(0.9 to 1.2 meters) in diameter and many rounded fragments of dolomite as well as slabs of the underlying slate, are not intraformational.

Lower Cambrian(?) marble.—This formation consists almost wholly of white marble of fine and medium grain, with a few layers of light-colored dolomite. It is represented in the Eastern sequence by a marble formation of the same character, which is almost continuous through the quarry region of Middlebury, Brandon, Proctor, and Danby.

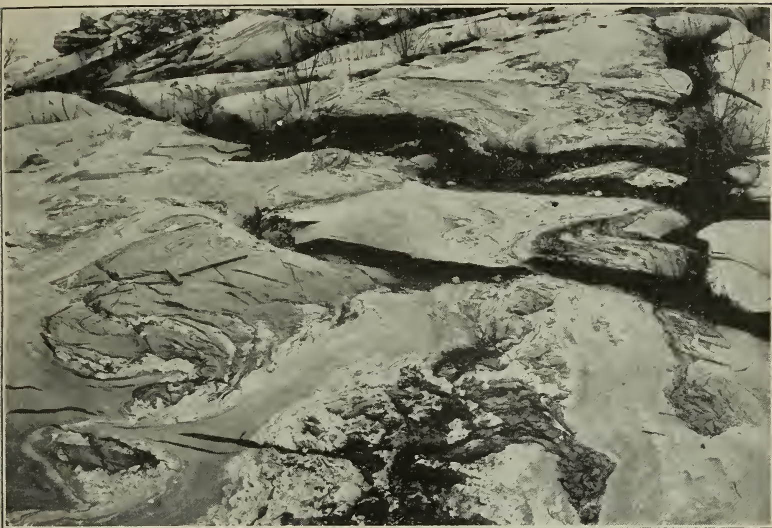
Middle Cambrian slate.—Middle Cambrian fossils have been found at the west border of the city of St. Albans. The formation contains only slate, which is dark gray and locally banded and is micaceous like the Lower Cambrian slate.

Limestone conglomerate (*Upper Cambrian*).—This formation is one of the most interesting in this region, although it is one of the smallest. At St. Albans it rests on the Middle Cambrian slate. The formation is of Upper Cambrian age, and an abundant fauna has been obtained from some of its limestone layers at Highgate Falls. The fossiliferous beds form very characteristic slabs an inch or two thick, and their fragments appear as angular slabs in the later conglomerates.

This formation is characteristically a conglomerate, and the fossiliferous limestones are only a small part of it. All the conglomerate beds contain angular fragments of dolomite, sandstone, and quartzite. Several layers also contain fragments and boulders of blue limestone and white marble, many of which exceed 3 feet (0.9 meter) in diameter. The marble appears to have been derived from Lower Cambrian(?) marble, which is the only rock of the sort that can be older than Upper Cambrian. The blue limestone boulders resemble some of the limestones of the Ordovician, but they resemble equally well the blue limestones in the reef deposits of the Lower Cambrian slate, found a few miles southwest of Highgate Center. This conglomerate bears a very strong resemblance to the Ordovician conglomerate, which is quite natural in view of the derivation of the boulders from the same sources.

Upper Cambrian slate.—This slate rests upon limestone conglomerate in the gorge at Highgate Falls. Most of the formation is exposed between the conglomerate and a thrust fault and consists in the main of dark-gray or black slate, usually well banded and with pronounced cleavage. The banding is so regular that it resembles glacial varves.

A remarkable phenomenon in the slate is the development in many localities of large masses of limestone entirely surrounded by the slate. They occur usually in the upper part of the formation above the horizon of the limestone layers above



A. RUPTURE OF DOLOMITE AND FLOW OF MARBLE IN QUARRY 1½ MILES (2.4 KILOMETERS) WEST OF FLORENCE, VERMONT

B. LIMESTONE REEF IN UPPER CAMBRIAN SLATE, GEORGIA, VERMONT

THE CHAMPLAIN THRUST AT LONE ROCK POINT, NEAR BURLINGTON, VERMONT

The weak Ordovician shale (below) has been eroded back, and the more resistant Lower Cambrian dolomite forms an overhanging cliff. Note the strong scoring at the base of the dolomite. Photograph by C. D. Walcott.

mentioned. They are found from the Canadian border southward nearly to Burlington.

These bodies are, for the most part, made up of massive, dense blue limestone without any visible structure. In the large masses, however, there is likely to be a portion of the mass showing a subdivision of the blue limestone into roughly rounded bodies separated by narrow zones of brownish impure limestone and also secondary quartz partly filling the spaces between the limestones. These rounded areas of blue limestone are the cross sections of columns which stand nearly vertical and can be seen in solution cavities to extend downward at least 5 feet (1.5 meters) from the surface. The most notable example is 2 miles (3.2 kilometers) west of north from Georgia, as is seen in Plate 9, *B*. It is evident from these exposures that the structure of these limestones is not due to any sedimentary process but is the result of some reef-building organism. Some of these reefs appear to have persisted to the end of the deposition of the Upper Cambrian shale, for they are directly overlain in places by the basal Ordovician conglomerate and appear to have furnished much local material for the conglomerate. A good nstance is also seen 2 miles nearly west of Georgia Center.

Upper Cambrian fossils have been found in this formation. There is no known contact between the slate and the next younger limestone formation.

Upper Cambrian limestone.—This limestone is exposed southeast of Burlington. It is cut off at the north by faulting and erosion but extends southward to the limits of the central sequence. It contains fossils of Upper Cambrian ("Saratogan") age.

The formation consists of a thick series of beds of hard gray dolomite and of blue limestone largely altered to marble. The beds are from a few inches to a few feet thick and are greatly disturbed. The hard dolomite layers are folded and broken apart into segments, and the marbles are mashed and squeezed nto the gaps and spaces between the dolomite bodies.

Ordovician conglomerate.—This conglomerate, like that in the Jpper Cambrian, is one of the striking formations of this region. t rests upon the Upper Cambrian slate and forms a series of enticular deposits between that formation and the overlying Ordovician slate.

The Ordovician conglomerate consists in the main of pebbles nd boulders of various limestones, marbles, and dolomites, most of them being limestone. The thin slabs of fossiliferous Jpper Cambrian limestone are numerous and conspicuous. Fossiliferous pebbles of Lower Cambrian limestone are occasionally found, and one boulder of blue limestone with apparent

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Cryptozoa lies in the conglomerate at Marye Ledge, 2 miles (3.2 kilometers) south of St. Albans. A limestone boulder 60 feet (18 meters) long and about 30 feet (9 meters) wide was found in the conglomerate 4 miles (6.4 kilometers) north of St. Albans. In the same exposures there were many boulders 5 or 6 feet (1.5 to 1.8 meters) in diameter. In the original description (25) of this region by the author the very strong resemblance of the Upper Cambrian and Ordovician conglomerates led to their description as one formation. Later detailed mapping and study showed that there were two conglomerates and that the older one was placed by thrust faulting south of Highgate Center on top of the Upper Cambrian slate, thus causing the confusion of the two.

Lower Ordovician slate.—This formation is the youngest known in the sequence and crops out continuously from the Canadian border to the northern part of the township of Georgia, 6 miles (9.6 kilometers) south of St. Albans. The formation consists almost wholly of dark-gray fine-grained slate. A very few limestone beds are found in this slate, and in one of them, 4 miles (6.4 kilometers) northeast of Highgate Center, were found fossils of Beekmantown age. The bottom layers also contain fossils of the same age.

EASTERN SEQUENCE

Several formations of Algonkian age are included in the eastern sequence; these consist mainly of sedimentary rocks, graywacke, marble, and phyllite. They are confined to the frontal ranges and hills of the Green Mountains and are seen in most sections into the mountains. There is a great unconformity between these formations and the quartzite of the Lower Cambrian.

Lower Cambrian quartzite.—By far the greater part of this formation consists of massive white vitreous quartzite, particularly in the upper beds. In the middle of the formation thin layers of black slate are interbedded with the quartzite but are not sufficiently well defined to constitute a regular subdivision of the formation. Nearly everywhere there is a conglomerate at the base of the formation. The quartzite varies considerably in thickness and has a probable maximum of about 800 feet (244 meters).

Lower Cambrian dolomite.—This formation consists almost wholly of dolomite. Its color is usually light or dark gray, and it has a fine or medium grain. Most of it is thick bedded, and there are few slabby layers. In the middle of the formation is found a small zone of light-colored limestones. Near the top of the formation is a thick bed of dolomitic sandstone, which makes prominent outcrops near Rutland. Below this there is 100 feet (30 meters) or more of dark-blue dolomitic limestone. Fossils found in this formation show it to be of Lower Cambrian age. A few fossils have been found in the topmost beds of the underlying quartzite, also of Lower Cambrian age.

The strata of this formation, like those of the preceding quartzite, are very massive and compact and have acted as a unit to minimize the folding; thus the syncline of Rutland Valley is one of the few open synclines in the region. Its western limb is found in Pine Mountain, and its eastern limb, which is locally faulted off, appears along the front of the Green Mountains. The strata in the middle of the fold are nearly horizontal. This open fold was thrust westward against the highly deformed beds of the upper part of the sequence.

Higher formations.—The remainder of the sequence consists chiefly of carbonate rocks, including marble beds that are quarried extensively. There are some intercalated slates and sandstones. The uppermost formation, a marble, contains fossils of Lower Ordovician (Chazyan) age.

TACONIC SEQUENCE

The rocks of the Taconic sequence are found only in the Taconic Range, as already noted, and they present a very striking contrast with the beds of the same age that form the lower ground on the east and west. The sequence consists almost wholly of various slates, but it has also one thin formation of limestone and one of quartzite. By means of these two formations in the Lower Cambrian and one of red slate in the Ordovician, the order and structure of these formations can be disentangled. The limestone contains a good Lower Cambrian fauna, and two of the slates have Lower Ordovician fossils. The formations of this sequence form a great mass that was thrust westward from the region far to the east over the rocks of the eastern sequence and later isolated by erosion.

GEOLOGY OF WESTERN VERMONT AND NORTHWESTERN MASSACHUSETTS

By Chester R. Longwell

GENERAL FEATURES

The Green Mountains of Vermont, near the mid-axis of the State, extend south into Massachusetts as the Hoosac Range and the Berkshire Hills. This mountain unit is composed chiefly of pre-Cambrian metamorphic rocks, intruded by granites and other types of igneous rock. A few miles to the west is the

Taconic Range, near the western boundary of Vermont and Massachusetts. This range is essentially parallel with the Green Mountain–Berkshire Hills axis; but whereas the Green Mountains are generally higher to the north and extend into Canada, the Taconic Range dies out rather abruptly in the latitude of Brandon. (See figs. 1 and 12.) The two ranges are separated by a narrow but remarkably continuous lowland belt, underlain by folded Paleozoic formations, principally metamorphosed limestones. In the Taconic Range the rocks are in large part metamorphosed clastic sediments; some formations have been identified as Cambrian and Ordovician, but a large part of the metamorphic complex is of uncertain age.

North of the Taconic Range, in northwestern Vermont, the area between the Green Mountains and the Adirondacks is in general a wide lowland floored with Paleozoic sediments. The stratigraphy and structure of this area are of exceptional interest but are extremely complicated. Before the middle of the last century Ebenezer Emmons, of the New York Survey, not suspecting the structural complexity, included most of the strata in this belt in his Taconic system. Somewhat later Sir William Logan, of Canada, called attention to a great thrust fault near the east side of Lake Champlain. Walcott and other paleontologists established the age of some key formations, and within the last few years Keith has found that a series of important thrusts, parallel with Logan's Champlain fault, divide the area into long, narrow north-south blocks which have been crowded one over the next from east to west until the original width has been greatly decreased. Recognition of this structure clarifies many of the stratigraphic relations that earlier appeared to be anomalous.

Farther south, particularly in the Taconic Range, the problems are more difficult. The bedrock in this range consists in large part of a great series of slates and phyllites, and hence it is hard to distinguish stratigraphic units with certainty. Moreover Prindle's work shows that the structure is characterized by complex recumbent folds, in contrast with the clean-cut thrusts of northwestern Vermont. Further intensive field work, supplemented by careful petrographic studies, will be necessary before this part of the region is properly understood. The limestone belt between the Taconic Range and the Green Mountain axis is better known, as the section contains many distinctive stratigraphic units. The limestones have been greatly deformed and metamorphosed, and there has been extreme thinning and thickening of beds by flowage.

NORTHWESTERN VERMONT

STRATIGRAPHY

All the formations recognized in the wide lowland between the northern Green Mountains and the Adirondacks are Cambrian and Ordovician. (See pl. 7 and figs. 12 and 13.) The section is complicated by the existence of several facies at each stratigraphic horizon. Because of the extreme shortening by thrusting, the most pronounced differences are found along east-west sections. (See fig. 14.) Thus there is an abrupt change, both in thickness and in character of the formations, at the Champlain fault, and equally pronounced differences on opposite sides of a thrust zone farther east. Keith (25)[8] has recognized a general threefold horizontal division of the formations—a western sequence, a central sequence, and an eastern sequence. (See fig. 12.) In northwestern Vermont the central sequence is particularly well developed; but it disappears abruptly to the south. According to Keith's interpretation it is overridden and concealed by masses thrust from the east.

Western sequence.—West of the Champlain fault the oldest Cambrian recognized is the Upper Cambrian Pots-

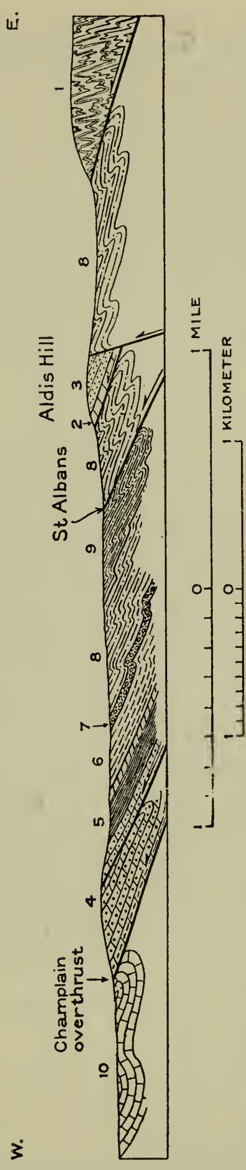

FIGURE 14.—Section from west to east near St. Albans, Vermont, showing the principal thrusts at that latitude and the three sequences of Paleozoic formations separated by the thrusts. 1, Undifferentiated pre-Cambrian and lower Paleozoic; 2, dolomite and schist, probably late pre-Cambrian; 3, Lower Cambrian quartzite (eastern sequence); 4–9, central sequence; 4, Lower Cambrian dolomite; 5, Lower Cambrian slate and dolomite; 6, Middle Cambrian slate; 7, conglomerate, base of Upper Cambrian (thickness exaggerated); 8, Upper Cambrian slate; 9, Lower Ordovician slate; 10, Ordovician of the western sequence. The coarse conglomerate at the base of the Ordovician in the central sequence (No. 9) is not exposed in the vicinity of this section.

[8] Numbers in parentheses refer to bibliography, p. 68.

dam sandstone, which was deposited in a late stage of the period. Evidently the long eastern flank of the Adirondacks was not submerged during most of Cambrian time; toward the end of the period the sea encroached farther and farther on the area, which had been worn to low relief by long-continued erosion. The resulting deposit was chiefly fine-grained quartz sandstone, with conglomeratic beds developed only locally; the section exposed in Ausable Chasm is typical of the Potsdam.

The Lower Ordovician Beekmantown limestone follows directly on the Potsdam sandstone. At the top of the limestone a distinct break indicates emergence before the deposition of Ordovician limestones and shales (Chazyan and Mohawkian). These formations or their time equivalents continue around the south side of the Adirondacks and into the Hudson Valley. About Lake Champlain the entire series has small or moderate thickness.

Central sequence.—Along the Champlain fault a considerable thickness of Lower and Middle Cambrian strata, in addition to Upper Cambrian, is thrust from the east over rocks of the western sequence. The full thickness of the Lower Cambrian east of the fault is not known; the lowest formation is red quartzitic sandstone, the base of which is not exposed. Most of the formations above it are irregular in thickness from north to south, and some have only local development. The Upper Cambrian consists chiefly of shale, limestone, and dolomite, in contrast with the Potsdam sandstone, to the west.

The Lower Ordovician of the middle zone starts with a remarkably coarse conglomerate laid unconformably across various Cambrian formations. Although no sharp pre-Ordovician folds are recognized, considerable warping and erosion must have occurred in late Cambrian time to produce the striking unconformity with the Lower Ordovician and to make possible the large assortment of rock types in the basal conglomerate. In contrast with the limestone to the west, the lowest Ordovician strata in the middle belt consist entirely of clastic sediments.

Relations of the principal stratigraphic units are shown in the following table:

Formations in northwestern Vermont

	Feet	Meters
Lower Ordovician:		
Slate, maximum thickness	3,500	1,067
Conglomerate	0–30	0–9
Unconformity.		
Upper Cambrian:		
Slate	0–300	0–91
Marble (horizon uncertain)	0–400	0–122
Dolomite, with abundant intraformational breccia locally	0–500?	0–152?
Conglomerate	0–15	0–15

	Feet	Meters
Disconformity (?).		
Middle Cambrian: Slate, of local development	0–200	0–61
Disconformity (?).		
Lower Cambrian:		
Dolomite	30–250	9–76
Slate with limestone reefs	0–200	0–61
Disconformity.		
Dolomite, very sandy	50–800	15–244
Red dolomite (marble)	250	76
Quartzite (base not exposed)	300	91

The following brief descriptions give the outstanding facts about each formation.

Central sequence quartzite: This is the "red sandrock" of early writers. It is more properly called a sandstone, as only part of the rock is quartzite. It is dominantly red but contains white and varicolored beds. Near the top there are many dolomite beds, and the formation grades into dolomite. Ripple marks, mud cracks, and other signs of shallow-water deposition are common. Lower Cambrian trilobites have been found in calcareous beds near the top of the section. The formation is not exposed north of the Lamoille River, 8 miles (13 kilometers) north of Burlington, or south of Snake Mountain, 35 miles (56 kilometers) south of Burlington, probably because it is cut out by faulting.

Dolomite: This series of beds also is not seen south of Snake Mountain, but it extends northward almost to the Canadian border. The lower part consists of compact, fine-grained dolomite, dominantly red, pink, and mottled. There is some intraformational breccia, and the bedding surfaces are wavy and irregular. Fossils were found in the lower part of the formation as early as 1847; Walcott referred them to the Lower Cambrian (*Salterella pulchella*, *Nisusia festinata*, *Ptychoparia adamsi*). The upper part of the series is thick-bedded and contains considerable sand. At the base are several beds of quartzitic sandstone, and rounded grains of glassy quartz are scattered throughout the gray dolomite. There is also considerable intraformational conglomerate, with pebbles of sandstone. Quartz geodes are common in the dolomite, and there are numerous veinlets of quartz. The fossils of the upper dolomite (*Paterina swantonensis*, *Salterella pulchella*, *Hyolithellus micans*, *Ptychoparia adamsi*, *Olenellus thompsoni*) are Lower Cambrian.

Slate: In the northern part of the area this slate is chiefly fine grained; to the south it becomes sandy and has layers of sandy dolomite. There are numerous large limestone lenses or reefs, as much as 100 feet (30 meters) in length. Some of the characteristic fossils are *Kutorgina cingulata*, *Nisusia festinata*, *Swantonia antiquata*, *Microdiscus parkeri*, *Mesonacis vermontana*, *Olenellus thompsoni*, *Olenoides marcoui*, *Bathynotus holopyga*, *Ptychoparia adamsi*, *P. vulcans*, *Protypus hitchcocki*, *Protocaris marshi*. The fauna is Lower Cambrian.

Dolomite: Gray dolomite, in part sandy, conglomeratic in its basal part. Thick bedded in lower 30 feet (9 meters), thin bedded in upper part. The exact date of the formation is not known, as it has not yielded diagnostic fossils.

Slate: Micaceous dark slate with small lenses of limestone and sandstone. The formation extends only a few miles from north to south, with its best development near St. Albans. It is of Middle Cambrian age. The guide fossils are the trilobites *Centropleura* (related to *Paradoxides*) and *Elyx*. This fauna, containing also some brachiopods, was discovered and described by Howell (24). The base of the slate is marked by conglomerate containing pebbles of dolomite.

North of Burlington the Upper Cambrian dolomite is thick bedded and several hundred feet thick. Farther north the character of the formation changes radically. From the Missisquoi River to the Canadian border the strata consist of slabby dolomite and limestone, some shale and sandstone, and intraformational breccias. There are three fossil zones, from which Raymond (26) has described more than 40 species of trilobites (Upper Cambrian), including *Plethopeltis armata*, *Lloydia seelyi*, *Saukia lodensis*, *Illaenurus quadratus*, *Platycolpus dubius*.

The Upper Cambrian slate consists chiefly of dark slate, much of it with varvelike bands, and contains local beds and lenses of limestone and dolomite. The banded character is best displayed in the vicinity of Highgate Falls. Many large lenses of limestone, probably algal reefs, are isolated in the shale. (See pl. 9, *B*.) It has yielded numerous genera of trilobites, including *Agnostus*, *Hypagnostus*, *Leiostegium*, *Pilekia*, *Maryvillia*, and *Lloydia*. At the base of this member is a conglomerate containing huge masses and angular slabs of limestone and dolomite.

The marble is well developed south of Burlington but dies out to the north, and its position relative to the Upper Cambrian slate is not known; possibly the two interfinger and are in part equivalent. It is a white to buff-colored marble in which no fossils have been found.

The Lower Ordovician conglomerate contains large blocks of limestone and marble derived from several older formations; the largest of these, more than 100 feet (30 meters) long, are at the base of the conglomerate and possibly are limestone reefs from the Upper Cambrian shale beneath. Ordinarily the conglomerate is not over 30 feet (9 meters) thick. No fossils have been found in the matrix.

The Lower Ordovician slate is a thick formation, dark gray or bluish, widely distributed in the eastern part of the middle belt.

It yields a trilobite fauna which affirms correlation with the Beekmantown limestone of the western sequence. Some of the forms are *Cholopilus* sp., *Petigurus cybele*, *Gignopeltis rara*, *Hystricurus* sp., and *Lloydia saffordi*.

Eastern sequence.—Near the western border of the Green Mountains in northern Vermont the Lower Cambrian formations brought up by thrust faults are strikingly different from formations in the middle sequence with which they are supposed to be correlative. The formations of the eastern sequence are as follows:

The quartzite, which rests unconformably on pre-Cambrian phyllite and dolomite, consists chiefly of white quartzite beds; the total thickness is about 1,000 feet (305 meters). Some layers of dark phyllite are included.

The dolomite consists chiefly of fine-grained gray dolomite, with some intercalated layers of sandstone and limestone. From abundant fossil evidence the greater part of the formation is correlated with Lower Cambrian dolomites of the middle sequence, but in lithology it is very different from those formations.

In northern Vermont the younger formations of the eastern sequence are not extensively exposed. Farther south the lowermost quartzite and dolomite are succeeded by several limestone and dolomite units of Cambrian and Ordovician age; these are described on pages 76-77, in the discussion of the marble district.

Two series of pre-Cambrian rocks underlie the Lower Cambrian quartzite along the mountain border. In the north a younger series, consisting of phyllite, quartzite, dolomite, and mica schist with local conglomerate, has been referred tentatively to the Algonkian system. In southern Vermont and western Massachusetts the Lower Cambrian quartzite rests in some places on injection gneisses, granites, and schists, presumably of Archean age.

STRUCTURE

The characteristic structural features of the area are thrust faults (fig. 14) and slaty cleavage. Folds are conspicuous locally, especially in the weak shales; but in general folding is much less intense than it is farther south.

There is considerable variation in the dips of the thrusts. Clearly the Champlain fault is inclined at a low angle, as the outcrop shifts horizontally along every intersecting valley of any considerable depth. At the exposure near Burlington the dip averages 17°; some other thrusts appear to be considerably steeper. There is no basis for a quantitative estimate of horizontal displacement on any of the faults. It is assumed, from the abrupt difference in facies of sediments on opposite sides of the larger thrusts, that the shortening amounts to many miles. In the area to be examined all the thrusts dip to the east.

The degree to which slaty cleavage is developed varies with the lithology of the formations and probably also according to location with relation to thrusts. In general the cleavage trends east of north, parallel with the strike of the thrusts, and is inclined rather steeply to the east.

The date at which the thrust structure was developed is not certainly known. Logan concluded that the Champlain fault, with its continuation along the St. Lawrence Valley, was formed at the end of the Ordovician period. Recent study by Schuchert supports this view. Keith has suggested that the thrusts are part of the Appalachian structure, developed late in the Paleozoic era; but there is no direct evidence supporting this suggestion, as no Paleozoic formations younger than the Ordovician are known in the region. The Taconian folding of late Ordovician time was severe in the lower Hudson Valley, and as deformation of that date was even more severe in southern Canada it is probable that at least a large part of the folding and thrusting in western Vermont and Massachusetts resulted from the same disturbance. It will be difficult to determine to what extent the structure may have been modified by later Paleozoic movements.

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AUSABLE CHASM, NEW YORK, TO ST. ALBANS VERMONT

By Chester R. Longwell

Ausable Chasm to Burlington (13 miles, or 21 kilometers).— From Ausable Chasm to the shore of Lake Champlain the bedrock is Cambrian (Potsdam) and pre-Cambrian, for the most part mantled with Pleistocene deposits.

If the weather is favorable the ferry trip across Lake Champlain gives an excellent panoramic view of the Green Mountains; their crest line is about 20 miles east of the lake, and a sloping plain (the Champlain Lowland) several miles wide separates the foothills from the shore. To the west the Adirondacks rise rather abruptly, though irregularly, near the water's edge.

The lake, named for the French explorer who discovered it in 1609, is about 130 miles (209 kilometers) in length; the greatest width, near the ferry crossing, is 11 miles (17.7 kilometers). Its shore line is made irregular by embayments and promontories, and its surface is broken by numerous islands, most of which have Cambrian and Ordovician bedrock. The maximum depth of the water is about 400 feet (122 meters), and the surface is 95 feet (29 meters) above sea level. During a late stage of the Pleistocene, when the ice had melted from the St. Lawrence River, the lake basin was an arm of the sea. Clays and coarser sediments mantle the surrounding low ground, and the marine character of at least part of the deposits is proved by numerous animal remains, such as invertebrate shells and the bones of whales. The sediments are best preserved on the wide plain east of the lake. Elevated beaches are recognized to a height of 440 feet (134 meters) above sea level; but it is not yet proved that the highest deposits are marine.

If weather permits the ferry will pass close to the shore of Lone Rock Point, near Burlington, to afford a general view of the Champlain thrust; at this locality Lower Cambrian dolomite lies above Middle Ordovician (Trenton) shale and limestone. (See pl. 10.)

[12] [9] In Burlington (fig. 13) the first locality visited is the Phelps quarry, which affords an excellent display of the red sandstone and quartzite (Lower Cambrian) of the central sequence. This is the oldest formation known in the central sequence; in the quarry, however, only the upper part of the formation is shown. Near the top of the cliff many carbonate beds indicate a gradation into the overlying marble (dolomite). The sandstone layers exhibit abundant ripple marks and other evidence of shallow-water deposition. Near the north end of the quarry the strata are cut by dikes of camptonite, which contain numerous inclusions not only of the sandstone but also of granitic rocks. The date of intrusion is not known; but the amygdaloidal character of the camptonite indicates that the sandstone was at a shallow depth when the dikes were formed.

The high ground near the University of Vermont affords a near view of the Green Mountains. Their western border, a few miles east of Burlington, is marked by a thrust fault; the pre-Cambrian rocks of the range have been driven westward over the Paleozoic sediments in the lowland. The flat attitude of the thrust is indicated by the retreat of the contact eastward

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[9] See Figure 13 for Nos. 12 to 15.

along the Winooski River and other streams that flow from the mountains.

[13] The gorge of the Winooski, in the northern part of the city, gives fine exposures of the beds transitional from the quartzite to the marble. Shallow-water deposition is indicated by sedimentary markings; even the typical marble has considerable intraformational breccia. Marine fossils have been found in both formations, however, and therefore the sandstone beds are at least partly of marine origin.

The route west to Lone Rock Point runs near the edge of high banks made of the Pleistocene Champlain sediments, at the south side of the Winooski flood plain. Nearer the lake the sediments disappear, and the gray beds of the upper part of the Lower Cambrian dolomite form large outcrops. Evidently there is a fault between the point and Burlington, for the quartzite underlies the city and the strata dip uniformly eastward. According to Keith's interpretation this fault is a branch of the Champlain thrust, on which the Lower Cambrian red quartzite overrides the younger rocks. (See fig. 13.)

[14] At Lone Rock Point the Champlain thrust is well exposed; at the contact the Lower Cambrian dolomite, projecting over the weak shale, is deeply scored and fluted. The thin-bedded Ordovician beneath is badly crumpled and is cut with a network of calcite veins. The average inclination of the thrust surface is 17° E.

[15] North of the point, in Ethan Allen Park, the topographic expression of the thrust is well shown. The resistant dolomite, dipping to the east, forms an asymmetric ridge; the thrust contact follows the base of the steep western slope. This ridge forms Malletts Head, a promontory between Malletts Bay and Lake Champlain.

Burlington to St. Albans (30 miles, or 48 kilometers).—From Ethan Allen Park the route goes north across the Winooski River and along the southern shore of Malletts Bay. Along the east side of the bay and extending farther south is a ridge made of the lowermost quartzite dipping eastward; the quartzite is brought up in this position, as in Burlington, by an eastern branch of the Champlain thrust.

Cobble Hill, a prominent landmark beside the highway about 10 miles (16 kilometers) north of Burlington, is formed by an outlier (*Klippe*) of the great thrust at the border of the Green Mountains. At Milton, where the road crosses the Lamoille River, dolomite of the eastern sequence is exposed; there are other good outcrops at the left of the road farther north. Arrowhead Mountain, on the left 2 miles (3.2 kilometers) north of Milton, is capped by Lower Cambrian strata in the thrust plate, like Cobble Hill. The rocks in the high scarp to the east are pre-Cambrian; they are overfolded or thrust up on strata of the eastern sequence.

Farther north there are few outcrops near the road; artificial cuts expose Lower Ordovician and Upper Cambrian slates of the middle sequence. About 3 miles (4.8 kilometers) south of St. Albans a steep isolated ridge (St. Albans Hill) rises 500 feet (152 meters) above the road on the right. The upper part is made of quartzite, probably of Lower Cambrian age; in the lower part the rocks are phyllite and dolomite. These rocks are thrust over the Upper Cambrian slate. (See pl. 7.)

[16] [10] Opposite the north end of St. Albans Hill and about 0.3 mile (0.48 kilometer) west of the highway, a prominent rock outcrop known as the Marye Ledge projects above the farm land. The surface of the outcrop was cleaned and smoothed by glaciation, and therefore the structure of the rock, which is coarse conglomerate, is well displayed. The boulders represent several rock types, but limestone and marble are conspicuous. Masses several feet in diameter are common. The outcrop has a prominent layered structure, inclined steeply eastward, which at first sight appears to be bedding, as the longer dimensions of the boulders are in the plane of the structure. Careful examination, however, shows that the bedding is nearly horizontal; the steeply inclined structure is cleavage, and the limestone boulders have been drawn out by squeezing.

Some of the limestone masses contain algal forms, and one boulder from this locality has yielded fossils of Upper Cambrian age. The formation, which is exposed more continuously north of St. Albans, appears to form the base of the Ordovician section in this area.

The bedrock beneath St. Albans is dark slate, partly of Ordovician and partly of Upper Cambrian age.

ST. ALBANS TO BRANDON, VERMONT

By Chester R. Longwell

St. Albans to Highgate Center (9 miles, or 14.5 kilometers).—St. Albans lies on a slope with an average altitude of about 400 feet (122 meters). This smooth slope is part of the highest recognized Champlain shore line of the late Pleistocene; the profile is well displayed a short distance north of the town on the right of the road. At the fork in the road north of St. Albans the route leaves the paved highway and follows the unpaved road north.

[10] See Plate 7 for Nos. 16 to 23.

[17] About 2 miles (3.2 kilometers) north of the fork there are excellent exposures of the Lower Ordovician conglomerate (pl. 11, *A*) in a pasture on the left. Some exceptionally large masses of limestone occur here; the largest, nearly 60 feet (18.3 meters) long, lies at the base of the conglomerate. There is some suggestion that this large mass is a reef from the underlying Upper Cambrian slate, little moved from its original position.

[18] About 1½ miles (2.4 kilometers) farther north, in the grounds of the Rockledge estate, west of the road, the conglomerate contains a limestone mass 170 feet (52 meters) long. The resistant conglomerate forms a discontinuous low ridge parallel to the road.

[19] A mile (1.6 kilometers) farther north, just beyond Skeels Corners, exposures of coarse conglomerate are exceptionally good. This conglomerate rests on Upper Cambrian dolomite, which contains considerable sand and some sandstone pebbles and is cut by a network of quartz veins. There are numerous fragments of this distinctive rock in the conglomerate, and sand grains are abundant in the matrix. The numerous thin slabs of dolomite and limestone included in the conglomerate were derived from the Upper Cambrian formation, which is well exposed below Highgate Falls.

[20] About 2½ miles (4 kilometers) north of Skeels Corners the road descends to the Missisquoi River at Highgate Falls. In the gorge below the bridge there are several interesting stratigraphic and structural features. Below the power house on the south side of the river the lower part of the Upper Cambrian section contains members not recognized farther south. Interbedded with thin layers of limestone, dolomite, and shale are several layers of conglomerate and breccia. One of these layers, near the power house, contains boulders of many kinds of limestone, some of them several feet in diameter. (See pl. 11, *B*.) It has been suggested that this conglomerate is a tillite. One large isolated limestone boulder lies in banded shale; the bands are broken and contorted, suggesting that the mass of limestone was dropped through water upon a muddy bottom. Possibly floating ice was the transporting agent.

Somewhat lower are several beds of remarkable intraformational breccia. The fragments are furnished chiefly by thin bands of dolomite and limestone, and in one zone all stages in the formation of the breccia, from the initial ripping up of the thin layers, are clearly shown. A few feet lower in the section limestone layers yield trilobites of Upper Cambrian age. No Middle Cambrian is recognized at this locality. Thick beds farther down the gorge contain abundant intraformational breccia. There is no apparent stratigraphic break in the section exposed here.

Part of the Upper Cambrian slate is characterized by varve-like banding; this feature is particularly well developed in the cliff just east of the power house.

Between the power house and the bridge a thrust fault is well displayed in a section on the north side of the gorge. The vertical displacement is only a few hundred feet; the underlying dolomite overrides the upper beds of Upper Cambrian slate from the east.

North of the river the road climbs through a section of the Champlain Pleistocene clays; Highgate Center is on a terrace of this material at 300 feet (91 meters) above sea level.

[21] Northwest of Highgate Center, in a railway cut, a particularly well-banded zone of the Upper Cambrian slate is exposed. The rock is highly calcareous, but slaty cleavage is well developed. This portion of the formation is most suggestive of seasonal banding.

Highgate Center to St. Albans by way of Swanton and St. Albans Bay (15½ miles, or 25 kilometers).—The route to Swanton follows the gently sloping surface on the Champlain clay north of the river. A short distance east of Swanton the road crosses the Champlain thrust (concealed by the clay); the entire village is built on white Ordovician limestone, which is exposed in the stream bed to the southeast. This limestone is part of the western sequence, overridden by formations of the central sequence. The thrust continues northeastward across the Canadian line, about 7 miles (11 kilometers) from Swanton.

[22] South of the Missisquoi River the road follows the front of the thrust. The Lower Cambrian marble of the central sequence, more resistant than the Ordovician limestone, forms a pronounced ridge to the east; a quarry east of the road exposes the typical mottled marble.

The Fonda quarry and mill, west of the road about 4 miles (6.4 kilometers) south of Swanton, exploit the Ordovician limestone of the western sequence.

About 0.6 mile (1 kilometer) south of the Fonda quarry the route leaves the paved highway on a road branching to the right; it crosses the railroad and the valley of a brook, and farther south it skirts the west base of a ridge made of Lower Cambrian dolomite and marble, which dip eastward from the Champlain thrust.

[23] About 2 miles (3.2 kilometers) farther south, near the junction of the road from St. Albans Bay to St. Albans, the Ordovician limestone appears east of the road, and the Lower Cambrian marble forms a bluff above it. One can walk for hundreds of feet practically on the outcrop of the thrust.

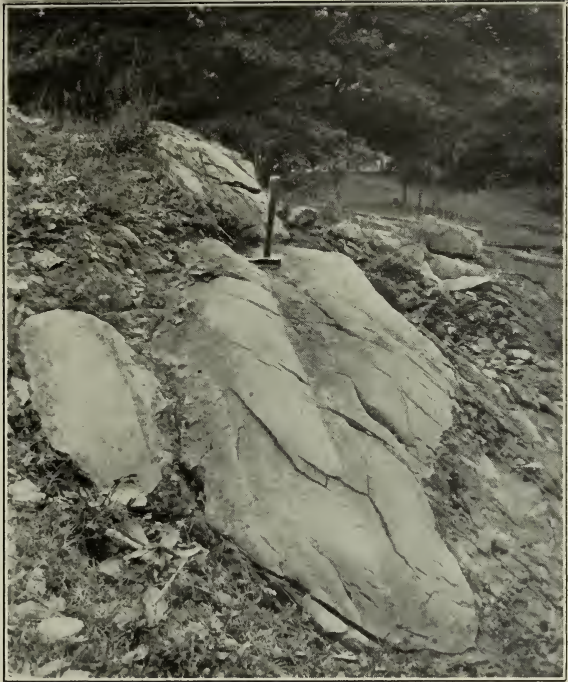
At the road junction the route turns east to St. Albans, crossing almost the entire Cambrian section in the middle sequence; all the formations dip gently eastward from the outcrop of the Champlain thrust. (See pl. 7 and fig. 14.)

St. Albans to Vergennes (50 miles, or 80 kilometers).—The route to Burlington goes over the highway traversed the preceding day. South of Burlington there are few exposures for several miles; the road crosses belts of the Lower Cambrian formations of the middle sequence, repeated in a complex way by thrusts branching from the Champlain fault. (See fig. 12.) There is little topographic expression of the structure until Shelburne, 7 miles (11 kilometers) south of Burlington, is passed. From that point the Lower Cambrian quartzite and marble make a ridge west of the road; Pease Mountain (altitude about 700 feet, or 213 meters), 5 miles (8 kilometers) south of Shelburne, is the highest point on this ridge. About a mile (1.6 kilometers) farther south the highway crosses the thrust front, which here retreats considerably to the east. Mount Philo (altitude 968 feet, or 295 meters), east of the road 7 miles (11 kilometers) south of Shelburne, has Lower Cambrian quartzite of the middle sequence at the top, resting on Ordovician of the western sequence. In the valley of Lewis Creek, south of Mount Philo, the thrust front is 2 miles (3.2 kilometers) farther east. Shellhouse Mountain, 4 miles (6.4 kilometers) directly south of Mount Philo, is another westward projection of the thrust. Vergennes, at an altitude of 298 feet (91 meters), is on Ordovician strata of the western sequence.

Vergennes to Brandon [11] (44 miles, or 70.5 kilometers).—Leaving Vergennes, the route passes over unmetamorphosed Ordovician (Chazyan and Mohawkian) to the foot of a steep slope nearly 2 miles (3.2 kilometers) southeast of the town. Here the road again crosses the Champlain thrust, which continues southwestward to Snake Mountain and beyond. The road passes over the lowermost quartzite beds and other formations of the central sequence.

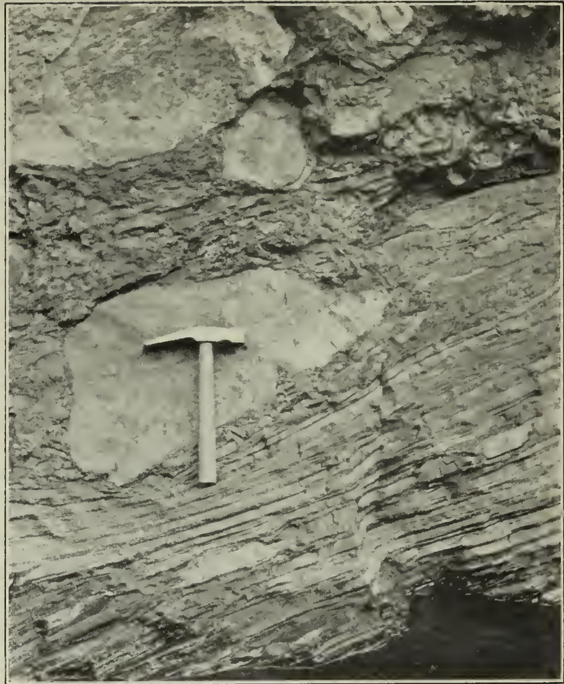
New Haven Junction (altitude 282 feet, or 86 meters), is on marble of the Taconic synclinorium; the marble continues 2½ miles (4 kilometers) farther north and there ends. The western border of the marble belt runs just west of the New Haven River about a mile west of the highway bridge at Brooksville. Deformed Chazyan and Mohawkian limestones in the middle of the synclinorium form outcrops beside the highway to Middlebury. From a point in the road at the north end of Chipman Hill, 2 miles (3.2 kilometers) south of Brooksville, the limestone

[11] By George W. Bain.



A. LIMESTONE BOULDERS IN THE LOWER ORDOVICIAN CONGLOMERATE

The large mass on which the hammer rests has been polished and furrowed by Pleistocene glaciation. Photograph by R. W. Sayles.

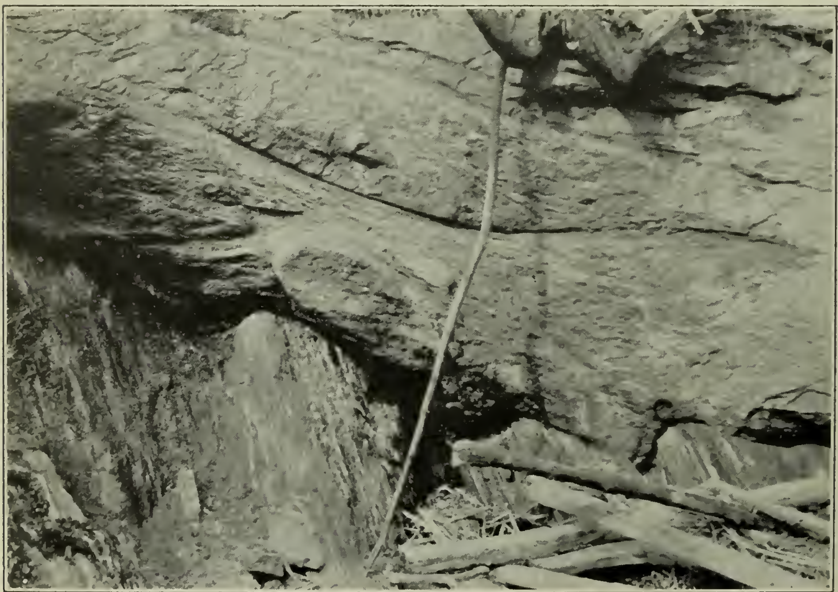


B. CONTACT OF LIMESTONE CONGLOMERATE AND UNDERLYING BANDED DOLOMITE, HIGHGATE GORGE, VERMONT

Note the contortion and brecciation of the dolomite around the limestone block on which the hammer rests. Photograph by R. W. Sayles.

A. INTRICATE FOLDING IN MARBLE AT HIGH STREET QUARRY, BRANDON, VERMONT

Folding is outlined by dark bands in the stone, which otherwise appears massive.



B. CLOSE VIEW OF UNCONFORMITY AT ROARING BROOK, SOUTHINGTON, CONNECTICUT

The Triassic sandstone dips 15° E. (right), and the foliation of the mica schist is nearly vertical.

valley can be seen to good advantage. High points that rise to the west and north are on quartzite of the central sequence; Hogback Mountain, to the north and east, is made of quartzite of the eastern sequence.

Middlebury (altitude 380 feet, or 116 meters), is on Otter Creek, which follows the limestone belt from the south. South of the town deformed Chazyan and Mohawkian limestones are exposed along the road for 2 miles (3.2 kilometers). Lower Cambrian dolomite of the eastern sequence is exposed in the highway west of the fork to East Middlebury.

Just beyond Salisbury (altitude 400 feet, or 122 meters), Mount Pleasant is the high hill east of the road. Quartzite of the eastern sequence (base of the Cambrian) in this hill marks the east side of the synclinorium. At 1½ miles (2.4 kilometers) from Salisbury the zone of limestone containing commercial marble crosses to the east side of the highway. It is exposed almost continuously along that side from Leicester to Brandon.

THE VERMONT MARBLE BELT

By George W. Bain

The highway (route 7) follows a series of valleys developed upon marble and limestone. Marble lies in two synclinoria; the northern or Hinesburg synclinorium extends northward from Hinesburg to the border; the southern or Taconic synclinorium stretches from a point 4 miles (6.4 kilometers) east of Vergennes southward into Connecticut. Only the east-central part of the southern synclinorium produces marble of commercial grade.

GEOMORPHOLOGY

The lowland has an average altitude of 340 feet (104 meters) and a width of 16 miles (26 kilometers) at Vergennes; it is gently rolling, with a few cuesta ridges. The bed of Otter Creek is 100 feet (30 meters) below the general valley level; in its narrow part south of Brandon the creek has thoroughly dissected the valley floor.

Flat tops on Mount Philo, the Monkton Hills, Buck Mountain, and the Cobble, between Burlington and Middlebury, are at altitudes of 800 to 925 feet (244 to 282 meters). Sunset Hill and Mount Pleasant, at Lake Dunmore, rise to 925 feet (282 meters). Benches on the mountain side at Wallingford occur at 1,100 to 1,200 feet (335 to 366 meters), and benches and the tops of notches in hanging valleys between Green Mountain and Mount Tabor occur at 1,300 to 1,500 feet (396 to 457 meters). These levels represent a more ancient valley level, when the base level was much higher than at present.

East of the valley the Green Mountains rise like a wall, faced in long stretches with white quartzite, which has effectively protected the rocks back of it. A gently rolling surface, from 1 to 6 miles (1.6 to 9.6 kilometers) wide, lies east of the wall and slopes upward at an increasing gradient to the backbone of the Green Mountains. This rolling surface, with an average altitude of about 1,600 feet (488 meters), represents an earlier extensive peneplain.

The Green Mountains consist of two chains separated by a rolling upland surface formed along tributaries to the Winooski, Lamoille, and Missisquoi Rivers, which cut westward directly across the resistant rocks of the mountains. These master streams established courses on a surface so ancient and high that it is lost in the mountain summits, and its existence is recorded in these superposed rivers only.

STRATIGRAPHY

The rocks of the marble belt range from pre-Cambrian to Middle Ordovician age. Igneous rocks are uncommon, but metamorphic effects suggest their presence at moderate depth.

Stratigraphic units in the marble belt [a]

Ordovician.	Mohawkian.	Blue marble.
	Chazyan.	Upper West Rutland marble. Main West Rutland marble. West Blue marble. Columbian marble.
	Beekmantownian.	Intermediate limestone. Sutherland Falls marble.
Cambrian.		Lower limestone. Dolomite. Quartzite.
Pre-Cambrian.	Chlorite schist, mica schist, gneiss, amphibolite, phyllite, and dolomite.	

[a] The names in the right-hand column are terms used in the marble quarries and not formation names that are generally accepted.

Pre-Cambrian metamorphosed rocks and Lower Cambrian beds lie in general east of the valley. The buff-weathering, thin-bedded Cambrian dolomite characteristically has slaty structure. This is the commonest rock along the main highway. Sandy cross-bedded limestone from 10 to 300 feet (3 to 91 meters) thick at the top of the dolomite serves as an excellent horizon marker. The Lower limestone is 160 feet (49 meters) thick; it is massive, thick-bedded, slightly silicified, and magnesian. The rock is gray and weathers light gray. Closely spaced joints are characteristic.

The Sutherland Falls marble is a lustrous white stone with mottling of dull dolomite crystals. It has an average thickness of 90 feet (27 meters). Highly distorted impure silicated beds indicate the structure of the deposit.

The Columbian marble averages 300 feet (91 meters) in thickness and is light blue or gray; it becomes white adjacent to silicated bands and is bleached white in exposures. Dolomite mottling is unusual except in the lower 10 feet (3 meters), and intricate deformation structure is exceptional. Buff-weathering gray dolomite beds subdivide the West Blue marble above. Crinoid stems and deformed *Maclurites* are moderately abundant.

Dolomite 3 to 20 feet (1 to 6 meters) thick separates the West Blue marble from the Main West Rutland marble. White marble with bands of green silicates predominates in the Main deposit. The silicates appear to be products of reaction of silicic acids and silicate solutions with nearly pure marble; these solutions probably removed the blue carbon coloring original to the stone and left white marble with green bands along the bedding planes, which served as principal solution channels. The Upper West Rutland marble resembles the Main marble but contains many dolomite beds.

Deformed *Orthoceras*, *Gonioceras*, *Maclurites logani*?, turritiform gastropods, colonial corals, and brachiopods are common in the Blue marble; the age of the rock is middle Ordovician. Disconformity between the Upper West Rutland marble and the Blue marble is pronounced at the north end of the chain of West Rutland quarries.

The Ordovician phyllite has cleavage partly parallel to and partly across the bedding. Pegmatites with predominant quartz and subordinate albite and orthoclase are abundant.

Granite intrudes the phyllites west of Danby. Lamprophyre dikes of much younger age occur along joints in both the marbles and the dolomites. The intrusion of the dikes was later than the folding of the marble.

STRUCTURE

The sediments in the Taconic synclinorium are highly folded, and the intensity of folding increases southward—so much so that the entire marble zone is compressed into 60 feet (18 meters) in the western part of Rutland. Overturning of folds shows a progressive increase from north to south. The marble belt lies in the Taconic synclinorium, between the Champlain overthrust and the Green Mountain arch. The southward pitch of numerous folds along the east side gives this boundary an irregular form.

Lower Cambrian quartzite and the pre-Cambrian schists are thrust over phyllites of possible Ordovician age and cut across the strike of folded Cambrian and Ordovician limestones on Pine Hill, between Proctor and Center Rutland. The outcrop of the thrust begins east of Brandon, follows the west crest of Pine Hill, and continues south with an irregular course to the vicinity of Wallingford, where it crosses to the east side of the valley, but it can not be recognized east of Danby. The largest overfolds and flowage folds, which cause abnormal thickening of beds and the formation of the marble deposits of commercial value, occur at the ends of this great thrust.

Other thrust faults appear farther south at the eastern margin of the limestone belt, but the structure is irregular. (See pl. 13.) Farther west in the Taconic Range the details of structure are not known.

THE MARBLE INDUSTRY

Marble is the basis of the largest centralized industry in Vermont; its value in 1927 exceeded that of granite, the closest State competitor among natural resources, by 28 per cent. The marble production for that year, which was average, was valued at $5,096,716, or 31 per cent of that for the United States and about 8 per cent more than that for Tennessee, the nearest competitor. The industry centers around Rutland, where the three essentials power, sand, and marble occur close to one another.

Falls along Otter Creek due to glacial disarrangement of drainage, supply over 30,000 horsepower. The highest-level waterpower development is at Ripley, between Rutland and Center Rutland, at 490 feet (149 meters) above sea level; every drop in the river is utilized to Weybridge, at 150 feet (46 meters). Some power is sold, but most of it is used in the quarries and mills where marble is worked.

Glacial outwash deposits of angular quartz and feldspar sand, essential to sawing the marble and rubbing it to size, occur between ridges extending southward from the Green Mountain front. The best sand has particles of variable size, ranging between 0.02 and 0.08 inch (0.05 and 0.2 centimeter). About half as much sand as marble is required by the mills.

Commercial marble comes from thickened parts of marble beds. Six broad groups of colors or color effects are represented, and over a hundred specific classes are listed by producers. The main groups are white with gray dolomite mottling, white, white with green veining, gray and blue-gray stone from the upper part of the deposit, fine-textured black marble from Isle La

Motte, and red dolomitic marble from Lower Cambrian beds at Swanton.

Vertical or nearly vertical deposits have a quarry floor cut into strips about 6 feet (2 meters) wide by channeling machines, each of which consists of a piston with five wedge-shaped tools attached in line, a pneumatic device for raising and lowering the piston approximately 200 times a minute, and a carriage on which the piston is mounted. The carriage moves back and forth on a track as the piston "chops" a cut in the marble. Eight feet (2.4 meters) is the economic depth of cutting any single channel. Ends of the strips are cut away from the walls, and one strip is cut transversely at about 6-foot (1.8-meter) intervals to leave blocks, one of which is the key block, free on five faces. The key block is wedged free and lifted out, and drills are mounted in the hole or keyway to drill beneath the remaining blocks preliminary to wedging them off.

Horizontal deposits present the additional problem of leaving overburden in place. A horizontal channel is cut parallel to and just over the top of the deposit to be quarried; holes are drilled above the channel and blasted with light powder charges. Waste is shoveled out of the tunnel so produced, and the deposit is quarried as if it were vertical. Recently machines have been designed to drill straight parallel holes close together, and a tool has been constructed to break out the intervening rock; this machine has greatly diminished the cost of driving a preliminary tunnel.

Blocks with joints or beds of stone that will not polish are discarded; most of the stone quarried is waste for one of these reasons.

The quarry blocks are sawed to size in "gangs," which consist essentially of a series of soft iron or steel blades about 0.1 inch (0.2 centimeter) thick and 4 inches (10 centimeters) wide, held in a reciprocating frame that can be lowered upon the marble. Angular sand suspended in water is poured over the marble as the blades move back and forth and scratch their way downward at the average rate of 1 inch (2 centimeters) an hour.

Finishing to size is accomplished on rotating cast-iron disks or rubbing beds, with sand and water flowing over them. Circular and irregular shapes may be turned or machined like cast iron. The rough marble is always honed smooth, and if a polish is specified, finishing is completed with pumice and a fine soft polishing agent, followed by buffers coated with the polishing agent only.

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BRANDON TO BENNINGTON, VERMONT

By George W. Bain

Brandon to Brandon Gap and return (12 miles, or 19 kilometers).—The marble beds strike through Brandon (altitude 416 feet, or 127 meters), and a section of Rutland dolomite is well exposed between Brandon and Forestdale (altitude 595 feet, or 181 meters). Pre-Cambrian phyllitic rocks appear along the highway from Forestdale eastward. Pre-Cambrian schists are exposed in the bed of the Neshobe River 1 mile (1.6 kilometers) to the east.

About 2 miles (3.2 kilometers) upstream from Forestdale the grade becomes rather steep; the road rises 200 feet (61 meters) in about 0.6 mile (1 kilometer). The grade becomes gentler at an altitude of about 1,200 feet (366 meters) and continues so to Goshen Four Corners (altitude 1,408 feet, or 430 meters). This abrupt break in the profile of the valley indicates that the mountain streams have not yet established grade since the uplift of an older land surface. From the foot of Brandon Gap [24],[11a] about three-quarters of a mile (1.2 kilometers) east of Goshen Four Corners, remnants of the old peneplain appear strikingly flat. The average altitude of the old surface is about 1,600 feet (488 meters). Brandon Gap, nearly a mile (1.6 kilometers) farther east, is at 2,184 feet (666 meters); the high points at the crest of the range to the north and south average 3,300 feet (1,006 meters).

Brandon to Rutland by way of Proctor (14 miles, or 22 kilometers).—[25] The High Street quarry, beside the road at the south edge of Brandon, is in a syncline of the Columbian marble. Glacial scratches and flutings are preserved on parts of the marble surface. The southward pitch of the syncline is evident in the abandoned workings, and the extreme distortion of the beds is shown by dark bands in the wall. (See pl. 12, *A*.) Dolomite crops out along the highway south through Pittsford, 5 miles (8 kilometers) south of Brandon. Derricks of the Pittsford Valley quarries appear on the west side of Otter Creek Valley; the Taconic Range, rising back of them, is made up largely of phyllites, slates, and thin-bedded quartzites, with a complex structure of thrusts and folds.

[11a] See fig. 12 for Nos. 24-27.

[26] The Pittsford Valley quarries (altitude 400 feet, or 123 meters), on the Columbian marble, have reached a depth of more than 300 feet (91 meters). Beds from the Intermediate limestone to the Cambrian dolomite are exposed in a recumbent anticline to the east; the syncline to the west containing the marble pitches about 10° S. Minor upfolds adjacent to the major anticline (fig. 15) pitch about 25° N. The term "flowage fold" has been applied to these minor folds.

The stone varies greatly in resistance to weathering. In exposures at the entrance of quarry No. 4 some beds, whose porosity is as low as 0.03 per cent, preserve glacial striations, whereas other beds have deep solution marks.

The extreme thickening and thinning by flowage is shown to best advantage in quarry No. 7. Flowage folds are shown in section on the quarry walls; they are outlined by thin bands of dark minerals. (See fig. 16.) In the bottoms of quarries the marble undergoes spontaneous expansion without increase of porosity.

The road from the quarries to a point 2 miles (3.2 kilometers) south of the mill at Florence runs east of the belt of commercial marble; from that point nearly to Center Rutland the road is on the marble.

Proctor (altitude 477 feet, or 145 meters) is the center of the Vermont marble industry. Mills here and at Center Rutland are open to visitors. The road crosses Otter Creek at the marble bridge and turns south along the east side of the stream toward Center Rutland. Cambrian quartzite above the Pine Hill thrust (fig. 17) forms steep bluffs east of the highway 4 miles (6.4 kilometers) south of Proctor; this quartzite has caused the falls at the marble mill in Center Rutland.

The route to West Rutland crosses the Pine Hill thrust at Center Rutland bridge and the marble deposit at the city line; the marble is squeezed to 60 feet (18.3 meters) in thickness at this section. Ordovician phyllite is exposed on both sides of the road as far as the railroad crossing near West Rutland.

[27] The West Rutland marble deposits are on the east side of the valley north of the village and on the west side south of it. An overturned anticline whose axial plane is inclined 17½° E. brings the marble to the surface. Flowage folds in all the quarries pitch south, whereas the major anticline pitches north.

Microscopic graphitic carbon colors the stone bluish gray, but the stone is white where beds are thickened and in the vicinity of green silicated bands. Probably the graphite was removed by the magmatic solutions that produced silication.

East of the lime plant north of Sheldon quarry No. 5 the disconformity between the Chazyan and Mohawkian can be

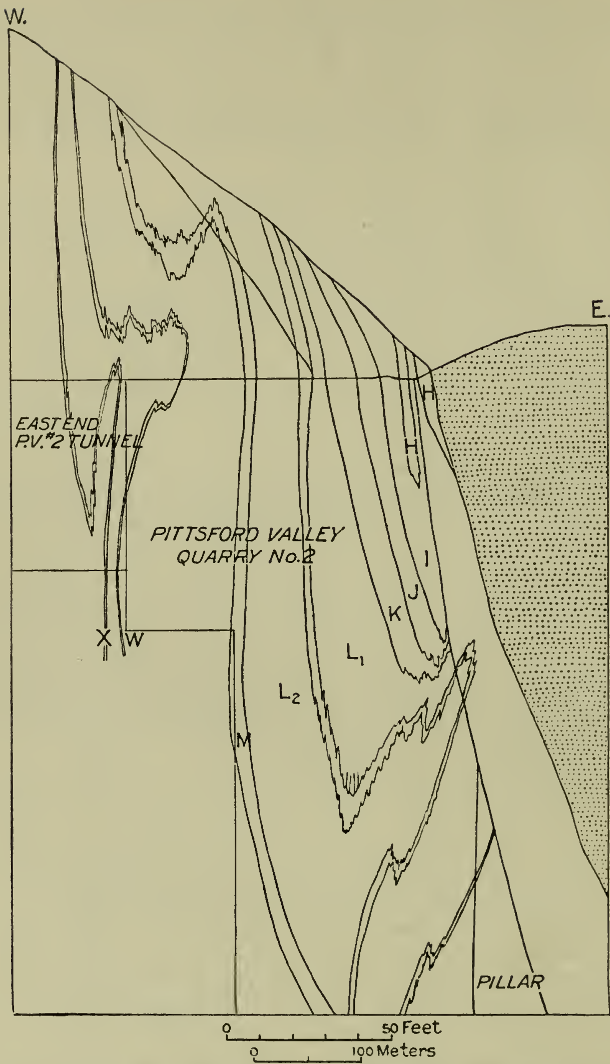

FIGURE 15.—Minor folds in marble, Pittsford Valley quarry No. 2, Pittsford, Vermont. Looking north. The beds are in the west limb of a major anticline (axis to the right of the quarry). Letters H to X designate individual beds recognized in the quarries

EASTERN NEW YORK AND WES

BLOCK DIAGRAMS OF THE MARBLE BELT FROM THE NEW HAVEN RIVER SOUTH TO EQUINOX MOUNTAIN, VERMONT

Green Mountains on the east; Taconic Range on the west. Structure shown for the marble belt only. Redrawn from copy submitted by G. W. Bain.

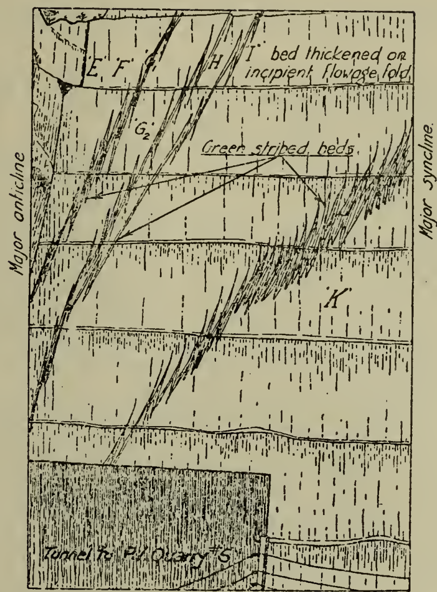

FIGURE 16.—Flowage folds in marble on the south wall of Pittsford Valley quarry No. 4, Pittsford, Vermont. The folds are outlined by greenish bands. Letters E to K designate individual beds recognized in the quarries

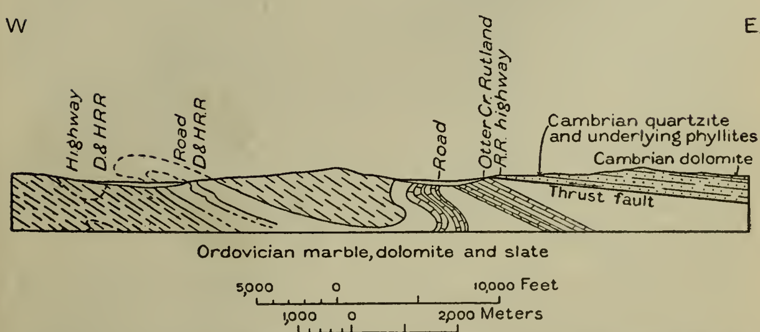

FIGURE 17.—Structure section across West Rutland and Otter Creek Valleys, Vermont. Shows part of the Pine Hill thrust at the right

seen. Beds of the Mohawkian marble lie upon successively lower layers of the highest Chazyan marble as they are followed northward.

Rutland (altitude 580 feet, or 177 meters) is an important railroad and distributing center for this part of Vermont. It has many handsome marble buildings.

Rutland to Danby (20 miles, or 32 kilometers).—The route from Rutland southward lies along a lowland developed on the Rutland dolomite. (See pl. 13.) The hills west of the lowland are composed of pre-Cambrian and Lower Cambrian rocks above the Pine Hill thrust. These same rocks, emerging from beneath the dolomite of the valley, form the mountain front on the east; the white quartzite is especially conspicuous.

At Danby (altitude 700 feet, or 213 meters) the marble crops out at an altitude of 1,060 feet (323 meters) on Dorset Mountain and about 1¾ miles (2.8 kilometers) south of the village; it continues to rise to higher levels southward through North and East Dorset. The Danby quarries [28, fig. 18] are in the upper part of the Columbian marble in an asymmetric syncline between the Green Mountains on the east and an anticline in Dorset Peak. The quarries extend westward at an inclination of 10° for 1,000 feet (305 meters) into the mountain side; beds at the surface, about 160 feet (49 meters) above, are inclined about 10° in the opposite direction. This discordance in dip is due to abnormal shortening and thickening of the marble beds. (See fig. 19.) Flowage structures are portrayed admirably on the quarry walls.

Danby to Bennington (38 miles, or 61 kilometers).—The "limestone valley" continues to the south; it is a topographic unit but is occupied by various streams. Otter Creek, flowing to the north, heads near North Dorset; over a low divide are the headwaters of Batten Kill, flowing south. Marble deposits continue south past Manchester; at this place the lowland widens, owing to a projection of the limestone area to the northwest along the valley of a brook between Green Peak (at the north) and Equinox Mountain (directly west of Manchester). The limestone beds in this district appear to lie almost undisturbed, but actually they are in recumbent folds whose axial planes are nearly horizontal. In the wall of a quarry below Owls Head, 5 miles (8 kilometers) north of Manchester, one bed is folded in and out thirteen times.

At Arlington, about 7 miles (11 kilometers) southwest of Manchester, Batten Kill leaves the open limestone valley and flows west through the Taconic Range in a deep, narrow valley. Several miles to the south the road climbs another low divide near Shaftsbury, at about 1,000 feet (305 meters), and descends to Bennington (altitude about 700 feet, or 213 meters).

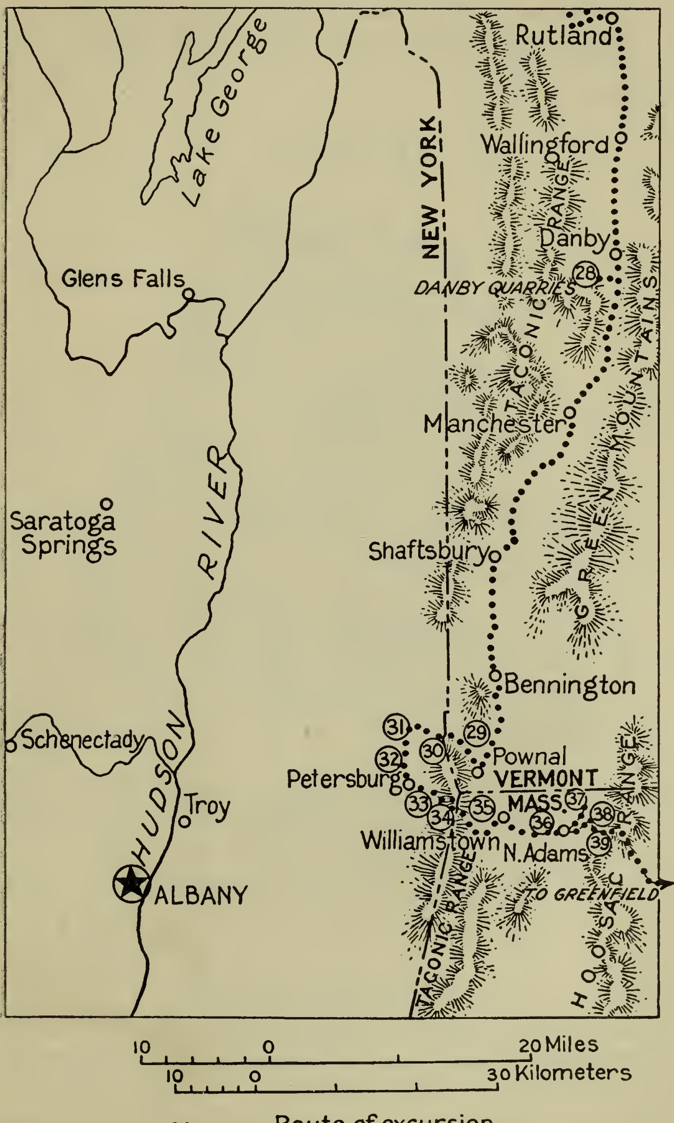

FIGURE 18.—Route map, Rutland, Vermont, to the Deerfield River, Massachusetts. Numbers in circles indicate localities mentioned in the text

The Walloomsac River crosses the limestone belt at Bennington. Unlike Batten Kill, it crosses the Taconic Range in a wide valley, traversing a belt of weak black Ordovician slate in a cross fold.

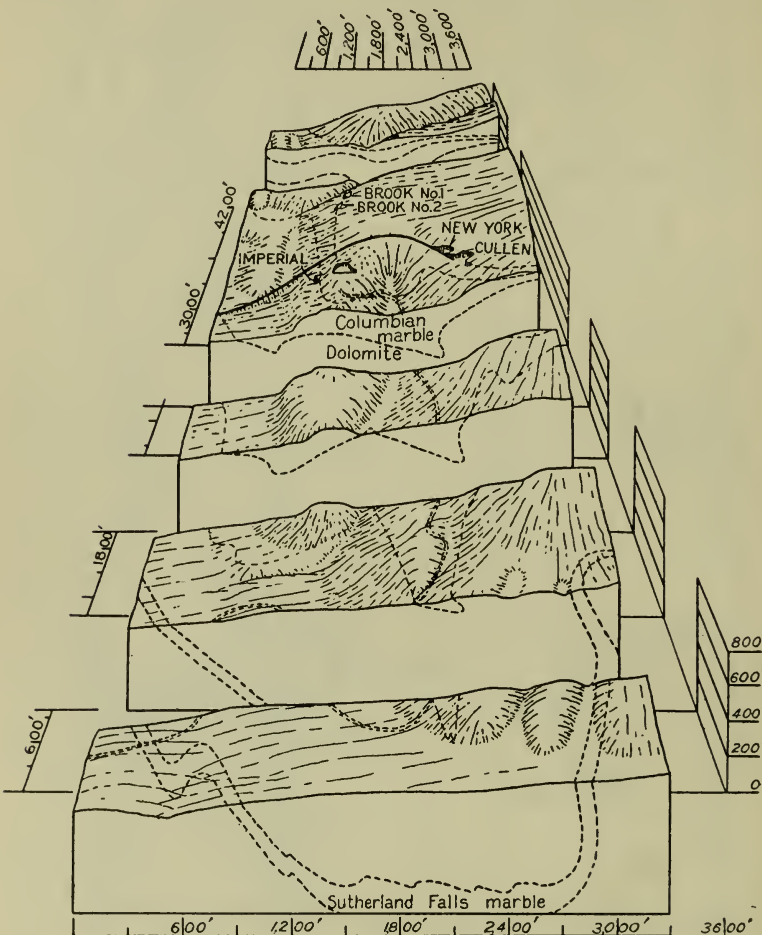

FIGURE 19.—Diagram showing structure at Danby, Vermont. Dashed lines show outcrops of marble members. Looking south

Northeast of Bennington, near the crest of Bald Mountain, the quartzite forms conspicuous white outcrops. This resistant formation plays an important part in maintaining the steep western front of the Green Mountains in this section, as it does north of Rutland.

Bennington is noted as the scene of a minor battle between the British and the Americans in the Revolutionary War. The monument that commemorates this engagement is built of Ordovician limestone; many of the blocks are crowded with fossils, chiefly large coiled gastropods. The limestone was not obtained in the marble belt; it was brought from eastern New York and belongs in the western sequence, west of the belt of intense metamorphism.

SECTION ACROSS THE TACONIC AND HOOSAC RANGES, SOUTHERN VERMONT AND NORTHWESTERN MASSACHUSETTS

By Chester R. Longwell

From Brandon to Bennington attention has been confined largely to the limestone belt, with only incidental reference to the high ranges adjacent to it. The general problems in each range are similar from north to south, and it is thought best to treat these problems in connection with a unit section from west to east showing the relation of one range to the other and the relation of both to the intervening limestone belt. Such a section is made most conveniently near the boundary line between Vermont and Massachusetts. As the geology is exceedingly complex, and much of it obscure, only the larger facts and the outstanding problems will be considered. Repeated reference to the geologic map (pl. 14) and the structure section (fig. 20) is essential for an understanding of the discussion.

The Hoosac Range, which is the southward continuation of the Green Mountains, consists largely of metamorphic and igneous rocks. Some of these are certainly pre-Cambrian; others are of doubtful age, either pre-Cambrian or lower Paleozoic; a few formations along the western border of the range are certainly lower Paleozoic. The oldest recognized formation is a banded gneiss, consisting in large part of metamorphosed sediments strongly injected with granite, pegmatite dikes, and quartz veins. This gneiss is intruded by granite gneiss, a striking coarse-grained rock, with gneissic structure, containing an abundance of bluish quartz. Unconformable on the granite gneiss and the older gneiss lies locally a metamorphosed coarse conglomerate. These three units are in place, forming the core of the range. The gneiss and granite gneiss are of pre-Cambrian age, as they underlie quartzite that carries *Olenellus*. Probably the conglomeratic gneiss also is pre-Cambrian, but its age has not been established definitely.

Covering much of the range, and structurally higher than the gneiss, the granite gneiss, and the overlying metamorphosed conglomerate, is an albite-mica schist locally rich in garnet. This is well exposed along the Mohawk Trail at the summit and on the west flank of the range. The base of the formation is a diaphthoritized garnet-mica schist. Wherever erosion has cut deep enough to expose the lower rocks the schist is seen to have a discordant relation to all of them; it is also discordant on the Lower Cambrian quartzite to the west. These facts, together with the petrologic character of the schist, suggest that it is part of a mass thrust across the axis of the range. A related schist, apparently stratigraphically higher, lies along the east flank of the range; this contains abundant chlorite, chloritized biotite, and some chloritized garnet, and its color is greenish. These schists, formerly considered to be Ordovician, are now regarded by Prindle as of Lower Cambrian age.

The Lower Cambrian quartzite lies along the western border of the range and dips under the limestone valley. The schist covers the quartzite in some areas, and long stringers of this schist appear to be folded into the quartzite locally. The limestones are intensely deformed, as they are farther north. Mount Greylock (maximum altitude 3,505 feet, or 1,068 meters), a great isolated ridge south of the Mohawk Trail, is an aberrant mass in the midst of the limestone. It has a general synclinal structure and consists of intricately folded limestone, quartzite, and schists. Valleys floored with limestone practically surround this complex mass, separating it from the ranges on the east and west.

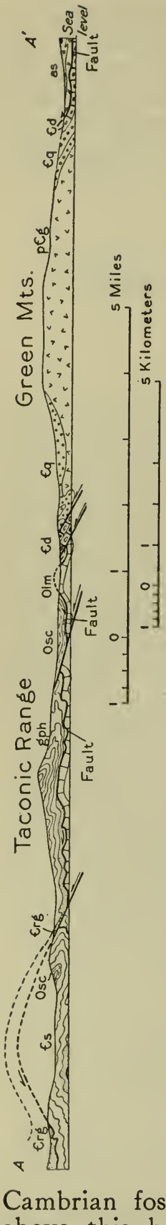

FIGURE 20.—Structure section across Taconic and Hoosac Ranges on line A–A′, Plate 14. By E. B. Knopf and L. M. Prindle. For explanation of symbols see Plate 14

The Taconic Range in this latitude is made up chiefly of slates and phyllites developed in isoclinally folded strata; the slaty cleavage and the axes of folds are inclined eastward. Near the west base of the range are gritty slates that have yielded Lower Cambrian fossils from thin limestone beds; stratigraphically above this horizon is a conglomeratic graywacke, which is exposed extensively on the Rensselaer Plateau, to the west; still higher is a great series of greenish and purplish slates, also Cambrian. A series of dark phyllites and slates on the east flank of the range is thought to be Ordovician, probably Normanskill. This entire Cambrian and Ordovician section has been thrust over the Cambrian and Ordovician limestones, which pass under the range from the valleys on each side. It is evident, from the attitude of recumbent folds, that the thrust mass came from the east. But where to the east is the "root" region from which it was derived? The Lower Cambrian on the west flank of the Hoosac Range and of the Green Mountains consists of quartzite and limestone, which underlie the limestones over which the thrust mass has passed. The Lower Cambrian of the Taconic Range is so radically different from this quartzite and limestone series that the two contemporaneous sequences must have been developed far away from each other, probably in different basins of deposition.

Therefore the slates of the Taconic Range must have originated far east of the present Hoosac Range. Can the schists of the Hoosac Range be related to the slates of the Taconic Range? Prindle, after many years of study in the region, believes that the schists and the slates are parts of one extensive thrust sheet, and that the contrast in lithology has resulted from their differences in metamorphic history. The peculiar character of these schists probably is explained by severe metamorphism accompanied by albitization, with later modification by mylonitization and diaphthoresis while the thrusting was in progress.

Evidence bearing on this interpretation will be examined during the excursion. As the Taconic Range appears to be essentially a unit in its stratigraphy and structure, the hypothesis implies that almost the entire range is a far-traveled mass, without roots. The radical differences in lithologic facies between the two Lower Cambrian sequences, together with the fact that the Hoosac schist lies on the pre-Cambrian basement rocks in the Hoosac Range, suggest that the mass from the east moved over an old land area which had supplied the Cambrian sediments to basins on opposite sides.

The structure of the Taconic Range is not dated definitely, but evidence in the Hudson and St. Lawrence Valleys indicates that the first deformation occurred near the end of the Ordovician period. Probably there was additional disturbance during the Appalachian folding in Permian time.

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BENNINGTON, VERMONT, TO AMHERST MASSACHUSETTS

By Chester R. Longwell

Bennington to Williamstown, Massachusetts, by way of Pownal, Vermont, and Petersburg, New York (33 miles, or 53 kilometers).—South of Bennington the limestone and dolomite form conspicuous outcrops; but these disappear near Pownal Center, 6 miles (9.6 kilometers) from Bennington, and the road climbs over and around a hill of dark slate. This slate, probably of Ordovician age, has been thrust over the underlying limestone. In a quarry to the west and at a lower altitude the limestone is exposed. East of the hill the quartzite is thrust over the limestone and the slate. (See fig. 20.)

At Pownal (altitude 549 feet, or 167 meters) the route leaves the paved highway and turns northwest down the Hoosic River. Limestone is exposed along the stream. Albite-chlorite schist similar to the schist of the Hoosac Range is exposed at the right of the road about a mile (1.6 kilometers) from Pownal. Half a mile (0.8 kilometer) beyond, on a hill to the right, is the quarry seen from the highway.

[29] [12] At the base and on the slope of the hill is a greenish schist which from its lithologic character Prindle correlates with the phyllitic schist of the Hoosac Range. On the flank of the hill the discordant contact of the schist with the overlying limestone is extremely folded, and both formations are sheared. In the quarry the Ordovician limestone is intricately folded with the overlying dark slate, the fold axes dipping eastward.

The major structure of the area is obscure; but as the limestone and the younger dark slate seem to pass beneath older slates of the Taconic Range, whereas at the quarry the limestone is thrust over the older rocks, Prindle interprets the structure in the Hoosic Valley and in the range to the west as a great folded thrust cut by a second thrust, as shown in Figure 20. Further evidence of this structure is seen at other points on the route.

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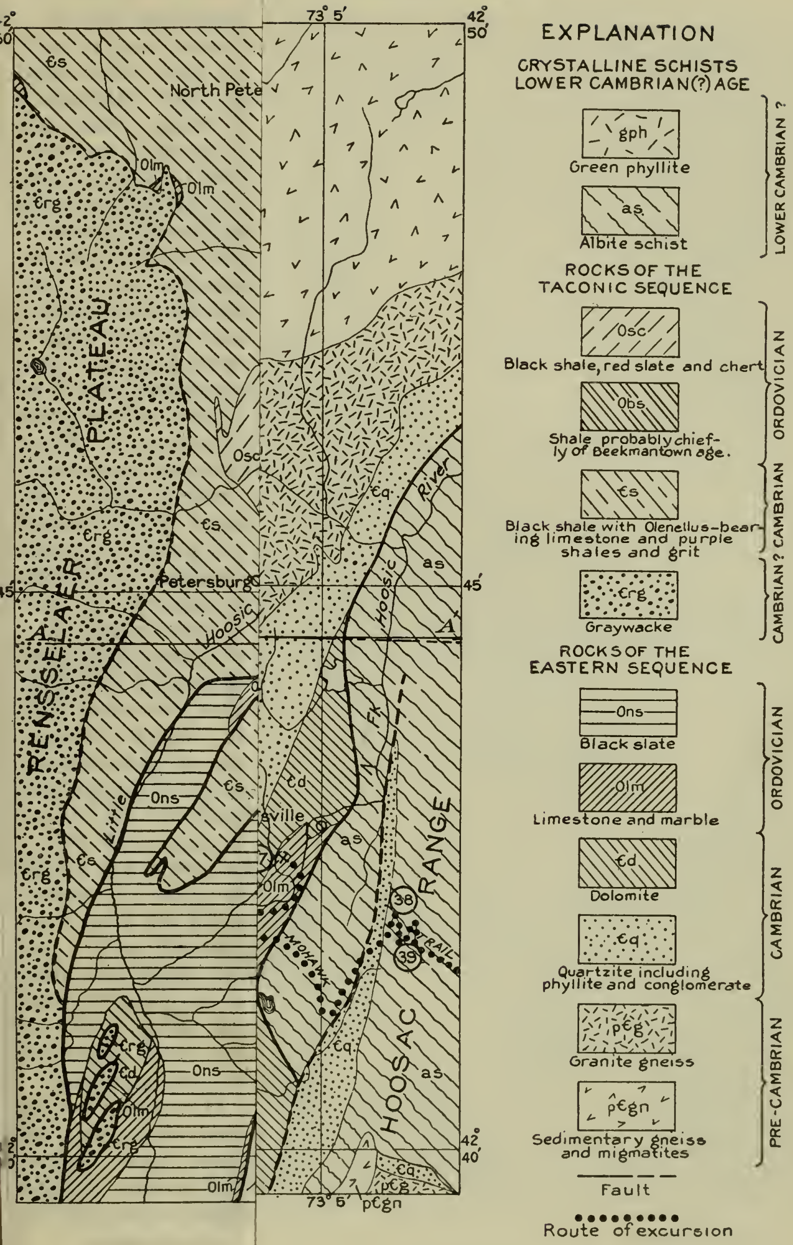
[12] See Plate 14 for Nos. 29 to 39.

PLATE 14



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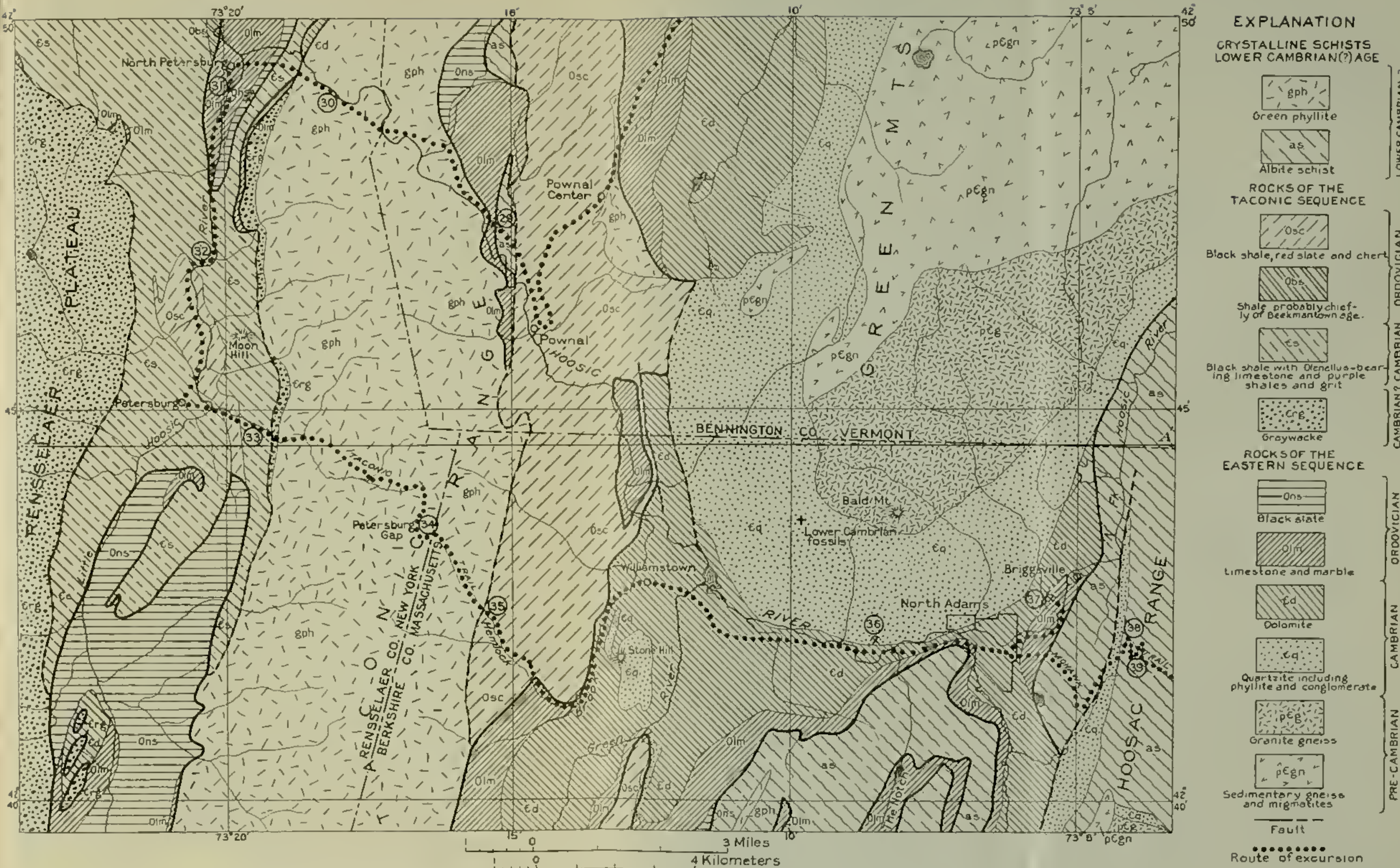


GEOLOGIC MAP OF TACONIC AND HOOSAC RANGES AND THE INTERVENING LIMESTONE BELT

By L. M. Prindle and E. B. Knopf. For Mount Greylock area (southwest of North Adams) and Hoosac Range earlier maps by J. E. Wolff and T. N. Dale have been used in part. Numbers in circles indicate localities mentioned in the text.

To the northwest the Hoosic River cuts through the range. The rocks are greenish and purplish slates, presumably of Cambrian age; they are well exposed beside the road 3 miles (4.8 kilometers) from the quarry on the west side of the valley [30]. The slates strike N. 15°–20° E. and dip 55° E.; generally the cleavage is nearly parallel with the bedding or crosses it at a small angle. Closely spaced joints, dipping 70° E., are conspicuous locally in addition to the slaty cleavage.

North Petersburg (altitude 465 feet, or 142 meters), which lies west of the range 1½ miles (2.4 kilometers) farther northwest, is on limestone. Thus the younger rocks appear in the valleys east and west of the range. North of North Petersburg a large area is floored with Ordovician rocks, which appear to pass beneath Lower Cambrian rocks to the west. Turning south at North Petersburg [31], the road passes outcrops of the limestone on the west side of the valley; the beds dip gently to the south, apparently not much deformed. Nearly 3 miles (4.8 kilometers) south of the village the purple and green slates appear, and farther along the Lower Cambrian greenish-gray banded slate forms large outcrops on the right [32]. The cleavage strikes N. 25° W. and dips 55° NE. There are other exposures farther south. The Rensselaer graywacke forms cliffs on the ridge east of the river.

At Petersburg, 5 miles (8 kilometers) south of North Petersburg, the route turns southeast on the Taconic Trail. About a mile (1.6 kilometers) from the village, at the right of the road [33], there are excellent exposures of the Cambrian green and purplish slates. An impressive succession of such outcrops occurs along the way to the crest of the range, at the crest itself, and along the eastern flank. The general strike of the cleavage and of the bedding is east of north, and the dip is eastward.

[34] The summit at Petersburg Gap, 1,900 feet (579 meters) above sea level, affords fine panoramic views east and west. Across the valley of the Little Hoosic River, to the west, the flat surface of the Rensselaer Plateau makes a remarkably even sky line. The Rensselaer graywacke underlies this surface, but the beds are highly folded and beveled, and hence the plateau is a large remnant of an uplifted peneplain, with an average altitude of about 1,700 feet (518 meters). The rocks of the plateau appear to form part of the Taconic thrust mass.

Eastward from the gap the highest point is Mount Greylock, about 7 miles (11 kilometers) distant. The Hoosac Range, so far as it can be seen beyond the Greylock mass, displays a broad summit with nearly uniform height; its average elevation is slightly above 2,000 feet (610 meters). This surface is part of the New England early Tertiary peneplain, above which the highest part of Mount Greylock stood as a conspicuous monadnock.

On the descent of the eastern slope of the range it is seen that the slates, which are well exposed along the highway, are similar to those on the west side. At a point far down the eastern slope [35], however, there is an abrupt change to dark carbonaceous slate, which Prindle identifies as the slate above the Ordovician limestones. It is brought against the Cambrian rocks by the thrust shown in Figure 20.

The road descends to the valley of the Green River, in the limestone belt at the west base of Mount Greylock. Outcrops of the limestone are seen on the way north to Williamstown. The buildings of Williams College are on both sides of the highway near the center of the town.

Williamstown to Greenfield (45 miles, or 72 kilometers).—The route to North Adams follows the Hoosic River, which is on limestone between the north end of Greylock and Bald Mountain. Cambrian quartzite flanks the slope north of the road, the outcrop curving broadly around the end of Bald Mountain, which is an anticline plunging steeply southward. (See pl. 14.) High on the slope is one of the localities at which Walcott found Lower Cambrian fossils in the quartzite. The character of the formation is seen at an old quarry a short distance west of North Adams [36].

The limestone belt projects up the tributary valley northeast of North Adams. Near Briggsville there is evidence that the schists of the Hoosac Range are thrust westward over the limestone.

On the east side of Hudson Brook, about a mile (1.6 kilometers) northeast of North Adams, a large quarry exposes the fold structure in the limestone [37]. The northeast wall of the quarry gives a section of a nappelike recumbent fold, rolled over to the northwest. Dark bands in the stone outline the minute details of small-scale crumples developed on the larger fold; the crests of minor anticlines and synclines are drawn out to long, sharp points, making an intricate pattern of zigzag lines.

The route returns to the Mohawk Trail and proceeds east on bedrock of Hoosac schist. On the steep slope of the Hoosac Range many fresh exposures have been made by grading. Directly above the sharp hairpin curve in the road [38] the Hoosac schist is banded with numerous quartz lenses and contains abundant albite. The crest of the range is broad and rolling. From the eastern and higher summit [39] there is a good view southeastward over the dissected peneplain surface. The east flank of the range slopes down to the valley of the Deerfield River; on the slope are exposures of the greenish Lower Cambrian(?) schist.

Remnants of high rock-cut terraces along the Deerfield River mark stages in uplift of the peneplain; lower terraces are constructional features built during the dissipation of the Pleistocene ice. About a mile (1.6 kilometers) west of Greenfield an eastward-facing escarpment marks the border of the upland developed on the old metamorphic rocks. The lower rolling plain on which Greenfield lies is developed on Triassic sediments.

Greenfield to Amherst (17 miles, or 27 kilometers).—There are few outcrops of the sandstones along the road near Greenfield. About a mile (1.6 kilometers) south of the city the route crosses the Deerfield River, and continues south 1½ miles (2.4 kilometers) to Old Deerfield, a village famous for its old colonial houses. Several bloody engagements with the Indians occurred here during the eighteenth century. South of Deerfield the highway follows the west side of a ridge made of conglomerate in the lower sandstones (the Sugarloaf arkose). Pocumtuck Rock is a high point on this ridge a short distance below the village. The base of the Triassic section is a mile to the west, and the strata dip to the east at a low angle.

East of South Deerfield, 4½ miles (7.2 kilometers) south of Old Deerfield, are two isolated remnants of the Triassic conglomerate ridge called North Sugar Loaf and South Sugar Loaf. The route turns east along the base of the southern hill. There are good exposures of the reddish arkose in the bluffs. The rock is a coarse conglomerate and highly feldspathic; it was formed in large part of disintegrated granite, and its source was east of the Triassic area.

The road crosses the Connecticut River to Sunderland. Mount Toby, formed of coarse Triassic conglomerate, is the high ridge to the northeast and east. The one lava sheet in this part of the area forms a bluff curving around the lower slope not far east of the road. In the low ground followed by the road the sandy soil is formed of Pleistocene lake deposits.

The Massachusetts State College is at North Amherst, 5 miles (8 kilometers) southeast of Sunderland. Amherst College is at Amherst, 2½ miles (4 kilometers) farther south.

THE TRIASSIC BELT OF MASSACHUSETTS AND CONNECTICUT

By Chester R. Longwell

GENERAL FEATURES

Triassic rocks underlie a belt of country reaching from northern Massachusetts to New Haven Harbor (pl. 15), a distance of 100 miles (161 kilometers), with a maximum width of 21 miles

(33.8 kilometers). The geology of this belt is fairly representative of the Triassic in eastern North America, which is confined to several small areas scattered from Nova Scotia to North Carolina. (See fig. 21.) In all these areas the sedimentary rocks—arkosic sandstones and conglomerates, with associated shales—are of continental origin. Red color is a common feature of these rocks, although many of the strata are gray, and exceptionally the shales are nearly black. In some of the southern areas there are local coal beds. Intrusive and extrusive bodies of basic igneous rock are conspicuous in nearly all the areas.

The Triassic strata of this region were deposited after the Appalachian folding and therefore are much less severely deformed than the Paleozoic formations around them. Faults of large throw affect most of the areas, and generally the strata have suffered strong tilting. Much of the Triassic that has been preserved is in fault blocks that were dropped below the level reached by post-Triassic erosion.

TOPOGRAPHY AND GEOLOGIC SETTING

The Triassic belt in Massachusetts and Connecticut is bordered on each side by older metamorphic and igneous rocks. Some of these are certainly of Paleozoic age, and possibly all belong to that era, but many of the formations have defied all efforts to date them. At the north end of the area Devonian fossils have been found in limestones at Bernardston, Massachusetts; no other rocks adjacent to the Triassic have yielded paleontologic evidence.

As most of the old crystalline rocks are resistant to erosion, they form uplands, whereas the weaker Triassic strata have been worn to a lower average altitude. For this reason the Triassic belt, especially in Connecticut, is commonly referred to as the Central Lowland, lying between the Eastern and Western Highlands. Actually the lowland has an irregular surface; igneous masses and some of the more resistant sedimentary strata form hills and ridges nearly or quite as high as the bordering highlands. In most parts of the belt the rocks have a strong eastward inclination, and the edges of sills and buried lava sheets form prominent ridges trending north and south, with numerous offsets caused by oblique faults. (See pl. 15.)

The principal river of the area is the Connecticut River, which follows the Triassic Lowland in a wide, open valley to Middletown, Connecticut, and there abruptly enters a gorgelike valley cut into the crystalline rocks of the Eastern Highland. This course, which is quite out of harmony with the present topography, is presumably an inheritance from an older cycle of erosion. Since the last uplift of the region the weak Triassic rocks have been etched below the level of the stronger crystalline rocks; the Connecticut River has widened its valley in the belt of weak rocks but has made much less progress in its lower course, where the rocks are resistant.

STRATIGRAPHY

Like all other formations of continental origin, the Triassic beds of this area vary greatly in character, both vertically and

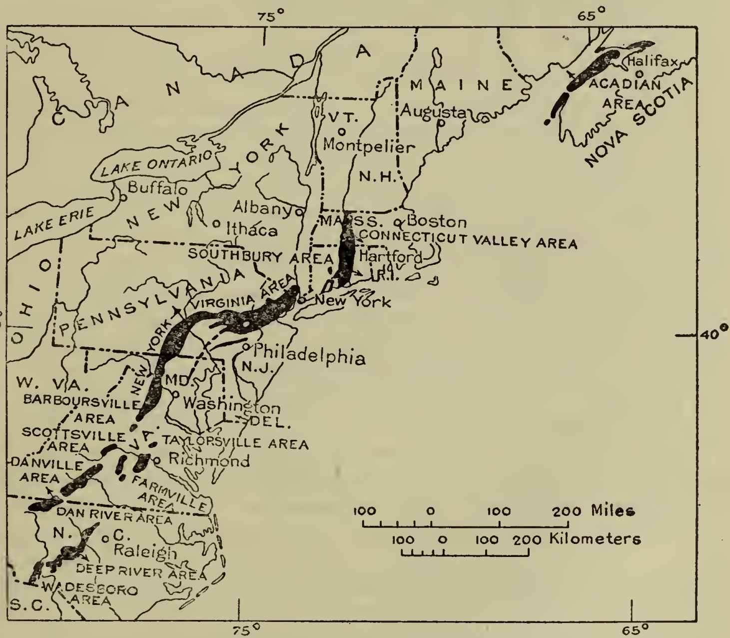


FIGURE 21.—Triassic areas of eastern North America (black). Courtesy of John Wiley & Sons

horizontally; and the thickness of any given unit changes considerably from point to point. A fortunate circumstance is the presence of widespread basaltic lavas, which serve as horizon markers. In Connecticut there are three of these sheets, two of which extend continuously, except for breaks caused by faults, across the State and far north into Massachusetts. The lowest sheet disappears near the Massachusetts line.

Triassic of Connecticut.—The table below shows the stratigraphic sequence in Connecticut.

Triassic formations in Connecticut

	Feet	Meters
Upper sandstones, in large part arkosic sandstone, with very coarse conglomerate near the eastern border	3,500	1,067
Upper basaltic lava	50–150	15–46
Sandstones and shales, including, in upper part, black shale with fossil fishes	800–1,200	244–366
Middle basaltic lava	300–500	91–152
Sandstones and shales, including, near base, black shale with fossil fishes and some limestone	300–1,000	91–305
Lower basaltic lava, with pillow structure	100–250	30–76
Lower sandstones, chiefly coarse arkosic sandstone and conglomerate, with subordinate sandy shale	5,000–6,500	1,524–1,981
Unconformity.		
Gneiss, schist, and other crystalline rocks (Paleozoic or older).		

All the units indicated above are recognizable at all latitudes in the State, except the lowest lava sheet, the outcrop of which is discontinuous near the Massachusetts boundary, but they vary considerably in thickness. This is particularly true of the upper sandstones, which in all parts of the area have suffered indeterminate loss by erosion and locally have been removed entirely. The two zones of black shale appear to be remarkably persistent, although the thickness of either does not exceed 100 feet (30 meters) at any locality. Both zones have been found in numerous sections from southern to northern Connecticut; but as these rocks are weak and normally are concealed by soil cover, it is not possible to demonstrate that either zone is actually continuous at a constant horizon.

Lower sandstones: The lower sandstone member contains a monotonous succession of coarse sandstones and conglomerates in irregular, lenticular beds, interspersed with thin layers of sandy shale. Characteristically these rocks have a reddish color from a variable content of ferric oxide in the cementing material. Feldspar is a conspicuous constituent of the coarse-grained sediments. The pebbles are predominantly of quartz, and most of them have been considerably worn by stream action. There is an abundance of mica throughout the deposit. Obviously the sediments represent the waste of old crystalline rocks, like those now exposed in the highlands. The source was not strictly local, however, for the basal Triassic beds do not contain pebbles that are recognizable as fragments of any formation directly to the west. Without question the lower sandstones originally extended considerably farther west than their present western limit in Connecticut.

The primary structure of the sandstone suggests deposition of the sediments by streams; and the generally uniform character of the deposit through so great a thickness indicates sedimentation in a subsiding basin. Lenses of gravel set in finer-grained sediments represent cut and fill by shifting channels. Cross-bedding and ripple-marking are conspicuous in the sandstones, and some of the shales are sun-cracked. The only evidence of Triassic life ever reported from the lower sandstones is the cast of a reptile's armor, found in a quarry near New Haven.

Lava flows and associated sediments: The three basaltic sheets are strikingly similar in composition, although the great thicknesses of sediments separating them indicate that a long time elapsed between successive lava floods. Probably all are derived from fissure eruptions, as suggested by their wide extent with nearly uniform thickness. No conduits have been discovered; probably some of the many basic dikes cutting the underlying strata represent the openings through which the lava escaped.

The lower lava sheet is characterized by pillow structure and by large quantities of ashy material, which appears to have originated as fragmental glass (palagonite), probably through steam explosions as the lava advanced over wet ground or into shallow water. In general the sediments that succeeded the flow are finer grained than those beneath it, including considerable shale. One of the black-shale zones, containing fossil fishes and plant impressions, is only a short interval above this flow, and at a slightly higher horizon beds of impure limestone, 15 or 20 feet (5 or 6 meters) in total thickness, occur locally. Beds of coarse arkosic sandstone recur throughout the section, interfingering irregularly with layers of finer sediments. Sun cracks, ripple marks, and other indications of subaerial or shallow-water deposition are abundant. Dinosaur and other reptilian tracks occur in some of the sandy shales, but are not nearly so abundant as they are at higher horizons.

The middle lava sheet is thick wherever it crops out in Connecticut or Massachusetts—generally from 400 to 500 feet (122 to 152 meters). In the vicinity of Meriden the sheet is made up of at least two separate flows; but in the southern part of the State, where the sheet has been studied in tunnels and other excellent artificial exposures, there appears to be only one flow, although the thickness in this area is near its maximum. The middle portion is very coarse grained, essentially a gabbro. At the top the scoriaceous vesicular character extends to a depth of 50 feet (15 meters) or more; the first sediments deposited upon this irregular surface trickled into the many openings, and consequently the separation between the basalt and the overlying strata is very poorly defined.

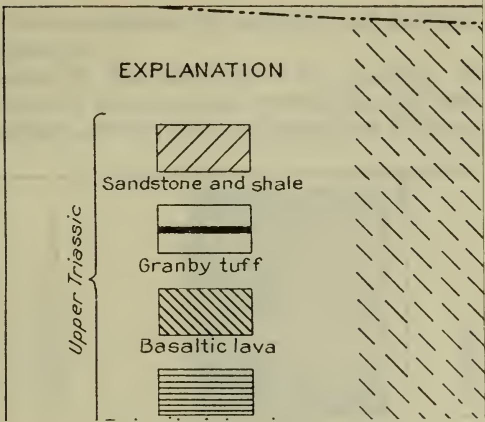
The general section of the sedimentary strata between the middle and upper lavas is as follows:

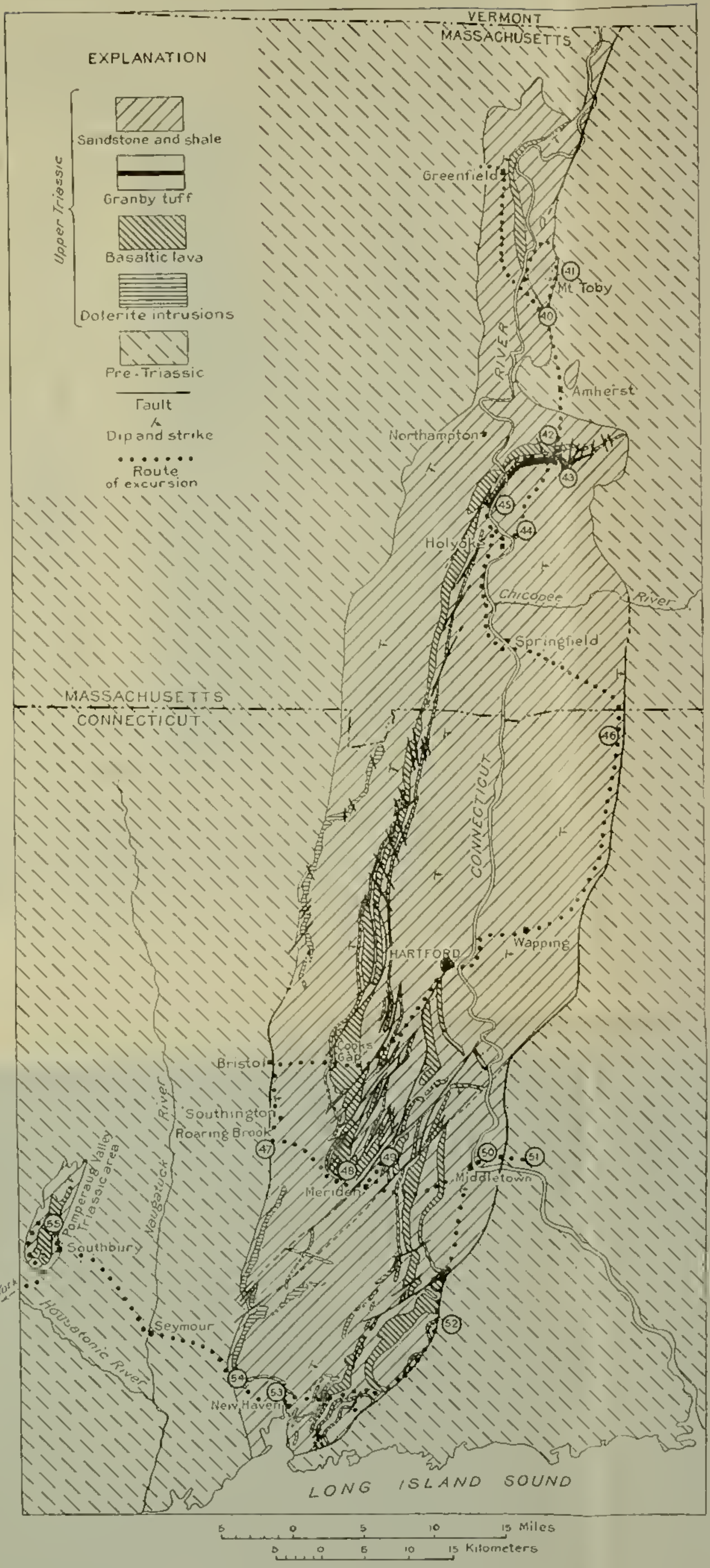
	Feet	Meters
Upper lava sheet.		
Red sandy shales, generally in thin laminae, with layers of arkosic sandstone	200–300	61–91
Dark-gray to black shales, with sporadic layers of arkose. Abundant fish remains and plant impressions, and considerable carbonized wood. Gradation at top and bottom into red beds	50–100	15–30
Red sandstone, conglomerate, and sandy shale, in varying proportions	400–600	122–183
Middle lava sheet.		

Large parts if not all of these sediments represent flood-plain deposits. The layers are predominantly thin and are replete with ripple marks, mud cracks, and rain prints. Footprints of dinosaurs and other reptiles are abundant, especially in the upper half of the section. The black shales probably represent shallow lakes and swamps, in which fresh-water fishes lived and vegetation grew abundantly. From the wide distribution and thickness of the dark deposits, it is inferred that exceptionally moist conditions persisted over much of the Triassic basin for considerable time.

The upper lava sheet is the thinnest of the three, and yet its north-south extent is considerably greater than that of the lower sheet. Probably the surface of the Triassic lowland was extremely flat when the last eruption of lava occurred. However, there was a distinct slope on the east, where fans of coarse débris were being built up at the edge of the highland. In southeastern Connecticut the upper sheet wedges out in the midst of this fan material.

The sedimentary rocks above the upper sheet are in large part arkosic sandstones of fine to medium grain, with an intermixture of conglomerate layers and sandy shale. Near the eastern border, however, the sediments grade into coarse débris, containing many large angular blocks. Local concentrations of coarse angular material appear to represent steep fans and cones or even scree, adjacent to a high scarp. In southern Connecticut this "border conglomerate" contains many large blocks of vesicular basalt, which indicate that some of the lava was erupted on the Eastern Highland as well as in the Triassic basin. In southeastern Connecticut, where strong warping and later erosion have exposed the section down to the lower lava, coarse border conglomerates containing boulders of basaltic lava and of crystalline rocks suggest that faulting was in progress near the present boundary while the Triassic sedimentation was in progress. This conception is expressed in Figure 22. The upper sandstones contain an abundance of dinosaur tracks and also


EXPLANATION
Upper Triassic
Sandstone and shale
Granby tuff
Basaltic lava



MAP SHOWING TRIASSIC AREAS OF MASSACHUSETTS AND CONNECTICUT

The trap outcrop in the Pomperaug Valley as shown in the drawing is considerably too wide. Numbers in circles indicate localities mentioned in the text.

many other evidences of subaerial and shallow-water deposition of sediments.

Triassic of Massachusetts.—In southern Massachusetts the stratigraphic succession is essentially the same as in northern Connecticut, except that the lower lava (Talcott trap) disappears

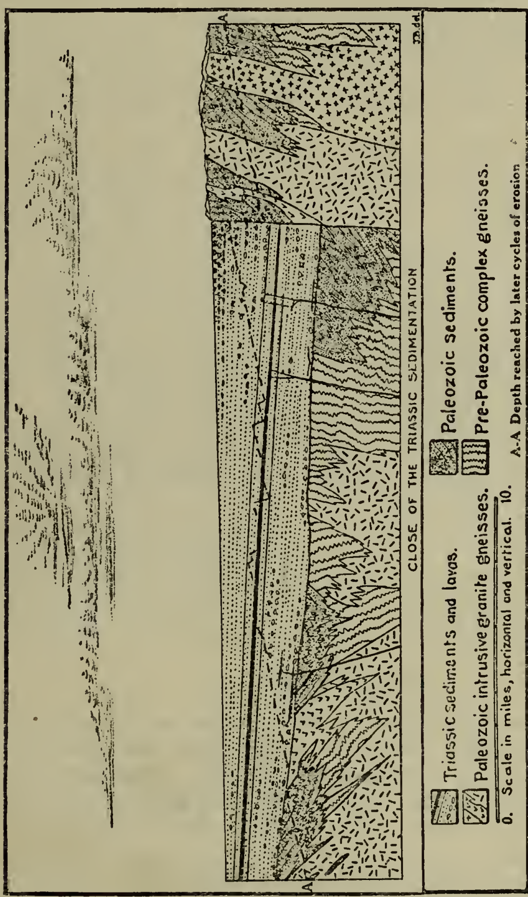


FIGURE 22.—Hypothetical section across the Triassic basin in Connecticut before faulting and tilting occurred. The broken line through the section represents the present surface, formed by faulting, tilting, and erosion. According to this conception the sediments extended far west of the present western border and were derived chiefly from highlands on the east, maintained by recurrent faulting near the present eastern border. (By Joseph Barrell)

near the State line. Farther north there are more pronounced differences. Near Mount Holyoke the outcrops of the lava sheets curve to the east, owing to post-Triassic deformation, and disappear at the eastern border of the Triassic belt. In this vicinity a fragmental volcanic formation lies directly above the upper lava. This formation is the only evidence of explosive volcanic activity in the Triassic area. It "consists of thick-bedded black tuff and tuffaceous sandstone ranging from fine-grained volcanic sandstone to coarse diabase breccias and agglomerates; from rocks made up wholly of volcanic débris to such as contain abundant fragments of granitic gneissoid rocks. The explosion occurred while the 'posterior' trap sheet was still liquid, for amygdaloidal blocks a foot across are sunk in the surface of the flow at the northeast outlook in Mountain Park." (37, p. 95.) [13] Several plugs found in the vicinity probably represent the conduits through which the fragmental material was expelled.

North of the Holyoke Range the Triassic belt is narrow (fig. 69), and there are several stratigraphic peculiarities. The lavas are lacking entirely for a distance of 10 miles (16 kilometers), possibly because they have been removed by post-Triassic erosion. Near Sunderland and farther north there is only one sheet, commonly known as the Deerfield sheet; probably it is correlative with the thick lava farther south. In general, the sediments in this northern part of the belt are coarse. The conglomerate at Mount Toby is a great pile of débris containing large angular blocks of schist and other crystalline rocks. Some of this material resembles scree; evidently there was very steep topography at the eastern edge of the Triassic basin when this material accumulated. The lava near Deerfield wedges out to the east in this coarse deposit.

In this northern basin the sedimentary section is not extremely thick. On the east side a large salient of older rocks, obviously part of the floor from which the Triassic strata have been eroded, projects westward; and near Amherst a small isolated remnant of Triassic sandstone lies east of the main body. (See pl. 15.)

INTRUSIVE ROCKS

Dikes, sills, and irregular intrusive bodies are numerous in the Triassic belt. Nearly all these bodies have the same general composition; they are formed of dolerite, chemically like the basaltic lavas, to which they undoubtedly have a close genetic relationship. The largest sill, in West Rock Ridge, is more than 300 feet (91 meters) thick. Mount Carmel is made of a large, very irregular mass of dolerite, at the margin of which there was some assimilation of arkose. In central Connecticut there are dikes of camptonite, which were formed at a late stage of the igneous activity.

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[13] Numbers in parentheses refer to bibliography, p. 103.

STRUCTURE OF THE TRIASSIC ROCKS

Numerous faults, some of large displacement, affect the Triassic rocks of this area. In Connecticut and in southern Massachusetts the entire Triassic section has a general tilt toward the east. In northern Massachusetts the dips are more variable; low dips to the west or a nearly horizontal attitude are common, but even in this section the general regional tilt to the east is pronounced. Throughout Connecticut and in southern Massachusetts the eastern border of the Triassic belt is defined by a fault of very large throw. Probably much of the displacement along this zone occurred during the Triassic sedimentation, but some of the movement is post-Triassic. From the Chicopee River northward in Massachusetts the eastern boundary is irregular, and there is no clear evidence of faulting except in the extreme northern part of the area. Along the western border there are some faults locally, especially in central Connecticut; but in general the base of the Triassic section appears to lie normally on the older rocks at the edge of the Western Highland.

Oblique faults, most of them trending northeast, cut across the Triassic belt and cause large offsets in the ridges of basalt and dolerite. Evidence of the faults is furnished chiefly by these topographic effects. The largest faults are in the vicinity of Meriden, Connecticut, where the total horizontal offset in the ridges is about 4 miles (6.4 kilometers). So far as can be judged from the available evidence, all these faults are normal, with downthrow on the northwest. Faults with other trends are recognized at some localities.

The general tilt in the Triassic belt appears to be the result of broad regional uplift in post-Triassic time, with maximum elevation along a north-south axis in western Connecticut. In northern New Jersey and southeastern New York the Triassic strata dip to the west, on the opposite flank of the regional arch. (See fig. 23.) The Pomperaug area of western Connecticut, preserved from erosion by downfaulting, indicates that typical Triassic sediments, with included basalt flows, existed on the crest of this arch, although they may not have been continuous between Connecticut and New Jersey.

PLEISTOCENE DEPOSITS

In central Massachusetts and Connecticut there is no sedimentary record between the Triassic and the Pleistocene. The last ice sheet covered this entire region, as far south as Long Island, and much of the Triassic belt is mantled with glacial deposits, both stratified and unstratified. Till forms a veneer of varying thickness, which reaches a maximum in scattered drumlins.

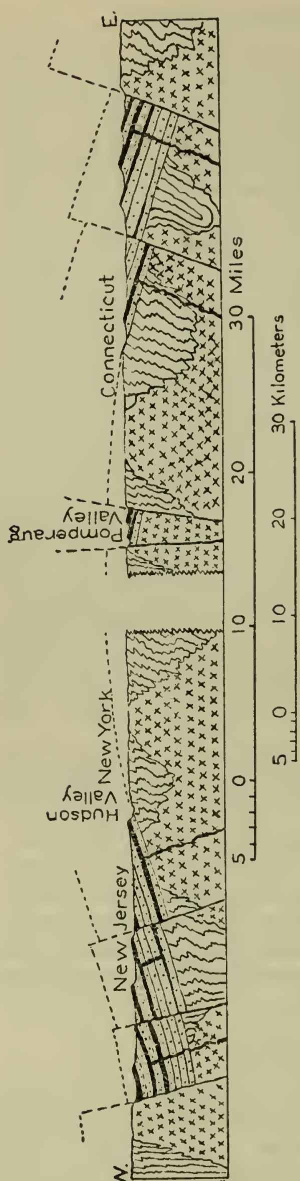

FIGURE 23.—Relation of the Triassic areas in Connecticut and New Jersey. The section is shortened by omitting western Connecticut, an area of metamorphic rocks 35 miles (56 kilometers) wide. It is open to speculation whether or not the Triassic deposits extended continuously across the axis of uplift

The stratified drift has particular interest; its character and distribution show that the ice, in the last stage of its existence, was stagnant over the entire region and disappeared slowly by wastage from the top. After the tops of hills and ridges appeared the ice, partly protected by débris on its surface, persisted for a long time in the valleys. As the drainage was obstructed, marginal streams and locally lakes existed in each of the larger valleys, between the ice and the valley sides, and in places overlapped the ice margins. Accumulating sediments were built against the irregular edge of the ice. When the ice melted the upper surface of such a deposit was left as a terrace, with a scalloped, dimpled front where the sediments had been molded against the ice; such characteristic terrace edges are ice-contact slopes. (See fig. 24.) Long crevasses in the rotten ice were filled with sediments. These fillings now are long, narrow ridges of sand, which resemble eskers except that they have level upper surfaces and usually are attached at one end to a marginal terrace. (See fig. 25.) As most of the crevasse fillings lie transverse to the direction of ice movement, they furnish additional evidence of stagnant ice.

As the ice disappeared from the narrow axial part of the valley, it was replaced by a deep, open lake in which varved clays extensively accumulated. The lake was succeeded by the Connecticut River, which cut terraces in the earlier deposits. (See fig. 26.)

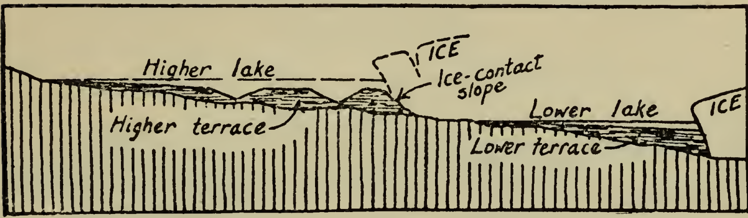

FIGURE 24.—Formation of two marginal terraces as stagnant ice in the valley disappears. The front of each terrace is an ice-contact slope. By R. F. Flint (Geol. Soc. America Bull., vol. 39, p. 966, 1929)

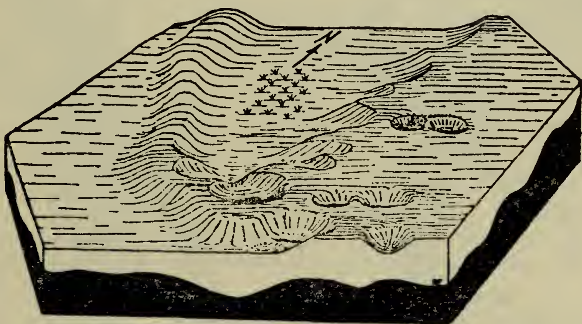

FIGURE 25.—Relation of an eskerlike ridge to a marginal terrace at Wapping, Connecticut. The ridge was formed by filling of a crevasse. The terrace is pitted with kettles and has a typical ice contact slope at the margin. By R. F. Flint (Am. Jour. Sci., 5th ser., vol. 15, p. 413, 1928)

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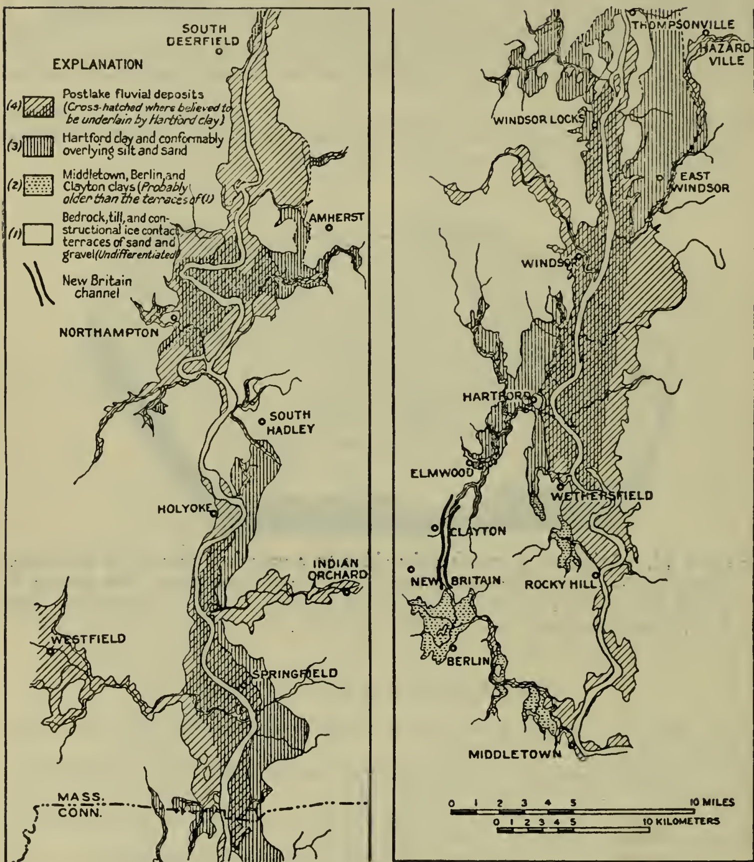

FIGURE 26.—Late glacial sequence of deposits in the Connecticut Valley, showing relation of lacustrine clays to earlier ice-margin deposits and later fluvial terraces. By R. F. Flint. Base from U. S. Geological Survey topographic maps

AMHERST, MASSACHUSETTS, TO HARTFORD CONNECTICUT

By George W. Bain and Chester R. Longwell

Amherst to Mount Toby and return (22 miles, or 35 kilometers).—Amherst (altitude 320 feet, or 98 meters) lies chiefly on old crystalline rocks of the Eastern Highland. For a time at the end of the Pleistocene the hill on which the town is situated was an island in glacial Lake Hadley. The North Amherst road crosses the broad beach on the Massachusetts State College campus, about a mile (1.6 kilometers) north of Amherst, and continues across the lake-bottom sands. Five miles (8 kilometers) north of Amherst the Montague road by way of Leverett turns eastward up the delta front of glacial Longmeadow Brook. A gravel pit [40] [14] exposes the long foreset beds and the topset beds. The top of the delta appears almost level, at an altitude slightly above 300 feet (91 kilometers). The head of the delta is at the Central Vermont Railway crossing. Triassic sediments extend some distance east of the road at this point, but farther north the road crosses granite and other rocks of the highland. These rocks project westward into the face of Mount Toby; at one point the base of the Triassic is 250 feet (76 meters) above the level of the railroad; but to the north and south the contact descends below the level of the track.

This triangular ridge of the pre-Triassic rocks rising into the conglomerate of Mount Toby, is interpreted as a spur of the old mountain front from which the sediments were derived. (See figs. 29 and 30.) There is no fault at the border of the Triassic area in this section; the base of the sediments rests on a highly irregular floor of deposition. The mountain mass is an erosion remnant formed of the coarse conglomerate deposited during Triassic time at the base of a high scarp that faced westward. The rocks that formed this scarp have yielded to post-Triassic erosion more readily than the conglomerate.

[41] Opposite Roaring Brook, 10 miles (16 kilometers) north of Amherst, an old road leads to the track at the base of the mountain. The highest point of the mountain, 1,275 feet (389 meters) above sea level, is nearly a mile (1.6 kilometers) to the west. Near the mouth of the brook the character and structure of the coarse, angular sediments are well displayed.

Continuing northwest around the mountain the road crosses to the west side of the Central Vermont Railway on the glacial delta deposits of the Sawmill River north of Mount Toby.

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[14] See Plate 15 for Nos. 40 to 55.

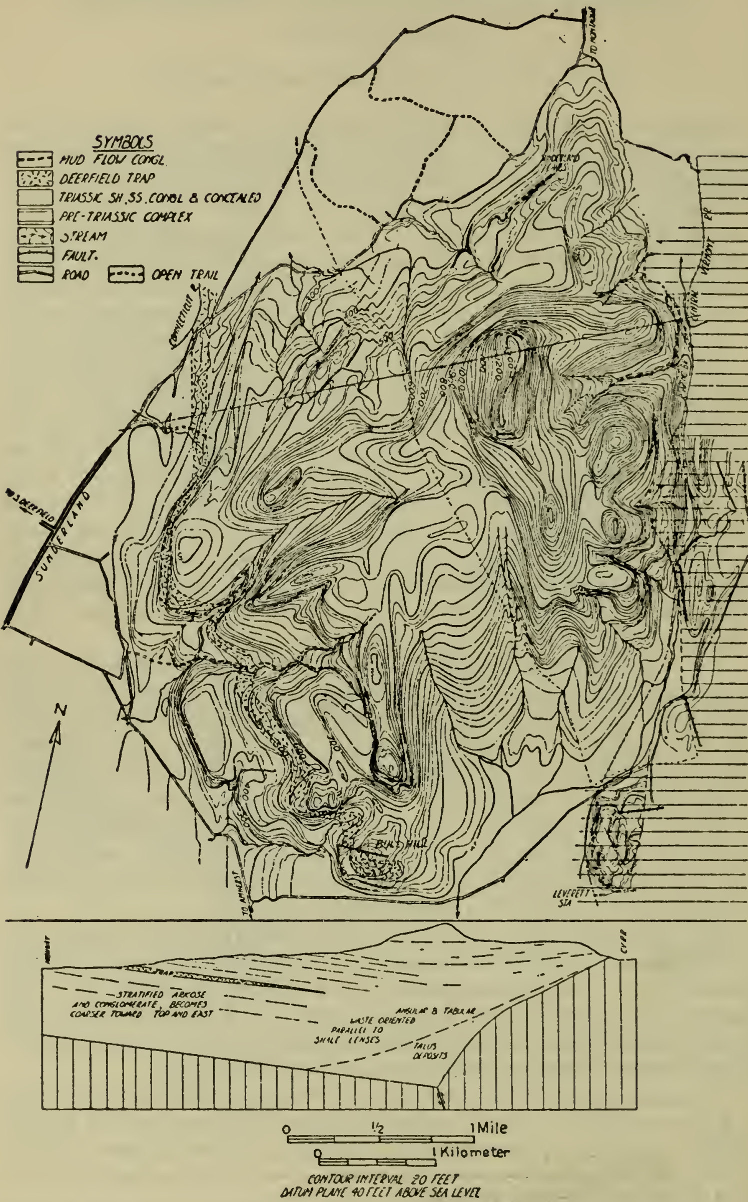

FIGURE 27.—Contour map of Mount Toby, Massachusetts, and structure section through the highest point along the full line on the map. (See p. 107.)

There are numerous kettles in this delta in the vicinity of Cranberry Pond.

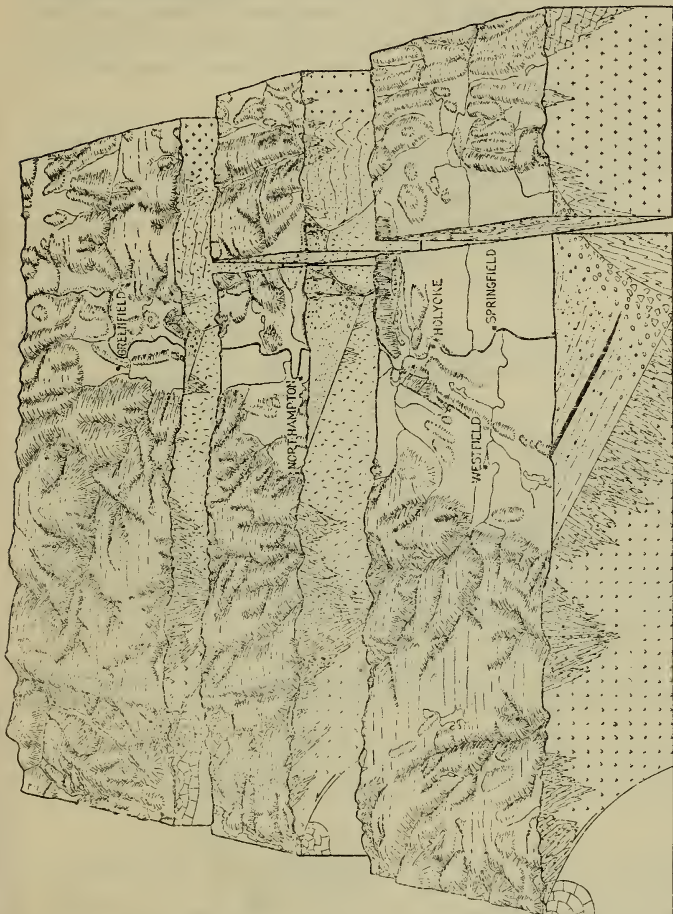

FIGURE 28.—Block diagram of the Massachusetts Triassic basin and adjacent highlands. The block is cut and the parts separated to show the structure at different latitudes. The ridge made by the thick lava sheet turns abruptly eastward north of Holyoke, as shown. Note the old dissected peneplain west of the basin. The Hoosac Range, in which the rocks are thrust to the west over the limestone belt, is shown at the left of the block. By G. W. Bain

The Sunderland Caves are on the northwest face of Mount Toby. Joint blocks of the conglomerate have slumped outward upon weak shales to leave gaping fissures. The shales are interpreted as local lake deposits. Landslide débris rests upon the lake beds and has greatly distorted them. Where the road

FIGURE 27 (continued).—The strata dip gently to the west at the east side, but on the west slope they have the general regional inclination eastward. The lava sheet wedges out in the coarse sediments, as shown. There is no fault exposed at the surface on the east, but the Triassic sediments were derived from a steep scarp, probably formed by faulting during the Triassic period. By G. W. Bain

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descends the front of the delta, black shales are exposed beside the Connecticut River. They contain numerous fossils representing individuals belonging to four species of fishes, and also a few plant remains. The road from Whittemores Ferry follows southward along the river. A short distance above Sunderland the lava is exposed beside the road.

At the east side of Sunderland (altitude 140 feet, or 43 meters) a broad natural levee rises 5 feet (1.5 meters) above the flood plain. Meander-cut terraces, formed during an earlier stage of the river, appear to the south. Mount Warner, a prominent hill beside the river west of Amherst, consists of old metamor-

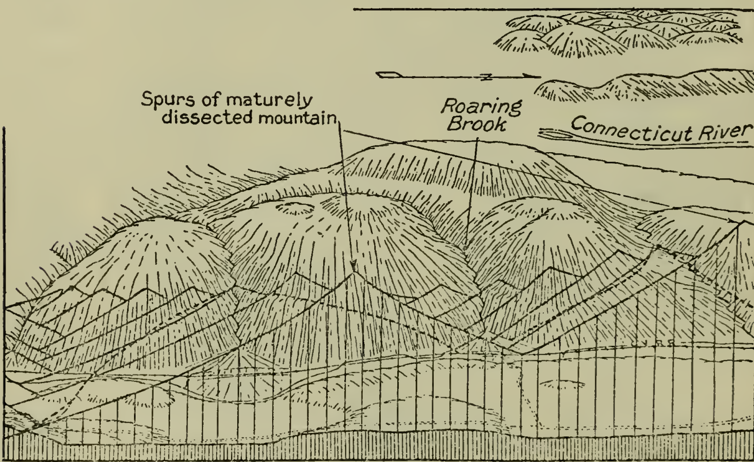

Figure 29.—Part of eastern face of Mount Toby, with hypothetic restoration of spurs that projected westward from the highland of Triassic time. The remnants of these spurs are exposed in the flank of the mountain. By G. W. Bain

phic rocks; it is part of a salient projecting westward from the highland into the Triassic area. (See pl. 15.)

Amherst to Holyoke through The Notch (16 miles, or 25.7 kilometers).—South of Amherst the road crosses the old lake beach at the railroad. Gneiss and pegmatite are exposed 2 miles (3.2 kilometers) south of the town, east of the highway and north of a series of drumlins between South Amherst and the Holyoke Range.

The lower sandstone and conglomerate underlie the slope north of the range; they are mantled in large part by marginal deposits of the Pleistocene lake.

[42] The Notch was cut by an ancient stream along a fault zone; the evidence of faulting is seen in offsetting of the base of the lava sheet on opposite sides of the gap. In the quarry numerous shear planes are exposed; on most of them the striae

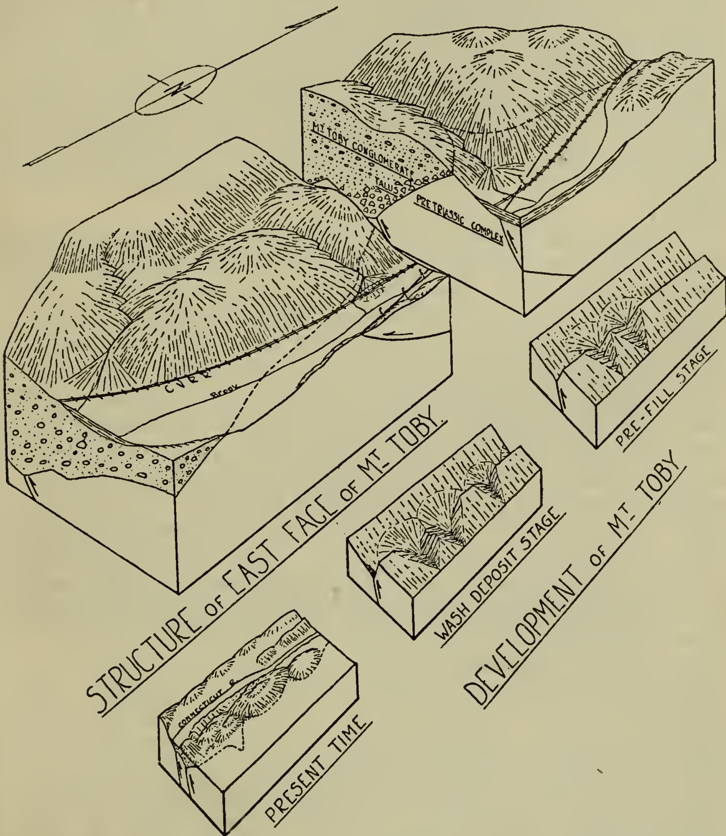

FIGURE 30.—Eastern front of Mount Toby, showing contact (broken line) of Triassic deposits on the older rocks. Below, three stages in the supposed development of the deposits and of the topography, from Triassic time to the present. By G. W. Bain

are nearly horizontal. The lava sheet is compound, as shown by the scoriaceous top of a lower flow exposed just north of the stone crusher.

Descending the slope south of the range, the road passes outcrops of the sandstone above the trap near the base. Farther along are outcrops of the upper lava sheet and of the tuff above it. The tuff here is dark and fine grained except for scattered angular inclusions. Farther south along the road the succession of formations is complicated by faulting.

[43] About a mile south of The Notch, in a field northwest of the road, the tuff is a coarse breccia containing inclusions of several rock types. Several large glacial erratics of the breccia offer fresh surfaces for study. An extensive volcanic complex lies in the rough ground west of this locality. Small necks of amygdaloidal basalt cut the sandstone; a large thickness of tuff lies upon it, as the second trap is missing at many places. North-south faults offset the formations and increase the complexity.

In a quarry at Moody Corner, 2½ miles (4 kilometers) southwest of The Notch, some fine specimens of dinosaur footprints have been obtained. South Hadley, 1½ miles (2.4 kilometers) farther south, is the site of Mount Holyoke College, the oldest college for women in America. Between South Hadley and South Hadley Falls [44] brickyards use the banded clays deposited in glacial Lake Springfield. There is a gentle dome structure in the beds, probably caused by a buried irregularity in the floor. At the top of the section the clays pass gradually into fine sand with thicker layers. Deformed bedding in the clay, extending outward from a sand-filled center, is a common feature. The last layer to be broken is a winter band, and the gap is filled by sand of the spring freshets. It has been suggested that the deformation was caused by stranded icebergs, but possibly the cause was bottom ice. The altitude of the brickyards is about 100 feet (30 meters); this is about 100 feet below the highest level of the lake.

Holyoke, west of the river, is an important industrial center, especially in paper manufacturing. Two miles (3.2 kilometers) north of the city, near the entrance to Mountain Park, a cut beside the highway exposes the top of the upper lava sheet in contact with the sandstone. A short distance farther north [45] a large surface of the sandstone has many footprints of a large bipedal dinosaur. (See fig. 31.) Some of the tracks are nearly 20 inches (50 centimeters) long. The length of stride is shown in several places by a succession of prints.

Holyoke to Hartford by way of Springfield and Somers (42 miles, or 68 kilometers).—The route follows the west side of the Connecticut River to West Springfield and crosses to Springfield, an important industrial center. Southeast of the city the road climbs to the surface of an extensive fluvial deposit at about 200 feet (61 meters) above sea level. The wide lowland reaching to the edge of the Eastern Highland has numerous features that mark the waning of the glacier ice. The highland front rises abruptly several hundred feet above the plain. This part of the front is known locally as the Wilbraham Mountains.

At North Somers, 9 miles (14.5 kilometers) southeast of Springfield, the route turns south parallel with the Triassic border. About 1½ miles (2.4 kilometers) south of Somers [46], along a side road to the west, numerous kettles and ice-contact slopes illustrate stagnation of the ice. Other examples are seen farther south. At Wapping the road descends to the surface of a stream terrace, at an altitude of 85 feet (26 meters). Three miles (4.8 kilometers) farther west there is another abrupt descent to a terrace at 45 feet (14 meters). This succession of

Figure 31.—Several types of dinosaur tracks common in the Triassic rocks of Massachusetts and Connecticut. All about one-twelfth natural size. By R. S. Lull (Connecticut Geol. and Nat. Hist. Survey Bull. 24, 1915). 1, *Anchisauripus* (*Brontozoum*) *sillimani;* 2, *Sauropus barrattii;* 3, *Gigandipus caudatus;* 4, *Eubrontes* (*Brontozoum*) *giganteus;* 5, *Otozoum moodii*

terrace levels marks the successive lowering of the lake as the ice melted and opened lower spillways.

Hartford, on the west bank of the Connecticut, is the capital city of the State and one of the most attractive residential cities in New England. Although the mouth of the river is more than 30 miles (48 kilometers) away, the tide reaches Hartford.

HARTFORD TO NEW HAVEN, CONNECTICUT

By Chester R. Longwell

Hartford to Roaring Brook, Southington (22 miles, or 35 kilometers).—About 3 miles (4.8 kilometers) south of Hartford the road passes Cedar Mountain, made of the middle lava sheet, which is brought up by faulting and warping. New Britain, 10 miles (16 kilometers) from Hartford, is noted for the manufacture of tools and machinery. Three miles (4.8 kilometers) west of the city the road passes through Cooks Gap, in the high ridge made by the middle lava sheet. This gap, evidently cut by a stream of considerable size, is now occupied by a tiny brook. It is believed that the ancient Farmington River flowed through the gap and joined the Connecticut near the site of Middletown. The lowland west of the gap, underlain by the lower sandstone of the Triassic, was the scene of important drainage changes in the Pleistocene.

Four miles (6.4 kilometers) to the west the road reaches the Western Highland front near Bristol. Two miles (3.2 kilometers) to the south the route passes over a long, narrow ridge of sand which resembles an esker; it is a crevasse filling, built out from the edge of a lake terrace into a large crack in the stagnant ice. Compounce Pond, on the west, is a large kettle left by disappearance of the ice between the crevasse and the high scarp. The highland front here is exceptionally high and steep.

[47] Two miles (3.2 kilometers) south of the pond the contact of Triassic sediments and the mica schist is well exposed in Roaring Brook. (See pl. 12, *B*.) The schist is of undetermined age; it is now considered to be either Lower Cambrian or pre-Cambrian. No fragments of the schist are recognizable in the sediments above it. The strata dip 15° E., and as this dip, projected upward to the west, would not carry the base of the sandstones over the highland front, it is probable that a fault exists along this part of the boundary. This probability is strengthened by the height and steepness of the scarp and by the exposure, in the shaft of an old copper mine, of a large fault at the foot of the scarp 3 miles (4.8 kilometers) north of Bristol.

Roaring Brook to Portland by way of Meriden (26 miles, or 42 kilometers).—Near Southington there are numerous large kettles and other glacial features.

[48] Four miles (6.4 kilometers) to the southeast are the Hanging Hills, made by the middle lava sheet. At the base of the high cliff a prominent wide bench is formed by the lower sheet. The highest point on the hills, West Peak, is 1,007 feet (307 meters) above sea level. (See fig. 32.) A road leads to the top of the lower bench. The lower lava sheet has well-defined pillow structure, a characteristic of this sheet wherever it is exposed. A tower on the high cliff, reached by a path, affords an excellent panorama; the topographic features seen in this view reflect the structure and especially the great oblique faults in the vicinity of Meriden. (See figs. 33 and 34.)

The route passes through Meriden, a city noted for its silver-plating industry, and follows the highway northeast. In Lamentation Mountain are the same rocks exposed in the Hanging Hills, offset about 4 miles (6.4 kilometers) by faulting. Northwest of Lamentation Mountain an old quarry [49] displays excellent pillow structure in the lower lava. A mile farther south the same sheet has a tuffaceous appearance—in fact, it has been called "the ash bed" at this locality. The ashy matrix contains isolated pillows and grades laterally into typical pillow lava. Probably the fragmental material was formed by steam explosions when the lava flowed over wet ground or into shallow water.

The road goes south to Meriden and turns east to East Meriden, just east of which it cuts through a low ridge made by the lower lava, and then climbs to a gap in the thick middle sheet;

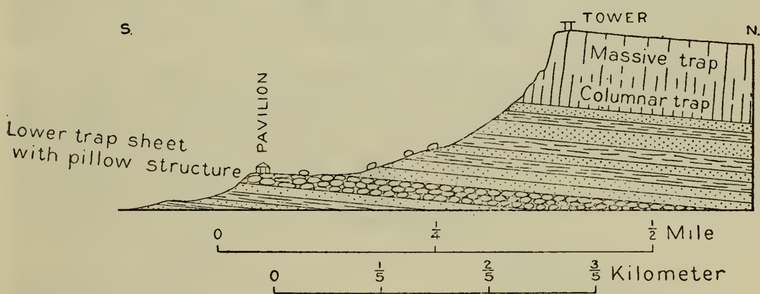

FIGURE 32.—Section through West Peak, northwest of Meriden, Connecticut, showing relation of bedrock to topography

columnar structure is exposed in the gap. Five miles (8 kilometers) to the northeast is Middletown, on the Connecticut River; Wesleyan University is located here.

[50] At Portland, on the east side of the river opposite Middletown, immense pits mark the site of old quarries in the upper sandstones of the Triassic. During the last half of the nineteenth century this stone, known as Portland brownstone, was used extensively for dwellings in New York and other eastern cities. In the quarries the strata dip southeastward at a low angle; in places they appear horizontal.

About a mile (1.6 kilometers) to the southeast, north of the highway to Willimantic, the sandstone is exposed in the hill along the railroad; here the dip is 30° SE. Other outcrops farther along the road show an increasing dip; in the last exposure of the sandstone, on the right as the road starts upgrade about 2 miles (3.2 kilometers) from Portland, the beds are inclined 50° and show the effects of shearing. The great fault at the border of the Triassic area is just beyond, and the next outcrops are of schist. Thus the strata near the fault are not dragged upward but bend

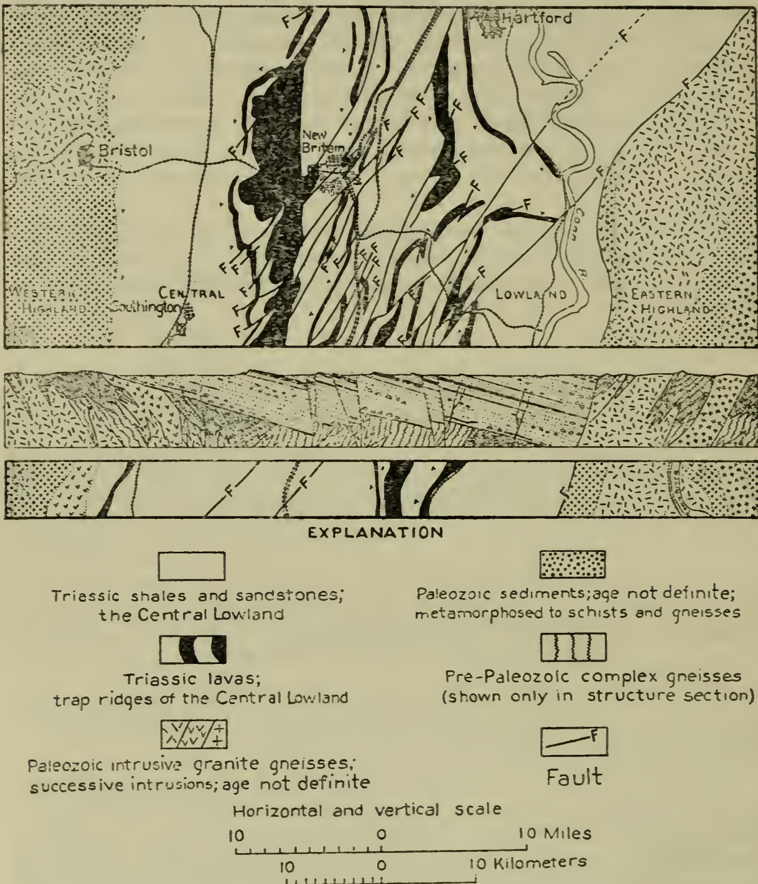

FIGURE 33.—Map of the Connecticut Triassic and section at the latitude of Meriden, showing the effect of oblique faults on outcrops of the lava sheets (black). By Joseph Barrell (Connecticut Geol. and Nat. Hist. Survey Bull. 23, 1915)

strongly downward; this relation exists at many localities along the great boundary fault.

From the position of the fault the road continues eastward over a low ridge. In the valley to the east a small lake (Jobs Pond) occupies part of an elongate kettle. Before Pleistocene time the

Connecticut River occupied this valley; now the stream bends strongly to the west at a point 2½ miles (4 kilometers) north of the pond and makes a wide loop past Middletown. During the disappearance of the Pleistocene ice the valley in this vicinity was blocked with ice and with sediments, and the stream was turned across a low divide into the valley of a tributary, the Mattabesett River.

At this point the Connecticut River leaves the Triassic area and follows a narrow valley in the old rocks of the Eastern Highland. The striking change in the character of the valley is evident from this position on the road.

[51] A belt of large pegmatite dikes lies just east of the boundary fault and parallel with it. Some of the quarries along this belt are well known for the minerals they have yielded.

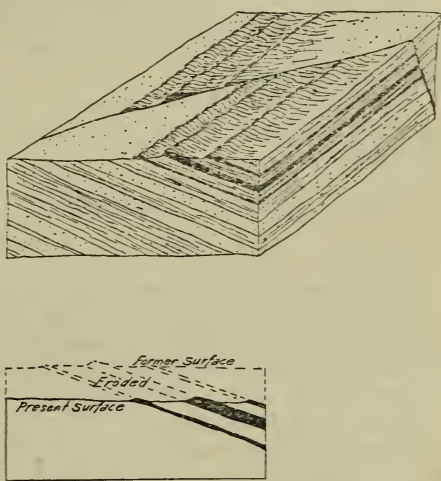

FIGURE 34.—Offsetting of the trap ridges in the vicinity of Meriden by faults trending northeast. The upthrow is on the southeast side of the fault, and erosion has caused the outcrops of the lava sheets to retreat eastward, as shown in lower part of figure. There is no important horizontal component in the fault displacement

Portland to New Haven by way of North Branford (30 miles, or 48 kilometers).—The route goes from Middletown south through Durham to Lake Quonnipaug. The road is well inside the Triassic area to a point about a mile (1.6 kilometers) south of Durham Center, 8 miles (13 kilometers) south of Middletown, where the boundary fault is reached. Mount Pisgah, to the east, is made of pegmatites in schist. The fault zone follows a troughlike valley for miles. Bluff Head, the prominent cliff west of the road 4 miles (6.4 kilometers) south of Durham, is the end of a ridge made by the middle lava sheet; the fault runs at the base of this cliff. Lake Quonnipaug, a mile (1.6 kilometers) farther on, is a glacial lake formed partly by erosion and partly by deposition of débris in the fault-zone valley.

[52] West of the lake a steep hill is made partly of trap and partly of coarse conglomerate or breccia. The trap is the upper lava sheet, and the coarse deposit is part of the upper sandstones.

The fragments are large and angular; many are thin slabs of weak schist that could not have been transported far. Some of the material had its source in a narrow belt of schist, now exposed directly east of the lake. This locality illustrates the kind of evidence from which it is concluded that movements on the fault maintained a scarp while Triassic sedimentation was in progress.

At North Branford, 5 miles (8 kilometers) to the southwest, the middle lava sheet again abuts against the boundary fault. Warping along a northwesterly axis lifted the sheet so high that erosion has cut through it and formed two curving ridges. A great quarry is located in the face of Totoket Ridge, north of the road. West of this point there are numerous small intrusive bodies of dolerite.

The Quinnipiac River, crossed at the east side of New Haven, has a wide tidal marsh, characteristic of streams along this drowned coast.

NEW HAVEN, CONNECTICUT, TO NEW YORK

By Chester R. Longwell

New Haven to the Pomperaug Valley (22 miles, or 35 kilometers).—New Haven is built for the most part on a low plain of stratified glacial drift. East Rock [53] is a remnant of a dolerite sill which lies about 6,000 feet (1,830 meters) stratigraphically above the base of the Triassic section. West Rock [54], in the northwestern part of New Haven, is the end of a long north-south ridge made by the edge of a large sill near the base of the Triassic section. The sandstone layers under the sill can be seen; the igneous rock cuts across them locally. Only a small remnant of the top cover remains, near the base of the east slope.

The top of the rock, 405 feet (123 meters) above sea level, is an excellent viewpoint. To the west, across the first valley, is the Western Highland, whose nearly even surface slopes gently to the south. Three miles (4.8 kilometers) directly east is East Rock. A chain of small east-west ridges represents a dike, probably the conduit through which magma flowed up from the West Rock sill to form the smaller East Rock body. Mount Carmel, a large irregular intrusive mass, lies 8 miles (13 kilometers) to the northeast. On a clear day the chain of ridges made by the middle lava sheet in the eastern part of the lowland is clearly visible far to the north. Long Island, across the sound, usually can be seen.

Judges Cave, on the crest of the ridge, is formed by a large erratic of basaltic lava which fell apart when the ice disappeared. The "cave" is merely a sheltered space between two of the dislocated blocks. After the Restoration in 1662 three of the judges who had condemned Charles I were fugitives in New Haven Colony, and two of them were hidden for a time in the "cave."

The route goes northwest and climbs the highland front. In this area the bedrock is phyllite of unknown age. It is highly carbonaceous at some horizons and contains local beds of metamorphosed limestone; probably it is a marine formation, but no fossils have been found to date it. The West River flows along the base of the Triassic sandstones, which rest on the phyllite with a normal sedimentary contact. The east side of the valley is formed by the palisaded edge of the West Rock sill, which on a smaller scale resembles the Palisades of the Hudson, near New York.

The road proceeds northwest across the phyllite and other metamorphic and igneous rocks. Seymour, 11 miles (17.7 kilometers) from New Haven, is on the Naugatuck River, which has a rather narrow valley cut into the highland since the regional uplift in Tertiary time.

Southbury, 11 miles (17.7 kilometers) northwest of Seymour, is at the eastern border of the Pomperaug Triassic area, which is only 8 miles (13 kilometers) long and 2 miles (3.2 kilometers) wide. The Pomperaug River and its tributaries have reduced the weak Triassic arkose to a level considerably lower than the surrounding highland, and the resulting basin was a logical dumping ground for glacial débris. There are prominent terraces of stratified drift near the road. As a result of the drift veneer, the arkose is exposed at but few localities, although its presence as bedrock is indicated by an abundance of the characteristic feldspathic sand in the glacial drift. One of the lava sheets, however, forms a high, bold ridge through the valley and several isolated hills in addition.

The total thickness of the Triassic section in the valley, as determined by drilled wells, is more than 1,200 feet (366 meters); this includes the prominent lava sheet, which is about 300 feet (91 meters) thick, and a lower sheet less than 50 feet(15 meters) thick. Probably these sheets correspond to the lower and middle sheets to the east, as the sedimentary strata between them include thin limestone and black shales that yield ganoid fishes, like the shales between the lower and middle sheets in the larger area. The entire section is inclined 15° E.

As outcrops are poor it is difficult to determine the structural relation of the Triassic strata to the highland rocks. Because of the uniform eastward dip there can be little doubt of a fault boundary on the east side of the area; and it is highly probable that the entire unit is a fault block, dropped into the older rocks and so preserved from complete removal by erosion.

[55] The larger trap sheet forms outcrops on each side of the road to New Milford, about a mile west of White Oaks; arkose beneath the sheet is exposed in the steep slope northeast of South Britain.

Pomperaug Valley to New York (60 miles, or 96 kilometers).— South of South Britain the highway runs southwestward to Danbury, which lies on crystalline limestone of uncertain age. The limestone belt continues to the north, with short interruptions, to the marble area of western Massachusetts and Vermont; but the strata at Danbury may be older than those in the northern part of the belt. It may be significant in this connection that the planes of the close folds in the limestones near Danbury dip consistently to the west, in contrast with the eastward dip farther north. The regional dip in the folded Ordovician formations of the Hudson Valley directly west of Danbury also is to the east.

From Danbury the route leads southwestward over complexly folded and metamorphosed rocks, in part pre-Cambrian and in part of doubtful age, to New York.