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CHARLES D. WALCOTT, DIRECTOR

GEOLOGY OF THE HUDSON VALLEY BETWEEN THE HOOSIC AND THE KINDERHOOK

BY

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 11, 1904.

SIR: I have the honor to transmit herewith the manuscript of a report on the geology of the Hudson Valley between the Hoosic and the Kinderhook, by T. Nelson Dale, and to recommend its publication as a bulletin.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

GEOLOGY OF THE HUDSON VALLEY BETWEEN THE HOOSIC AND THE KINDERHOOK.

By T. Nelson Dale.

INTRODUCTION.

This paper treats of a strip of the Hudson Valley between the Hudson River on the west and the Rensselaer Plateau and the Taconic Range on the east. It is roughly bounded on the north by the Hoosic and on the south by the Kinderhook, and has an area of about 315 square miles, situated mostly in Rensselaer County but partly in Columbia County, N. Y.; it includes a portion of the area of the Cohoes, Troy, and Kinderhook sheets of the topographic atlas of the United States Geological Survey.

This area presents several geological problems which have long been in process of solution. These are: The delimitation and age of the several formations, the order of their local deposition, and their present structural relations. These problems would be easily solved but for the rarity of fossil localities and the obscure character of many of the fossils, the petrographic similarity of beds belonging to several formations, the minor overturned folding which marks almost the entire belt, the reverse faulting in places, and the general prevalence of glacial deposits.

The publication of this paper carries out a design originated by Prof. Raphael Pumpelly, while in charge of the Archean division of the United States Geological Survey, to carefully study a belt, from 20 to 40 miles wide from north to south, extending from the highly metamorphic zone of the Green Mountain range in Massachusetts to the zone of unaltered sediments at the Hudson River. Monograph XXIII of the United States Geological Survey, on the Green Mountains in Massachusetts (1894), and the writer's paper on the Rensselaer Plateau in New York (1893), marked the execution of the more important part of this plan, and the present paper completes it.

This paper does not claim to be exhaustive, but is intended to facilitate more minute explorations by others, as well as the extension of the work southward and northward. It is offered as a contribution chiefly to the stratigraphy of the region, paleontological investigations having been made entirely subsidiary to that and having been confined to the reference of fossils to paleontologists for determination.

The paper presents mainly the results of three months' field work done by the writer, assisted by Mr. Louis M. Prindle, in 1893, and also of a month's work, without his assistance, during 1890, 1891, 1894, and 1895, of another month's work in 1898 and 1899, and of about three weeks' work in 1901, in all equivalent to eight and three-fourths months' field work by one person. On the map (Pl. I) are shown several important fossil localities, some hitherto unpublished, discovered by Mr. Charles D. Walcott prior to 1890, some fossil localities discovered by Ford in Troy, and several localities either discovered or located in Troy and Nassau by Mr. August F. Foerste during a three weeks' reconnaissance made in 1892 and in a few days of 1890. Mr. Foerste submitted a report of his detailed work about Troy to Professor Pumpelly, from which a few quotations and figs. 13 and 14, which embody his general results, have been taken. Figs. 4, 5, and 6 are from Mr. Prindle's note book. Paleontological determinations have been credited in their places. Mr. Rudolf Ruedemann's published graptolite localities on the Deep Kill and at Schaghticoke are specially designated on the map.

The extension of geological field work by this Survey in recent years through the Cambro-Ordovician belt, along the west side of the Taconic Range, in Washington County, N. Y., and Rutland County, Vt., has thrown much light on the relations of these formations in the Hudson Valley, and will facilitate the interpretation of the phenomena to be described.

LITERATURE.

Omitting the maps and descriptions of the early surveys, the modern geological literature of this tract is as follows, arranged in chronological order:

1. Ford, S. W. Notes on the Primordial rocks in the vicinity of Troy, N. Y.: Am. Jour. Sci., 3d ser., vol, 2, pp. 32–34, 1871.

2. Ford, S. W. Note on the discovery of a new locality of Primordial fossils in Rensselaer County, N. Y.: Am. Jour. Sci., 3d ser., vol. 9, pp. 204–206, 1875.

(See also other paleontological articles by the same author in vols. 11, 1876, and 19, 1880, of same journal.)

3. Ford, S. W. On the age of the glazed and contorted slaty rocks in the vicinity of Schodack Landing, Rensselaer County, N. Y.: Am. Jour. Sci., 3d ser., vol. 28, pp. 206–208, 1884.

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15. RUEDEMANN, RUDOLF. Hudson River beds near Albany and their taxonomic equivalents: Bull. 42 New York State Mus., vol. 8, Apr., 1901.

16. RUEDEMANN, RUDOLF. Trenton conglomerate of Rysedorph Hill and its fauna: Bull. 49 New York State Mus., pp. 1–114, 1901.

17. DALE, T. NELSON. Structural details in the Green Mountain region and in eastern New York (second paper): Bull. U. S. Geol. Survey No. 195 (Plano-convex limestone concretions from Nassau, Rensselaer County, N. Y.), p. 12, 1902.

18. ULRICH, E. O., and SCHUCHERT, CHARLES. Paleozoic seas and barriers in eastern North America: Rept. of the New York State Paleontologist for 1901, 1902, pp. 633–672.

19. RUEDEMANN, RUDOLF. The graptolite (Levis) facies of the Beekmantown formation in Rensselaer County, N. Y.: Rept. of the New York State Paleontologist for 1901, pp. 546–574, 1902.

20. RUEDEMANN, RUDOLF. The Cambric Dictyonema fauna in the slate belt of eastern New York: Rept. of the New York State Paleontologist for 1902, pp. 934–958, 1903.

21. DALE, T. NELSON. Taconic physiography: Bull. U. S. Geol. Survey No. — (in preparation).

TOPOGRAPHY.

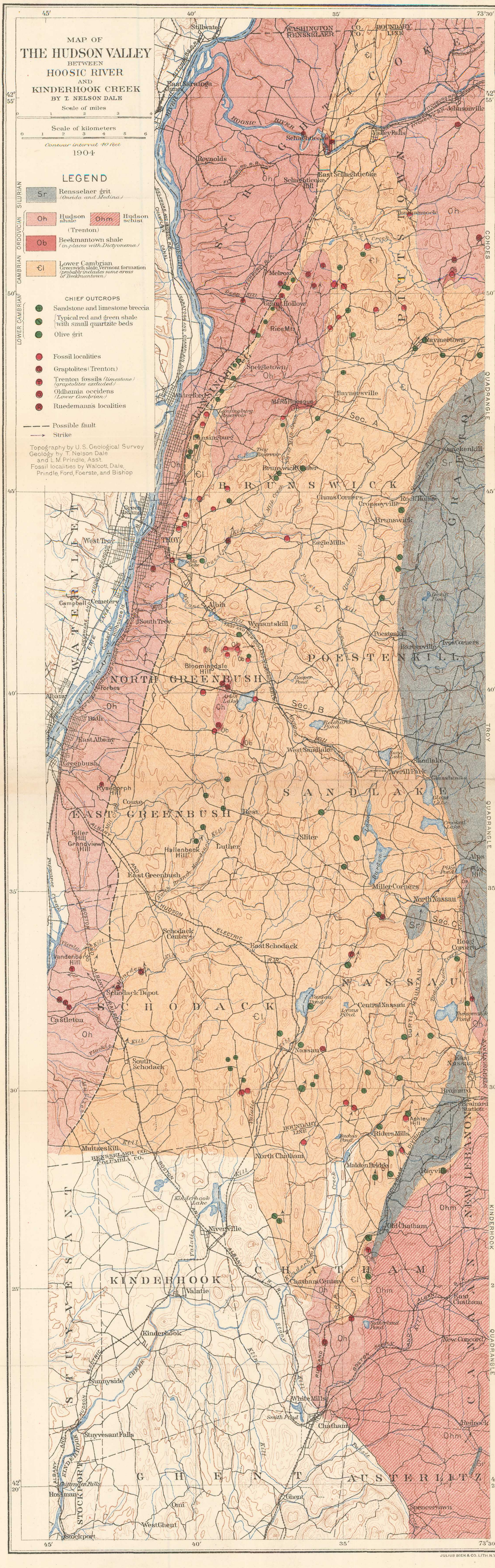
The most salient topographic feature in this tract is the line of hills bordering the horizon on the east, and ranging in height from 1,200 to 1,400, rarely to 1,600, feet above sea level. This is the western edge of a plateau only a third of whose area appears on the map. Along the central part of the eastern edge of the tract here mapped this plateau is 3 miles wide, but in Grafton, at the north, and in Nassau, at the south, the plateau front recedes farther eastward. South of this plateau a somewhat irregular mass of hills, belonging to the Taconic Range and ranging from 800 to 1,150 feet above sea level, advances westward as far as Chatham. Between the point where the northern edge of the plateau turns eastward and the Washington County line there are no highlands.

The lowland is marked by numerous more or less oval hillocks, usually from 100 to 200 feet high, and mostly of glacial [illegible]. Two conspicuous isolated hill masses, Mount Rafinesque in Brunswick (1,10[illegible] feet), with the adjacent Rice (or Bald) Mountain (925 feet) in Lansingburg, and Curtis Mountain (Dusenbery Ridge) in Nassau (1,180 feet), rise from 500 to 600 feet above the lowland. The lowland drops gradually from the 600- and 700-foot levels at the east to the 250-foot level at the west in a distance of 7 to 11 miles, and within another mile descends to tide water. The drainage is all to the Hudson. The principal streams, beginning at the north, are the Hoosic, the Poesten Kill, the Wynant Kill, the Moordener Kill, and the Kinderhook. Numerous smaller streams enter the Hudson directly, having cut deep ravines in the terrace-capped shales which form its eastern bank. The Hoosic, near Schaghticoke, has cut a canyon nearly 200 feet deep through similar materials. The Poesten Kill, which drains a large part of the plateau, flows through a deep incision in its western edge, and has cut a small gorge 2½ miles east of the Hudson and another at Troy. Owing to the glacial deposits and river terraces outcrops occur chiefly along the watercourses.

For the general physiography of the region the reader is referred to the writer's forthcoming "Taconic Physiography" (No. 21, p. 11).

AREAL GEOLOGY.

The principal geological traits of the strip are shown on the map (Pl. I). There is a central longitudinal Cambrian belt, consisting mainly of shale, extending from the Washington County line to Chatham Center and beyond, which is from 1¾ to 11 miles wide. This Cambrian belt includes, however, two outliers of upper Ordovician age, one covering about three-fourths of a square mile in North Greenbush, the other about 9 square miles, including Mount Rafinesque and Rice Mountain, and situated partly in Brunswick, Pittstown, Lansingburg, and Schaghticoke. This Cambrian belt is bordered on the west by the upper Ordovician shale and grit through which the Hudson flows, the boundary between the two formations being probably a fault. At the north the Cambrian belt narrows, and is bordered on both sides by Ordovician shale and grit. Ordovician areas likewise recur at the south, alternating with Cambrian strips, and also in places along the foot of the plateau. South of the plateau Ordovician schist, the metamorphic equivalent of the shale and grit, constitutes the Taconic Range and merges into these at the west. There are also a number of very small areas of Beekmantown shale (lowest Ordovician) overlying the Cambrian. Finally, the Rensselaer grit, with its interbedded slate


MAP OF
THE HUDSON VALLEY
BETWEEN
HOOSIC RIVER
AND
KINDERHOOK CREEK
BY T. NELSON DALE
Scale of miles
Scale of kilometers
Contour interval 10 feet
1904
LEGEND
Sr Rensselaer grit (Oneida and Medina)
Oh Hudson shale
Ohm Hudson schist
(Trenton)
Ob Beekmantown shale (in places with Dictyonema)
Єl Lower Cambrian Greenwich slate, Vermont formation (probably includes some areas of Beekmantown)
SILURIAN
ORDOVICIAN
CAMBRIAN ORDOVICIAN
LOWER CAMBRIAN
CHIEF OUTCROPS
Sandstone and limestone breccia
Typical red and green shale with small quartzite beds
Olive grit
Fossil localities
Graptolites (Trenton)
Trenton fossils (limestone) (graptolites excluded)
Oldhamia occidens (Lower Cambrian)
Ruedemann's localities
Possible fault
Strike
Topography by U. S. Geological Survey
Geology by T. Nelson Dale and L. M. Prindle, Asst.
Fossil localities by Walcott, Dale, Prindle, Ford, Foerste, and Bishop
COHOES QUADRANGLE
TROY QUADRANGLE
KINDERHOOK QUADRANGLE
SCHAGHTICOKE
PITTSTOWN
BRUNSWICK
GRAFTON
POESTENKILL
NORTH GREENBUSH
WATERVLIET
SAND LAKE
EAST GREENBUSH
SCHODACK
NASSAU
NEW LEBANON
CHATHAM
KINDERHOOK
STUYVESANT
GHENT
AUSTERLITZ
CANAAN
TROY
Sec. A
Sec. B
Sec. C

and shale, representing the basal part of the Silurian, constitutes the plateau, besides an outlying lenticular area of 4½ square miles in Nassau and Chatham, another of half a square mile near North Nassau, and a much smaller area resting on the Ordovician schist near Spencertown in Austerlitz, 12 miles south of the plateau.

Each of these formations will now be described in detail.

LOWER CAMBRIAN.

FOSSIL LOCALITIES.

The map shows 30 localities of Cambrian fossils, all Lower Cambrian (*Olenellus* fauna), according to determinations by Ford, Walcott, or Foerste. The fossils usually occur in small limestone beds in the shale. In places the limestone is made up so exclusively of *Olenellus* fragments as to deserve the name Trilobite limestone. In some places pteropods are frequent; in others, brachiopods.

Besides these there are 5 localities where the calcareous alga or nullipore, *Oldhamia* (*Murchisonites*) *occidens* Walc., has been found. These are designated by a separate symbol on the map. (See paper No. 10, p. 11. Mr. Walcott's figure is here reproduced—fig. 1.) The description of the localities, sent to him by the writer for inclusion in that paper and therein published, is here repeated:

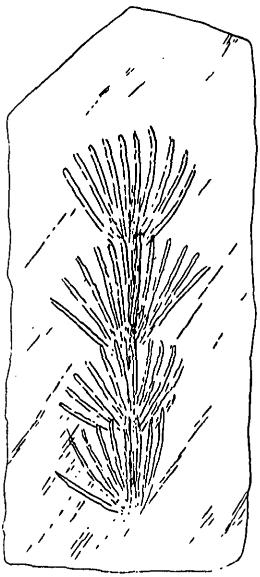


FIG. 1.—*Oldhamia* (*Murchisonites*) *occidens* (Walcott). A single frond. Natural size. Possibly a nullipore. Lower Cambrian. From the gorge of the Poesten Kill, 2¼ miles east of Troy. Copied from Proc. Nat. Mus., vol. 17, 1894, p. 314, fig. 1.

> The *Oldhamia* was first found in reddish shales associated with greenish shales and beds of quartzite, ranging from 1 to nearly 22 inches in thickness, at a sawmill dam midway between Burden Lake and Nassau Pond, in the township of Nassau; again in similar rocks about 2 miles farther up the same stream and 1½ miles south-southeast from the south end of Burden Lake. It occurs also on the Moordener Kill, about 1¼ miles northeast of Schodack depot, in the township of Schodack, and in great abundance in the gorge of the Poesten Kill, 1¾ miles east of Troy, near the Eagle Mills [Millville] road, along the right bank of the river, which there flows south. The *Oldhamia* is here associated with various trails, and both cover large surfaces of the rock.

Still another *Oldhamia* locality is about a mile east of Nassau village, between two road corners, on the north side of the road. The fossil will probably also be found near the South Schodack railroad crossing and at many other points. The locality near Troy is the most accessible and the most likely to reward collectors.

Mr. Walcott regarded this *Oldhamia* as closely related to the *Oldhamia antiqua* of the Cambrian of Ireland, but "the determination of the geologic horizon" as "somewhat uncertain." His assignment of the reddish shale to "the post-Lower Cambrian and pre-Trenton" was based mainly upon the writer's interpretation of the stratigraphy at that time, when the reddish shale seemed to him to overlie the Lower Cambrian fossiliferous limestone. The determination of the precise position of this reddish and greenish shale with beds of quartzite of various thickness with reference to the Lower Cambrian limestone is attended with no little difficulty. The reddish color is not a safe guide in this region, for such shale is sometimes associated with black graptolite shale and is then of Trenton-Hudson age. It is also interbedded with the Rensselaer grit, and then belongs to the Oneida and Medina. But in places it also occurs below the Lower Cambrian fossiliferous limestone. The stratigraphic reasons for finally assigning the *Oldhamia* shale to this last position will be given under "Stratigraphy."

FIG. 2.—Fossil casts of organic impressions in quartzite from the Lower Cambrian shale in brook bed a mile north of Poestenkill village. Redrawn from a photograph taken by Dale and Foerste.

The same series of alternating red and green shale and small quartzite beds is also marked by annelid trails and casts of bifurcating impressions which have as yet no chronological or paleontological importance. These casts are, however, here quite characteristic of the series, which also carries the *Oldhamia*. Fig. 2 will serve to convey an idea of their general appearance and dimensions. As the forms stand out in relief on the quartzite surfaces the impressions themselves must have been made on the clay surfaces and then filled with sand, which has become quartzite or grit. The more important outcrops of this typical shale are indicated on the map.

PETROGRAPHY.

Certain rocks of the Lower Cambrian have such marked characteristics as to deserve special notice. A metamorphic olive grit, usually weathering a light brick red, crops out at a few points, and is also typical of this formation in Washington County. (See p. 179 of the paper No. 13, p. 11, for microscopical description.) It occurs one-half mile east of Lake Ida, in Troy, and also north of its eastern end; one-half mile southwest of Wynantskill; at the milldam in Raymertown; at Brunswick Center; in Lansingburg, at Oakwood Cemetery, on the north side of the outlet of the pond, where it contains organic impressions and is in contact with the Ordovician shale; and at a point a mile south of Grant Hollow.

Still more characteristic of the Cambrian, and of much more frequent occurrence, is a calcareous sandstone and an associated limestone breccia. (See pp. 183, 184 of No. 13, p. 11, for a description of this sandstone as it occurs in Washington County.) This rock usually consists of roundish quartz grains held together by a cement of crystalline and granular calcite or of dolomite. On the weathered surface these grains stand out in relief and are slightly opalescent. They are even noticeable in the loose stones of the rye fields, and may be taken as an almost infallible indication of Cambrian age. Associated with these quartz grains is an occasional grain of plagioclase. Pebbles of carbonaceous-siliceous shale or of chloritic shale are quite character-

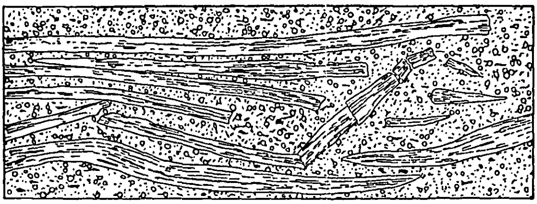


FIG. 3.—Sketch of a specimen of calcareous sandstone with small brecciated limestone or dolomite beds, typical of the Lower Cambrian of Rensselaer County. About one-third natural size. Locality, south of Lake Aries, in North Greenbush. From Sixteenth Ann. Rept., pt. 1, p. 569.

istic of this rock. There are also oölitic calcareous spherules from 0.12 to 0.75 mm. in diameter, which are sometimes ferruginous, suggestive of rhizopods, and grains of limestone consisting of similar spherules. A microscopical drawing of the rock is shown in Pl. II, *A* (p. 20).

This sandstone very often includes beds of bluish fossiliferous limestone from one-half to 1 inch thick, which are generally brecciated, probably because of their greater rigidity under lateral compression than the intervening sandstone. (See fig. 3, which is taken from p. 569, fig. 99, of paper No. 12, p. 11.) The abutments of the grade crossing a mile south-southwest of the Lansingburg reservoir are built of this material and exhibit well its general character.

This sandstone is frequently associated with (either passing horizontally into or underlain at no great interval by) a quartzite in which the cement is either very slightly calcareous or sericitic. Both sandstone and quartzite are apt to be traversed by a network of veins and veinlets of quartz, which, owing to the rapid weathering of the $CaCO_3$ of the cement, project on its surface. This sandstone crops out in

Oakwood Cemetery in Lansingburg, and continues north northeast for a mile to a hillock, known locally as "Diamond Rock," on account of its abundance of quartz crystals; these occur in association with such veins.

The more important outcrops of the olive grit and of the calcareous sandstone and breccia are shown on the map, Pl. I. Outcrops of the latter at which fossils were found are, however, designated simply as fossil localities.

A limestone conglomerate deserves notice. Two miles south of Schodack Landing (Coxsackie quadrangle), or 7 miles west-southwest from North Chatham, the Cambrian shale and limestone form a cliff about 70 feet high (fig. 17, p. 28). Near the top is a bed about 10 feet thick, the lower part of which is a brecciated limestone, but the upper resembles a conglomerate; and it looks as if the brecciated limestone had for a while been exposed to wave action. The pebbles are limestone carrying Lower Cambrian fossils, but the cement is shaly. Some of the pebbles have pitted surfaces. This bed is capped by a few inches of coarse-grained limestone also carrying Lower Cambrian fossils. At Ashley Hill, a mile northeast of Riders Mills, in Chatham, the brecciated Cambrian limestone seems also to pass into a conglomerate, and the pebble-like nodules are likewise pitted from the impression of the quartz grains of the matrix. This pitting will be found explained and illustrated in pp. 312, 313, and fig. 24 of paper No. 9, p. 11. Foerste traced similar pebbles in the Cambrian shale at Troy to small limestone beds which had undergone a process of brecciation, slip cleavage, and partial solution. (See p. 569, fig. 100, of paper No. 12, p. 11.) Such "pebbles" might also be accounted for by a concretionary process taking place in sediments which were partly calcareous and partly argillaceous; or, finally, by a slight crustal movement exposing the limestone to wave action during a brief period and then submerging it again. The applicability of the first two theories should be carefully tested before resorting to an explanation involving geographical changes. It is, however, quite possible that such changes did occur here in Lower Cambrian time, and that in some localities there are true conglomerates[a], in others autoclastic ones.

A greenish shale, occasionally slightly reddish or blackish, covers a number of square miles of the Cambrian area. In places it underlies and is interbedded with the fossiliferous limestone. Under the microscope it is a very fine-grained aggregate of muscovite and chlorite scales, angular quartz grains, rarely plagioclase grains, with brownish dots which are probably limonite. The direction of the bedding is shown by bands of quartz grains, but the bedding foliation is crossed by an incipient slip cleavage, so that the muscovite scales

[a] Walcott, Charles D., Paleozoic intraformational conglomerates: Bull. Geol. Soc. America, vol. 5, pp. 191-198, Pls. V-VII, 1894.

appear as if arranged in two directions, at a large angle to each other. Pl. II, *B*, shows a microscopical drawing of this shale. The ledge from which the specimen came has bedding planes striking N. 5° E. and dipping 35° W., crossed by a cleavage foliation striking N. 7° W and dipping 70° E., besides vertical joints striking N. 70° E. In consequence of these three systems of partings the rock weathers into stick-like fragments, and this mode of weathering is very common in this shale. The economic importance of this will be shown under "Economic geology." The microscopical composition and structure of this shale indicate that it would probably not have required a vastly increased amount of compression to transform it into schist.

This shale is very frequently interbedded with quartzose beds, weathering rusty-brown, from one-half inch to 2 inches thick. These little beds, when examined microscopically, prove to range from an almost pure quartzite to a dolomitic quartz grit. With the quartz grains, which are generally angular, are always a few of plagioclase and of zircon, and sometimes scales of muscovite and of chlorite and grains of tourmaline. The cement varies in quantity and in material, being sometimes purely siliceous, or partly siliceous and partly calcareous or sericitic, and sometimes entirely dolomitic. There are also black particles, probably graphite, and there is limonite staining from the decomposition of pyrite or carbonate. A typical section of the more gritty beds is shown in Pl. II, *C*.

There remain to be described certain greenish coarse and fine quartzite beds interbedded with the red and green shale bearing *Oldhamia occidens*. These differ little from those just described except in the occasional abundance of chlorite or chlorite-schist areas or fragments. Belonging to the same series are beds of massive quartzite, from 8 to 50 feet thick, of similar character, but including here and there small beds of quartz conglomerate, in which the pebbles measure up to one-fourth and even one-half inch in diameter, and occasionally a pebble of dark-greenish slate.

The reddish shale associated with all these quartzite beds varies much in the amount of its hematite and, therefore, in the intensity of its color. In the gorge of the Poesten Kill, a little east of Troy, and also in other places, the color is purplish. In the hill mass west of Burden Lake the red is deep. The green shales owe their color to chlorite, the purplish ones probably to chlorite and hematite, and the blackish ones, naturally, to carbon.

STRATIGRAPHY.

The paleontological evidence as to the age of these beds having been given, and their petrographical features shown, they will now be examined stratigraphically. At the outset, however, it must be stated that it is impossible to determine their total thickness, because they consist so largely of closely folded and easily weathering shale and because there are so few deep cuts across them. When a bed of quartzite disappears beneath the shale, there are no means of identifying it and fixing its position in a series which includes several such beds. A number of detail sections of the Cambrian beds follow, which will afterwards be generalized in tabular form. Their relations to the Cambrian series of Washington County, N. Y., and of the Green Mountain range, in Massachusetts and Vermont, are shown in the table on page 43 and are discussed on page 50.

About a half mile northwest of East Nassau the Kinderhook turns at a right angle to flow south between two steep hills. The eastern hill consists of Rensselaer grit, but the western one of thick beds of quartzite and thin-bedded red and greenish shale, which, for reasons to be given, are all regarded as being Lower Cambrian. Fig. 4 represents a diagrammatic cross section of this hill. It shows two thick beds of

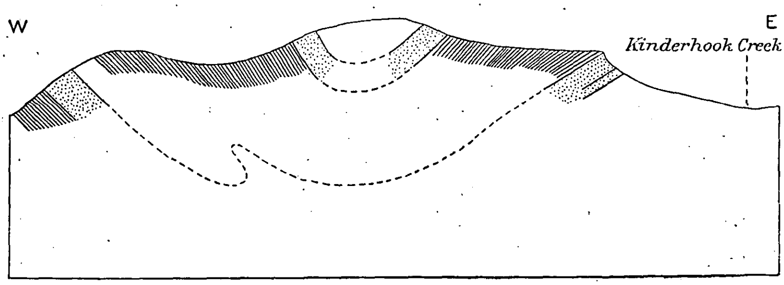


FIG. 4.—Diagram section of first ridge west of Kinderhook Creek and Snake Hill, in Nassau. Dotted beds, quartzite; lined beds, shale. Height, about 200 feet. Quartzite, about 30 feet thick.

quartzite and two masses of shale. The lowest of these shale beds is red, and the upper contains small beds of quartzite. This same series recurs 2 miles north-northeast along the strike, making up the ridge on the east side of Tackawasick Pond, which continues 2 miles north to Hoag Corners. The structure of this ridge is complex. At the extreme north it consists of a simple syncline of massive quartzite underlain by red shale, as shown in fig. 5 (p. 21). About a half mile south a small anticline of the same rocks appears east of this syncline, and within another half mile another syncline is added east of that anticline. Combining the observations made at all points the structure of the whole ridge appears to be approximately as shown in fig. 6 (p. 21), and thus, like that shown in fig. 4, consists of two thick quartzite beds separated by red shale, and the lower quartzite also underlain by red shale. There is considerable variation in the thickness of the quartzite; the bed sometimes divides into smaller ones, and these unite again farther on. The folds here have a marked northerly pitch and have been greatly eroded.

PLATE II.

PLATE II.

MICROSCOPICAL SECTIONS OF TYPICAL ROCKS.

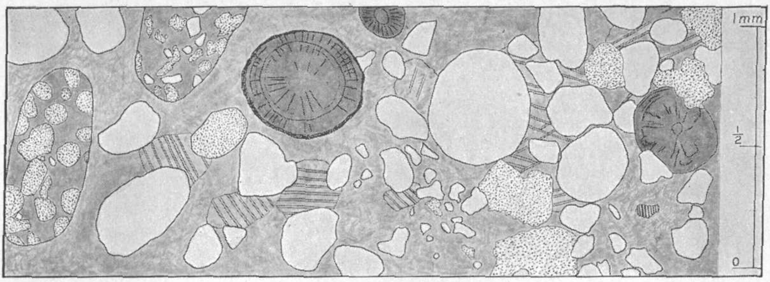
A. Microscopical drawing of two thin sections of calcareous sandstone typical of the Lower Cambrian of Rensselaer County, showing roundish quartz grains (unshaded), grains of concretionary limestone containing quartz grains, grains of granular limestone or dolomite (finely dotted), large ferruginous concretions, and a small grain of plagioclase, all in a matrix of crystalline calcite with some large plates of calcite.

B. Microscopical drawing of thin section of greenish shale typical of the Lower Cambrian of Rensselaer County, from near Nassau village. The section crosses three minute beds, two of which are made up largely of quartz grains (unshaded particles). Direction of bedding shown by arrow. The position of some of the muscovite and chlorite scales (black particles) shows an incipient cleavage. Two grains of plagioclase (banded).

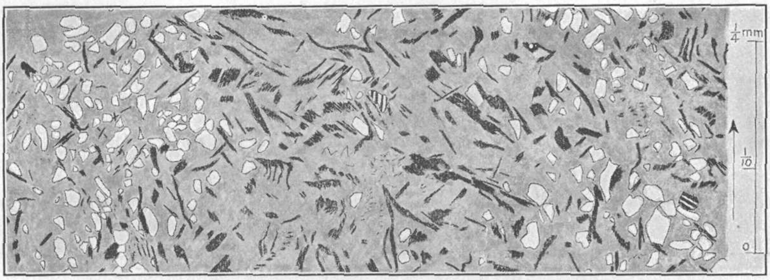
C. Microscopical drawing of a thin section of a small gritty bed typical of the Lower Cambrian shale of Rensselaer County, from one-fourth mile north of Lake Ida, in Troy, showing angular quartz grains (unshaded), three plagioclase grains, and two zircon grains, in a matrix mainly of sericite.

D. Microscopical drawing of a thin section of grit typical of the Hudson formation of Rensselaer County, from 1½ miles south of Grandview Hill, in Greenbush, showing angular quartz grains (unshaded), grains of plagioclase and orthoclase, two grains of zircon (lower left corner), one large grain of quartzite, presumably of Cambrian origin, and some carbonaceous matter (black), all in a matrix of fine argillaceous material with considerable calcite (finely dotted areas).

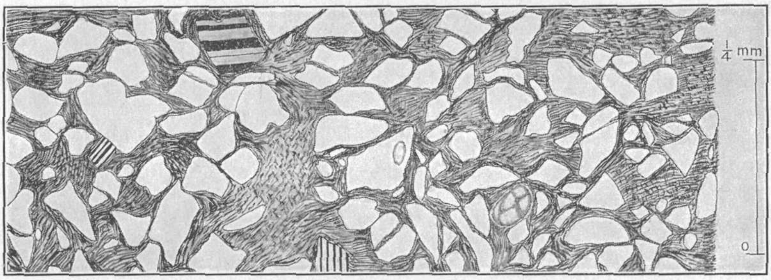
E. Microscopical drawing of a thin section of Silurian grit typical of the Rensselaer grit, from the western edge of the plateau, showing large and small angular grains of quartz (unshaded), four grains of plagioclase, one grain of microcline, one of orthoclase, and several grains of ilmenite (?), all in a matrix of sericite and chlorite.



A



B



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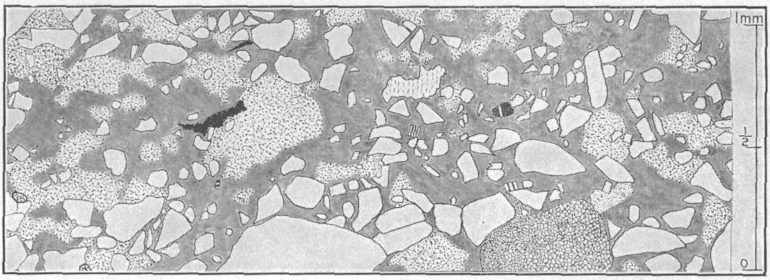

D

E

The north-south hollow through which runs the road from East Nassau to Hoag Corners separates this last ridge from another east of

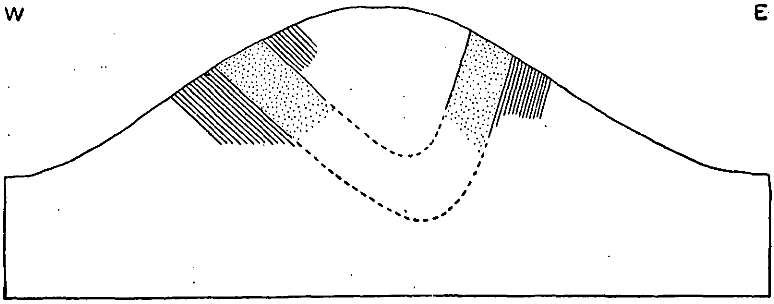

FIG. 5.—Diagram section of ridge southwest of Hoag Corners, in Nassau. Dotted beds, quartzite; lined beds, reddish shale containing small beds of quartzite with casts of organic impressions, etc.

it. Upon this is situated the Coonradt farm. This ridge is separated from the edge of the Rensselaer Plateau by still another hollow.

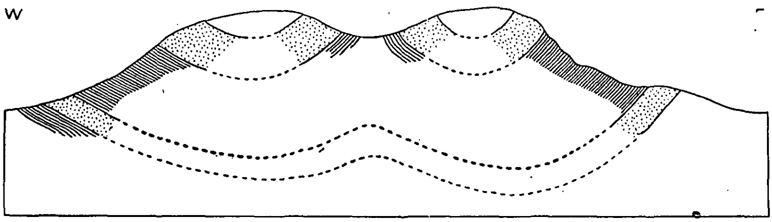

FIG. 6.—Diagram section showing the general structure of the ridge between Tackawasick Creek and Pond and the Rensselaer Plateau, in Nassau. Dotted beds, quartzite; lined beds, shale. Height, about 200 feet.

This ridge also consists of two thick beds of quartzite, each of which is both underlain and overlain by red and green shale with small quartz-

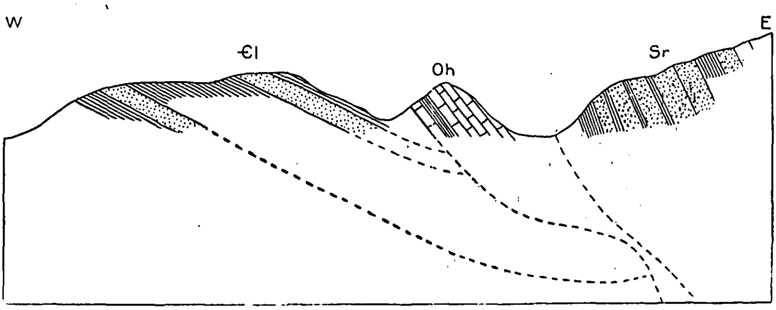

FIG. 7.—Diagram section across the western edge of the Rensselaer Plateau and the second ridge east of Tackawasick Pond, in Nassau, showing the surface relations and the probable structural relations of the Lower Cambrian quartzite and shale (Ꞓl), the Hudson limestone and shale (Oh), and the Silurian Rensselaer grit (Sr). Dotted beds (Ꞓl), quartzite; lined beds, red and green shale with small quartzite beds with organic impressions. Height of western ridge, 90 feet.

ite beds having casts of organic impressions. (See fig. 7.) The section has been extended eastward across a small hillock in the adjoining hollow to the edge of the plateau.

A similar series is also exposed on Curtis Mountain, better known locally as Dusenbery Ridge. This can best be observed by ascending the mountain from the saddle between two road forks a half mile south of the western part of Tackawasick Pond. There is first a 40-foot bed of quartzite dipping steeply west and 90°, with red shale under it on the east, followed on the west by 50 to 70 feet of reddish shale with small quartzites with similar dip; then at the head of a ravine there is a ledge, several hundred feet long, of reddish and green shale with small quartzites capped by another bed of quartzite, 15 feet thick, with a low westerly dip. Higher up, after an interval, comes greenish shale with steep westerly dip, recurring at the summit, where it forms an open syncline capped by a slightly calcareous quartzite bed, 10 feet thick, with a gentle southerly pitch. Now, descending the ridge on the west, there is a large body of greenish shale with easterly dip, followed, near the road which skirts the crest on the west, by a bed of quartzite, about 40 feet thick, dipping 45° E., underlain by shale and small quartzites. Within 80 feet of the road is still another bed of quartzite, nearly 10 feet thick, with like dip; and west of that road in a brook (a mile southwest of Tackawasick Pond) is the typical red shale with small quartzites dipping 45° E. and 80 feet thick. These two beds of quartzite with the alternating shale can be traced 1¼ miles north along the crest of Curtis Mountain. A similar series with like dip, evidently belonging to the western part of the same syncline, crops out 1¼ miles south of this last locality, between a small brook crossing the road to Nassau about 3 miles east-southeast of that village, and a corner east of it where three roads meet. Here an upper quartzite, 20 to 25 feet thick, dipping from 45° to 50° E., is underlain by 30 to 40 feet of red and green shale with small quartzites, and these again by another bed of quartzite 8 to 20 feet thick. The same series, but on the eastern side of the syncline, is again exposed on the east side of Curtis Mountain a mile south of the section. Unfortunately the relations are obscured there by overturning and by the coming in of other folds. The general structure of the Curtis Mountain syncline is shown in fig. 8.

Ashley Hill, in Chatham, between Riders Mills and Brainard, lies in the direction of the strike of the syncline on Curtis Mountain. The relations there, however, become perplexing, owing either to faulting or to the syncline being close and followed on both the east and the west by anticlines. Indications of an anticline in the southern part of Curtis Mountain, east of the syncline, have just been pointed out. There is a bench west of the crest of Ashley Hill with a fine exposure of limestone breccia and conglomerate, about 20 feet thick and one-fourth mile long, with the fauna of the *Olenellus* zone.[a] This breccia is associated

[a] See, for petrography, p. 15, and also pp. 312–314 and map, Pl. XCVII, of paper No. 9, p. 11.

with grayish and black shale. At the western edge of the bench is the typical calcareous sandstone with a westerly dip, while east of the fossiliferous belt is a noncalcareous quartzite, probably of the same horizon. In following the strike of the fossiliferous beds northward, down along the ravine to the Kinderhook, the breccia disappears, but the associated black and gray shale crops out occasionally. The calcareous quartzite occurs on both sides of the ravine, with a dip varying according to the overturn of the syncline or as the axis of either adjacent anticline is crossed. This quartzite recurs 1¼ miles north-northeast of Ashley Hill, along the east-west road on the north side of the Kinderhook, and appears to be the same rock as that capping the southward-pitching syncline at the top of Curtis Mountain, 2½ miles north-northeast of Ashley Hill, from which the fossiliferous limestone would thus appear to have been eroded. In the northern part of the bench on Ashley Hill the calcareous quartzite is underlain on the east by a mass of grayish shale, and this by a bed of massive quartzite, 45 feet

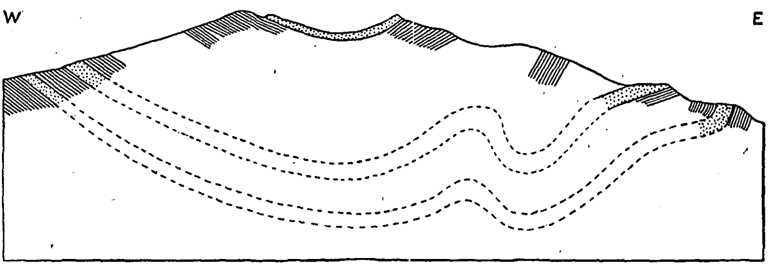

FIG. 8.—Diagram section across the southern part of Curtis Mountain (Dusenbery Ridge), in Nassau, showing the relation of the two thick quartzite beds and the red and green shale with small quartzite beds to the calcareous quartzite syncline at the top. Height, about 400 feet.

thick, dipping 70° W. Farther south, owing probably to an overturn, the dip changes to 55° E., and the gray shale there apparently underlies the massive quartzite. Still farther south is a small outcrop of noncalcareous granular quartzite, already referred to and regarded as the continuation of the calcareous quartzite, and lying east of the fossiliferous bed. East of this is a space of 550 feet of the typical red shale and small quartzites, with the usual casts; 480 feet of these dip steeply east, but the last 70 feet are greatly contorted and have folds pitching 60° S.[a]

East of these are about 150 feet of green shale, then the massive quartzite, 40 feet thick, dipping 65°–70° E., and forming the crest of the hill. About 300 feet farther east is another thick bed of quartzite, dipping 25° E. The gist of all these data is that there is here a bed of calcareous quartzite underlain by shale, and this by two beds of massive greenish quartzite with intervening thicknesses of shale, or by one bed of quartzite doubled in an anticline, the whole closely

[a] See p. 552 and fig. 75 of paper No. 12, p. 11.

resembling the series on Curtis Mountain, but here overlain by the fossiliferous limestone breccia and conglomerate. The general structure of Ashley Hill thus appears to be that shown in fig. 9. That there is a syncline on the western side of the hill is shown by the easterly dip of a bed of quartzite, 8 feet thick, along the highway a half mile west of the top.

About a mile south of Ashley Hill and three-tenths of a mile west of Rayville station, in Chatham, is another important locality. Its

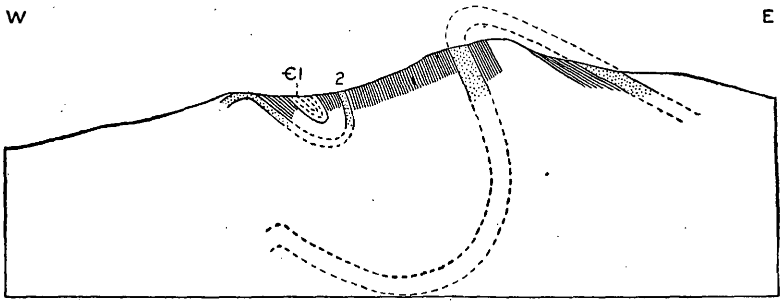

FIG. 9.—Diagram section across Ashley Hill, northeast of Riders Mills, in Chatham, Columbia County, showing the relation of the upper massive quartzite bed and the red shale with small quartzite beds to the calcareous quartzite (2) and the fossiliferous Lower Cambrian limestone breccia (Ꞓl).

stratigraphy is shown in fig. 10. Here are two small synclinal hillocks separated by an anticlinal hollow. The fossiliferous Lower Cambrian limestone, about 100 feet thick, is underlain by gray and red shale with small quartzite beds. The eastern syncline has a 5-foot bed of

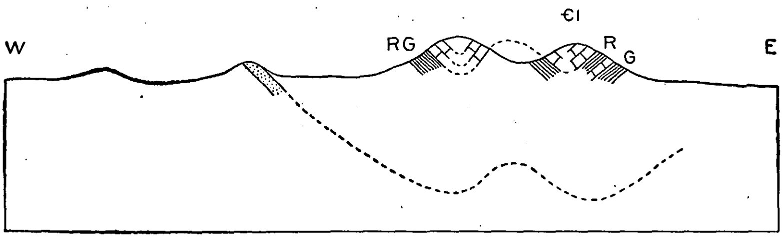

FIG. 10.—Diagram section across the hillock a mile south of Ashley Hill, in Chatham, Columbia County, showing the relation of the quartzite (dotted bed) and of the red shale (R) and green shale (G) to the fossiliferous Lower Cambrian limestone (Ꞓl). Height, 60 feet.

brecciated limestone below the red shale, and this is underlain by gray shale with quartzite beds from one-half inch to 2 inches thick. West of these hillocks is a bed of calcareous sandstone dipping toward and probably under them. This tends to corroborate the interpretation of the structure of Ashley Hill as to the relations of the sandstone to the fossiliferous beds.

At a small limestone quarry in East Greenbush, 2 miles south-southwest of Lake Aries and 2 miles southwest of West Sandlake, a mass of

Lower Cambrian bluish limestone or dolomite and calcareous quartz-sandstone, interbedded with dark-gray shale, and a mass of gray shale in contact with it on the east, all dip steeply west; and 200 feet west another outcrop of the same limestone dips east, and there is also easterly dipping shale south of it. These outcrops, taken altogether, indicate the structure shown in fig. 11. Among the limestone strata are large disk-shaped, veined concretions (septaria). Similar Cambrian beds in Nassau contain plano-convex concretions which are

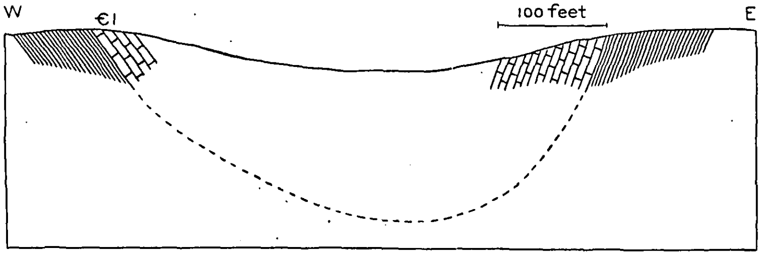

FIG. 11.—Diagram section 2 miles southwest of West Sandlake, in East Greenbush, showing the relation of the Lower Cambrian limestone (€l) and gray shale.

not veined. See paper No. 17, p. 11. The eastern limb of this syncline is again exposed about 800 feet south, but there with an easterly dip.

At a small quarry about 1¼ miles west of Lake Aries, on the south side of the road which follows the north side of the lake, the calcareous sandstone and limestone breccia, with the *Olenellus* fauna, is in contact on the west with greenish shales for one-fourth of a mile along the strike. That this shale here overlies the limestone seems probable from the presence of a small anticline in the limestone along the

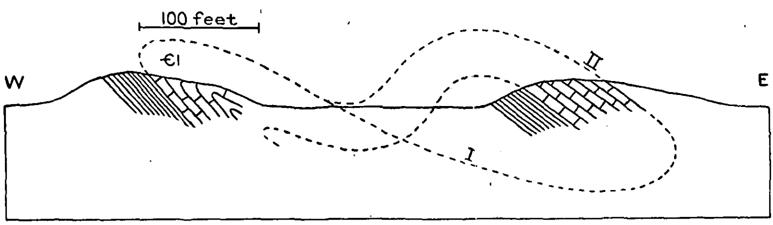

FIG. 12.—Diagram section 2 miles east of Defreestville, in North Greenbush, showing two interpretations of the relations of the greenish shale to the Lower Cambrian fossiliferous limestone (€l),

road, as well as from the almost horizontal dip of the limestone on the east side of the knoll. About 200 feet east of the quarry the shale crops out again, dipping east under beds of calcareous sandstone. The lower part of this shale has small quartzite beds with casts of organic impressions (fig. 12). The evidence as to the relations here is not conclusive. The figure shows two hypotheses: According to I the sandstone would underlie both masses of shale, but according to II it would overlie the shale with quartzites and underlie that at the west without quartzites. There is also a third possibility—that there is no repetition of beds, but two calcareous and two shale beds.

Foerste found that the Cambrian fossiliferous beds east of Troy,

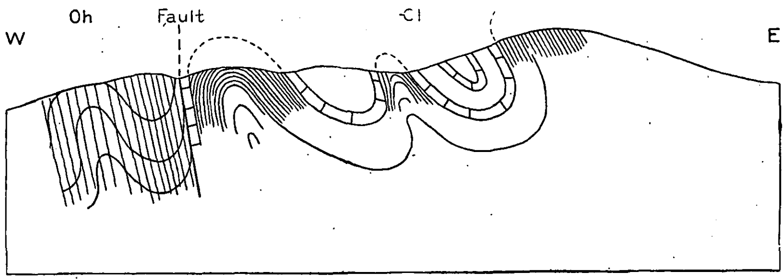

FIG. 13.—Diagram section by Foerste, but slightly modified, showing the probable general relations of the Lower Cambrian fossiliferous limestone (Cl) at Troy to the red and green shale (lined beds) and to the Hudson shale (Oh).

between the 200- and the 400-foot levels, constitute two synclines and two anticlines, underlain by reddish and greenish shale and separated from the Ordovician beds by the overthrust, as shown in fig. 13. He

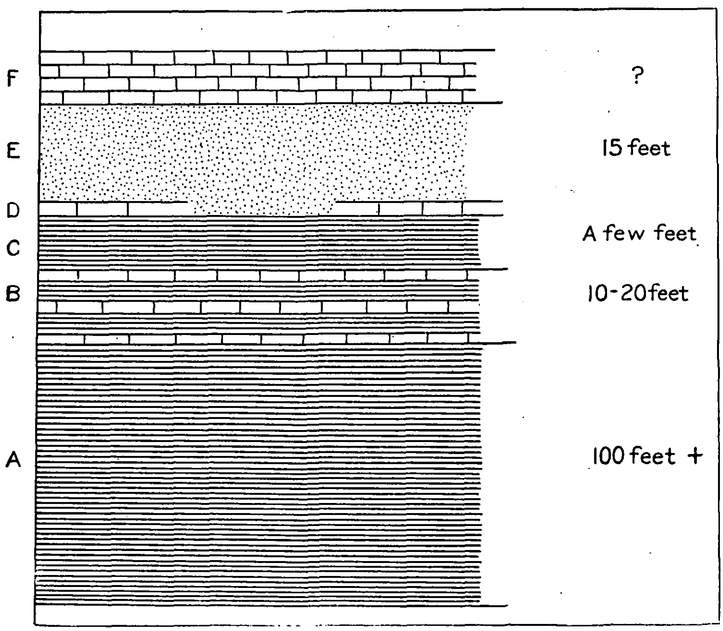

FIG. 14.—Columnar section by Foerste, showing the Lower Cambrian series exposed at Troy. A, red and green shale, in places with small quartzite beds. B, light-blue dolomitic limestone intercalated as fine layers and sometimes forming "brecciation pebbles" in the shale. C, shale with or without limestone beds. D and E, quartz sandstone more or less calcareous, sometimes replaced by sandy shale. F, light-blue dolomitic limestone.

also gives the following section, fig. 14, as representing the Cambrian series of that vicinity.

If the Cambrian beds be followed northward, a different series is found. From Oakwood Cemetery to the vicinity of Melrose the olive grit, already referred to under "Petrography," crops out occasionally between the Ordovician shale and the Lower Cambrian sandstone, giving a cross section approximately like that shown in fig. 15. This olive grit occurs also at Raymertown associated with the same sandstone. Its exposures near Lake Ida at Troy would bring it, by over-

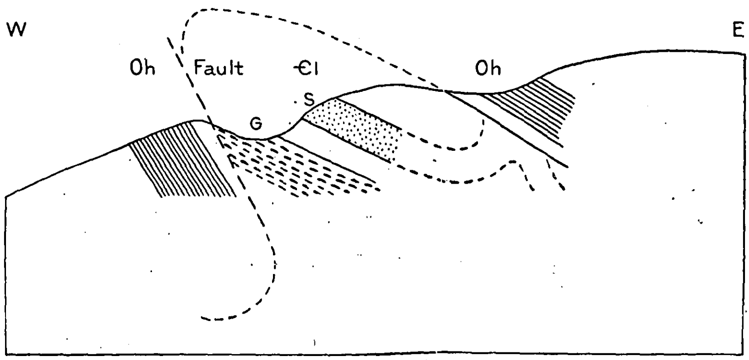

FIG. 15.—Diagram section near Speigletown in Lansingburg, showing the general relations of the olive grit (G) to the Lower Cambrian sandstone (€l) and the Hudson shale (Oh).

turned folding, under the red and green shale with annelid trails and *Oldhamia*, which in turn underlies the fossiliferous Cambrian limestone.

The following section, fig. 16, embodies the writer's observations at and below the dam in the Poesten Kill at Troy. Here reddish, purplish,

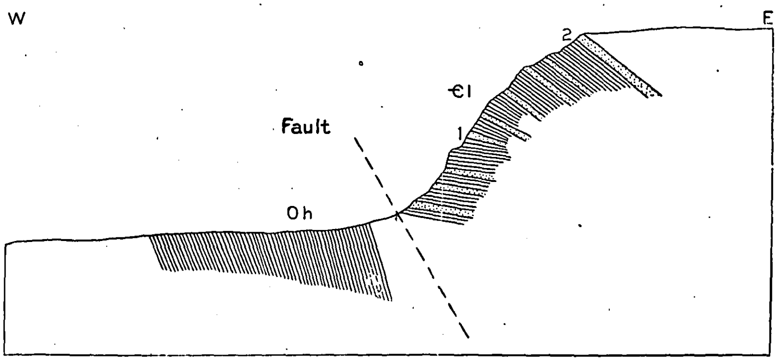

FIG. 16.—Diagram section across the dam in the Poesten Kill at Troy, showing the relation of the Hudson shale (Oh) to the Lower Cambrian red, purple, and green shale (1) and the relation of these to the sandstone bed with Hyolithes and Hyolithellus (2). Height, 100 feet.

and greenish shale underlies a sandstone bed carrying the *Olenellus* fauna, as determined by Mr. Walcott. This colored shale with trails closely resembles that occurring about 2 miles northeast of this locality, which carries *Oldhamia*.

To these sections should be added one at the well-known locality 2 miles south of Schodack Landing, i. e., 7 miles west-southwest from

North Chatham, described by Ford (see paper No. 4, p. 10), as it throws much light on the thickness and order of the Lower Cambrian beds. (See fig. 17.) The section combines the observations at the cliffs, where the thrust plane is not exposed, with those made a third of a mile north, where, however, the beds dip more steeply, the Cambrian 50° and the Ordovician 55°. The dip of the beds in the figure is taken from the cliffs.

These sections will serve to convey a general idea of the Cambrian stratigraphy in this region. Its main features consist of a series of fossiliferous limestone beds, alternating with shale and sandstone, and carrying the *Olenellus* fauna, underlain by gray, red, or purple and green shale, as shown in figs. 11, 14, and 17. On Ashley Hill (fig. 9) this shale is underlain by a calcareous quartzite, and also near Ray-

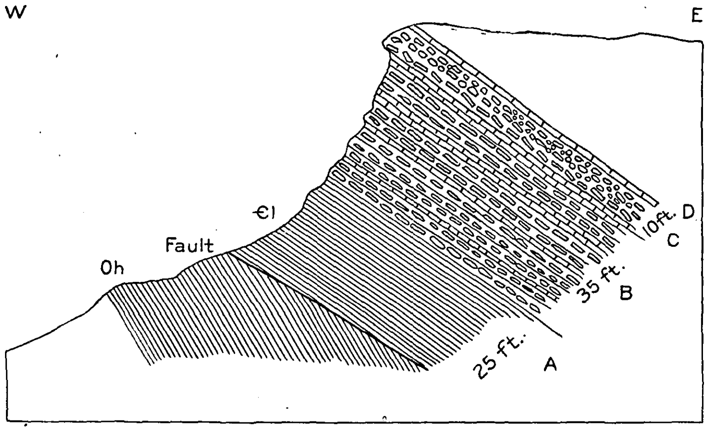

FIG. 17.—Diagram section showing the relation of the Lower Cambrian linestone (B, C, D) and shale (A) to the Hudson shale (Oh) as exposed at two localities near Schodack Landing in Rensselaer County. B, bedded limestone and nodular limestone in shale (*Olenellus* fauna). C, Conglomerate with a brecciated limestone stratum below it. The pebbles have *Olenellus* fauna. D, Coarse-grained limestone bed with *Olenellus* fauna.

ville station (fig. 10). North of Troy this shale is underlain by an olive grit with or without the intervening quartzite. On Curtis Mountain (fig. 8) the calcareous quartzite is underlain by three horizons of shale, alternating with two of quartzite. These appear again in the ridge south of Tackawasick Pond (fig. 4) and in that east of it (figs. 5 and 6). The red, purple, and green shale which underlies the fossiliferous limestone at Troy (fig. 16) probably belongs to the same horizon as that which 2 miles east of that city carries the *Oldhamia*. The red and green shale with casts and *Oldhamia*, in Nassau, is petrographically identical with that which is interbedded with the two massive quartzite beds (figs. 4, 5, 6, 7, 8, and 9).

All the data in sections 4 to 17 are combined in the following table, to which estimates of thickness, based upon measurements at various localities, have been added, as well as references to the figures.

Table showing the Lower Cambrian series as exposed in Rensselaer County and part of Columbia County, N. Y.

Serial letter.	Description of strata.	Evidence.		Estimated thickness.
		Figure.	Fauna.	
				Feet.
J	Greenish shale	12 ?		50
I	Thin-bedded limestone, or dolomitic limestone, in varying alternations with black or greenish shale and calcareous quartz sandstone. Some of the limestone beds brecciated within the sandstone or shale and forming brecciation pebbles, in places, however, beach pebbles.	9, 10, 11, 12, 13, 14, 17.	*Olenellus* fauna	[a] 20-200
H	Greenish, reddish, purplish shale, in places with small beds of more or less calcareous quartzite. At Troy, in upper part a 2½-foot bed of calcareous sandstone.	10, 11, 13, 14, 16, 17	*Oldhamia*, annelid trails. *Hyolithes* and *Hyolithellus*.	25 ?-100+
G	Granular quartzite, in places a calcareous sandstone.	8, 9, 10		10-40
F	Olive grit, metamorphic, usually weathering reddish; absent at south.	15	Traces of ?	18-50
E	Greenish, or reddish and greenish, shale with small quartzite or grit beds.	7, 8, 9	Casts of impressions, *Oldhamia*.[b]	65-535
D	Massive greenish quartzite, in places very coarse.	4, 6, 7, 8, 9		10-50
C	Reddish and greenish shale with small beds of quartzite or grit (rarely up to 5 feet thick).	4, 5, 6, 7, 8	Casts of impressions, *Oldhamia*.	30-80
B	Massive greenish quartzite, in places very coarse.	4, 5, 6, 7, 8		8-40
A	Reddish and greenish shale with small beds of quartzite or grit, from 1 to 12 and, rarely, 24 inches thick.	4, 5, 6, 7, 8	Casts of impressions, *Oldhamia*.	50-80

[a] Usually 50. [b] *Oldhamia* occurs in A, C, or E, and quite possibly in all three.

Minimum, 286. Maximum, 1,225+.

AREAL AND STRUCTURAL RELATIONS.

The greenish and reddish shale which makes up the greater part of the Cambrian area belongs to the several shale horizons A, C, E, H, I, and J. The shales of these horizons can be distinguished only where they come in contact with either the fossiliferous limestone or the two beds of massive quartzite. As some areas of Beekmantown shale may yet be found, here and there, within the Lower Cambrian area, the age designation of that area on the map should not be strictly interpreted. The finest exposures of the reddish and greenish shale with small quartzites having organic impressions (horizons A, C, E), which either carry *Oldhamia* or are likely to do so, are in the eastern half of the Cambrian area as indicated on the map. Most of the exposures of the massive quartzite of horizons B and D are in the township of Nassau.

There is a considerable area of the greenish shale with small quartzite and small limestone beds, extending from a point 2 miles northeast of Melrose, on the west, to Tomhannock and Valley Falls on the east, and north to the Washington County line and beyond, which is regarded as belonging to the Cambrian. Mr. Ruedemann's Upper Cambrian fossil locality at Schaghticoke (paper No. 20, p. 11), for reasons given on page 31, is regarded as being in an outlier of Beekmantown.

As the Middle Cambrian is absent and the Upper Cambrian essentially so, the Lower Cambrian is here unconformably related to all the formations which adjoin it as well as to the outliers which rest upon it. On the west it appears to be thrust over onto the Hudson by a fault which is clearly present near Schodack Landing on the south and at Bald Mountain, in Greenwich, on the north, but which may be inconsiderable here, and, in places, disappear altogether, being simply an unconformity and an overturned fold. The observed relations of the Lower Cambrian to the Hudson have been shown in figs. 13, 15, 16, and 17, and they will be further considered in the study of that formation. Its relations at one point to the Rensselaer grit are shown in fig. 7, and will also be further described under that heading. Its relation to the Beekmantown will be considered more fully under the next heading.

BEEKMANTOWN SHALE.

FOSSIL LOCALITIES.

Mr. Prindle found some graptolites in very small grayish arenaceous layers, interbedded with small layers of finely banded quartzite, cropping out on either side of the road running from West Sandlake to Defreestville, about a mile southwest of Lake Aries, in North Greenbush, and again in similar rock at a point about 2½ miles north-northeast of the first locality and a mile south of Wynantskill, in the same town. These were referred to Mr. Charles Schuchert, who identified them provisionally as *Graptolithus quadribrachiatus* (Hall), *G. bryonides* (Hall), *G. bifidus* (Hall), *Clonograptus flexilis* (Hall), *C.* near *salteri* (Hall), *Dictyonema murrayi* (Hall), *D.* near *irregulare* (Hall), and pronounced them "faunally much like the Quebec (Levis) graptolite zone." Mr. Prindle soon afterwards found similar rocks with similar graptolites at a point a mile southwest of Wynantskill, and again at another point 1½ miles west-southwest of that village. In 1895 the writer found some graptolites at a point 2 miles northeast of Raymertown village, in Pittstown, in small micaceous, calcareous, quartzose, finely banded, grayish beds covered with trails. These were referred to Mr. R. R. Gurley, who identified them as *Dichograpsus* sp., *Dichograpsus?*, and *Tetrograpsus* or *Dichograpsus*, and called the horizon Calciferous, i. e., Beekmantown.

Mr. Ruedemann's new graptolite localities in the Deep Kill, east of Grant Hollow, in Schaghticoke (paper No. 19, p. 11), appear to be in one or two masses of Beekmantown shale separated from the Hudson shale on the west by an outcrop of Cambrian breccia, noted by the writer in 1899. Typical Cambrian rocks occur also one-fourth of a mile southwest and three-tenths of a mile northeast. The fauna of his eastern outcrop, which measures 40 feet from east to west and is separated from the western one by 825 feet of drift, he regards as Beekmantown or Chazy, and in any case as more recent than that of the other. This eastern outcrop may be continuous with—i. e., its beds may pass under—the Hudson outlier to which Rice Mountain belongs.

In some shale at Schaghticoke Mr. Ruedemann found *Dictyonema flabelliforme* (Eichwald) and *Clonograptus proximatus* (Matthew), which he regards as Upper Cambrian (see paper No. 20 on page 11), but on page 936 he observes:

> It is evident that there was no difference or break whatever in physical conditions from the time of the deposition of these Cambrian beds to that of the lower Siluric beds.

As these forms are not quite conclusively or exclusively Upper Cambrian, and as the genera *Clonograptus* and *Dictyonema* occur mingled with Beekmantown graptolites a mile southwest of Wynantskill, as shown on page 30, this fauna is regarded as essentially Beekmantown, with possibly a few surviving Upper Cambrian forms. This locality is, therefore, shown on the map as occurring in a small area of Beekmantown shale resting upon the Lower Cambrian. It should be added that the surfaces of the fossiliferous Beekmantown beds in North Greenbush are marked by coarse branching casts of organic origin.

All these localities are shown on the map.

PETROGRAPHY.

The finely banded quartzite beds which mark this horizon, when examined microscopically, prove to consist of angular grains of quartz, with rare fragments of plagioclase and occasional scales of muscovite. The banding is due to fine stringers of sericite stained with limonite and containing here and there what appear to be carbonaceous particles. These undulating stringers of sericite are from 0.12 to 0.62 mm. apart. In places the beds are very calcareous. The associated grayish and greenish shale was not examined microscopically. Outwardly it resembles the Cambrian shale of the same colors.

STRATIGRAPHY AND AREAL AND STRUCTURAL RELATIONS.

Several areas of Beekmantown shale are shown on the map. That on the south side of Mount Rafinesque, in Brunswick, and three of those in North Greenbush, were identified only petrographically. More minute exploration may bring others to light. From the relative position of the areas in North Greenbush to the Cambrian fossil localities, the outlier of Hudson shale with Normans Kill graptolites is probably surrounded and underlain by Beekmantown shale, and that by the Lower Cambrian. Its structure would be a complex syncline. Near Wynantskill, however, the Beekmantown seems to occur in a narrow fold. In Pittstown the areal relations indicate a westwardly overturned anticline of Beekmantown from which the Hudson has been eroded. Whether the Beekmantown always intervenes here between the Lower Cambrian and the Hudson is uncertain. The map indicates the formation only where it has been identified.

The exposures of Beekmantown shale are not sufficiently satisfactory to be represented in sections. At the first-mentioned locality, which is about 200 feet west of the tollgate, the greenish-gray shale, with small beds of finely banded quartzite, measures about 100 feet across the strike, followed on the west by 93 feet of similar shale not banded, which may be Cambrian. The whole series is in minor folds more or less overturned to the west. The fossils were found 25 feet east of the boundary between the two varieties of quartzite. The situation of the outcrop west of the tollgate in relation to the Normans Kill graptolite locality north of the road, and of this to another outcrop of Beekmantown east of it, indicates a synclinal structure here for the Beekmantown, with the Hudson shale overlying. At the second locality (south of Wynantskill) the outcrop is about 80 feet wide from east to west; the beds strike N. 25° E. and are in minor folds. Limestone, probably Cambrian, occurs in close proximity. At the locality a mile southwest of Wynantskill from 30 to 40 feet of this shale and quartzite overlie the fossiliferous Cambrian limestone.

At the locality northeast of Raymertown, in ascending the brook from the road on the west, the following series is crossed: Green shale with small quartzite beds, underlying light-green, red, and purplish shale, striking N. 30° E. and dipping 45° E. These colored beds are covered with trails, etc. Farther up comes red shale with small calcareous quartzite beds. In a gulley a few hundred feet north of the creek is an outcrop of typical Hudson grit. Farther up the main creek is the gray shale with small calcareous quartzite beds containing Beekmantown graptolites. About a half mile north, in the direction of the strike, is the black Hudson shale with graptolites, and 40 feet west of this is the red and green Hudson shale which was crossed at the beginning of the section.

In all of these localities the close proximity of the Beekmantown beds to both the Lower Cambrian and the Hudson beds is noticeable. This signifies: (1) An unconformity between the Lower Cambrian and the Beekmantown by the absence of the Middle Cambrian and, as far as present evidence goes, of the Upper Cambrian also. (2) An unconformity between the Beekmantown and the Trenton, the Chazy being absent, if not the base of the Trenton also. Mr. Ruedemann is not quite sure of the Chazy age of the Deep Kill fossils (his zone C), but is sure of the Chazy age of the fossils in certain limestone pebbles in the conglomerate of Rysedorph Hill (see pp. 89, 107, of paper No. 16, p. 11), and Chazy limestone beds have not yet been found in this tract.

The thickness of the Beekmantown shale at the localities described in this paper is roughly estimated at about 50 feet. As there is a possibility that some of the green shale without banded quartzites and without fossils belongs to this formation, this estimate should be taken as a minimum. Mr. Ruedemann estimates it as high as 200 or 300 feet on the Deep Kill (p. 550 of paper No. 19, p. 11).

HUDSON SHALE AND HUDSON SCHIST.

As the schist of the Taconic Range is the metamorphic equivalent of the shale and grit of the valley, they will all be here treated as one formation.

FOSSIL LOCALITIES.

Twenty-five fossil localities are shown in the Hudson areas. The fossils collected at the locality one-half mile southwest of Lake Aries, in North Greenbush, were identified by Mr. Charles Schuchert as *Diplograptus* cf. *angustifolius*. From a point a mile north-northeast of that he identified *Didymograptus sagittarius*, *Lasiograptus mucronatus*, as well as *Diplograptus* cf. *angustifolius*. Graptolites also occur a half mile west of this last place. From a place on the north bank of the Hoosic, a mile west of Schaghticoke, he identified *Climacograptus bicornis*, and from the locality near the paper mill on the Moordener Kill, three-fourths of a mile north-northeast of Castleton, in Schodack, the following: *Didymograptus sagittarius*, *Diplograptus* cf. *angustifolius*, *Lasiograptus mucronatus*, *Dicellograptus sextans*, *Dicranograptus ramosus*, *Climacograptus bicornis*, and *C. parvus*.[a]

Graptolites were also found at the five localities indicated in Pittstown and two in Schaghticoke, near Melrose. They were found in 1890 by Foerste south of and in the railroad cut between 1 and 2 miles north of Chatham. (See Pl. XCVII of paper No. 9, p. 11.)

In the Boston and Maine Railroad cut near the Deep Kill, a mile southwest of Melrose, in Schaghticoke, a very thin calcareous bed in the Hudson shale carries brachiopods, crinoids, and polyzoa.

There are also important conglomerates in these shales. The Rysedorph Hill locality in East Greenbush has been exhaustively described by Mr. Ruedemann. (See paper No. 16, p. 11.) Mr. Prindle, when visiting this locality in 1893, noted that the pebbles of the conglomerate

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[a] Ruedemann gives from this locality: *Diplograptus foliaceus*, *D. angustifolius*, *Climacograptus bicornis*, *Lasiograptus mucronatus*, and *Corynoides calicularis*. (See p. 544 of paper No. 15, p. 11.)

were a blue limestone, that the cement on exposed surfaces was yellowish, and that both pebbles and cement were fossiliferous. On Van Denburg Hill, in Schodack, about 5½ miles south-southwest of Rysedorph Hill, is a limestone breccia (and conglomerate ?) containing Ordovician brachiopods and crinoids.

On the Moordener Kill, 200 feet upstream from the graptolite locality already mentioned, Mr. Prindle noted 1-foot blocks and small fragments of limestone conglomerate in a dark-gray fossiliferous shale. The pebbles of this conglomerate, as well as its cement, contained Ordovician brachiopods and crinoids. Two hundred feet farther upstream a similar bed of conglomerate was found, producing a waterfall 10 feet high. He was unable to determine whether this was a lenticular mass within the shale or the core of an anticline. Here a vertical cliff of shale 200 feet high, containing similar pieces of fossiliferous conglomerate, forms the right bank of the stream. About 200 feet farther upstream, and 50 feet below the upper falls, is a third bed of conglomerate, 12 feet thick, also carrying brachiopods. Between this point and the falls is a fourth bed, separated from the last by about 25 feet of shale. About 500 feet beyond the upper falls Mr. Prindle found a fifth mass of conglomerate, 50 feet thick, in the shale. This, like the others, contains pebbles of bluish fossiliferous limestone in a brownish cement. It afforded, however, no clue to its structure. Mr. Ruedemann describes two of these conglomerates and gives a list of fossils showing both pebbles and cement to be of Trenton age.[a] It was not determined whether these conglomerates were distinct beds or repetitions of one or more beds. A half mile northeast of Schodack depot, on the same kill, the Hudson grit and shale contain thin beds, with crinoids and polyzoa.

Passing now to the Ordovician on the east side of the Cambrian belt, there are several fossiliferous limestone localities, one at the foot of the Rensselaer Plateau in Nassau, a half mile northeast of Tackawasick Pond, the structural relations of which are shown in fig. 7 (p. 21). This locality was first described on pp. 311, 312, and the map Pl. XCVII, of paper No. 9, p. 11. The fossils found here by Foerste were Trenton: "*Monticulopora*, *Murchisonia*, *Calymene*, an orthis of *O. plicatella* type, and crinoid stems." This limestone contains a bed of gray shale, and this shale recurs at the south. Both are, therefore, regarded as Trenton.

Another locality is in Chatham, about midway between Sutherland Pond and the Chatham and Lebanon Valley Railroad. This appears to be about a mile east of one of Bishop's localities and is probably connected with it. (See p. 440 of paper No. 5, p. 10). The limestone is interbedded with greenish rusty shale and dolomite. A poorly pre-

[a] See pp. 544–546 of paper No. 15, p. 11.

served gastropod and a loosely laminated *Stromatocerium*, as determined by Mr. E. O. Ulrich, were found here. A wall by the road here is made of fossiliferous limestone. Adjacent to this locality on the east and south is grayish-greenish shale. This limestone seems to recur a half mile south of Old Chatham, in a hillock known as Tonys Nose, there also associated with dolomite. At the top, limestone fragments, apparently from an outcropping grayish-greenish shale, contain traces of fossils. Between these two localities is a ridge composed of two thick beds of quartzite, alternating with red and green shale with small quartzites, typical of horizons B, C, D, E, of the Lower Cambrian series.

The last locality is one of Bishop's, 1½ miles north of Chatham, where Foerste obtained *Leptaena sericea*, a *Murchisonia*, a *Pleurotomaria*, etc. (See p. 315 and Pl. XCVII of paper No. 9, p. 11.) Bishop mentions from here, and from a point a mile south, besides the above, *Strophomena alternata*, a doubtful *Maclurea*, an *Ophileta*, an undeterminable *Orthoceras*, and the polyzoon, *Ptilodycta*. The Hudson grit, a half mile west of Schaghticoke, on the south bank of the Hoosic, and again a half mile south of Schodack depot, on the railroad, has organic impressions preserved as casts, somewhat similar to those occurring in the quartzite beds of the Lower Cambrian series.

PETROGRAPHY.

The unaltered part of the Hudson formation consists of black, gray, greenish, and reddish shale, with interbedded grit; black, white-weathering, cherty-looking beds; limestone, and limestone conglomerate; and in places small beds of quartzite.

The most typical and significant of these rocks is the grit. This is a loose aggregate of angular grains of quartz, plagioclase feldspar, scales of muscovite, and graphite, together with particles of several clastic rocks, all held together by a carbonaceous, calcareous, and rarely sericitic cement. As the writer has already published microscopical descriptions of this rock, based upon a number of thin sections,[a] it will be sufficient, in order to convey an idea of its general character, to add a microscopical drawing (Pl. II, *D*) and also to call attention again to the significant occurrence in it of grains of clastic rocks. A description of a thin section of this grit from a point 100 feet below the dam in the Poesten Kill, at Troy, is here repeated from paper No. 13, p. 11. The rock contains grains of quartzite, limestone with veins of calcite, grains consisting of quartz fragments, muscovite scales without orientation, chlorite, and rutile needles (which indicate a slate in parallel section, or else a shale), a grain of micaceous quartzite, a grain of stratified carbonate rock with quartz grains—i. e.,

[a] See pp. 187, 188 of paper No. 13, p. 11.

quartzose limestone or dolomite—and a grain of slate with aggregate polarization, containing quartz grains, chlorite, and tourmaline.

At the western foot of Rice Mountain, 1¼ miles south-southwest from Grant Hollow and about 700 feet southeast of the road corner, in the town of Schaghticoke, a small excavation has exposed Hudson grit strata, about 30 feet thick, containing a few inches of conglomerate, the pebbles of which scarcely exceed one-sixth of an inch in diameter. These pebbles prove to be mostly fine-grained dolomite, but there are also pebbles of slate, carbonaceous shale, carbonaceous sandstone, cryptocrystalline quartz, vein quartz, and plagioclase and orthoclase feldspar. The grains of clastic rock show that during the deposition of the Hudson grit certain slates, shales, limestones, dolomites, quartzites, and sandstones were above water at no very great distance. At a quarry south of the Poesten Kill, in Troy, the grit contains minute globular masses of anthracite, each surrounded by a film of chalcedony.

The cherty-looking beds referred to crop out at several points. At Grandview Hill, in East Greenbush, this rock consists of a carbonaceous matrix containing angular fragments of quartz and plagioclase and scales of muscovite. Its weathering white may be due either to the loss of carbon or to the kaolinization of a fine feldspathic cement.

In a small ravine 2 miles west-southwest of East Greenbush, south of the Boston and Albany Railroad crossing, the Hudson shale contains small irregular beds or nodules of fine-grained calcareous quartzite, in which the particles are angular and almost entirely quartz, with an occasional grain of plagioclase or zircon or a flake of muscovite.

The metamorphic part of the Hudson formation consists of the sericite-schist which constitutes the Taconic Range. This has been so often described[a] that it will be sufficient to state that it is sometimes black from the presence of graphite, or greenish from the abundance of chlorite, or purplish from the addition of hematite. In Chatham the transition from shale to schist, in passing from the west to the east, is so gradual that it is often difficult in the field to determine whether a given rock is a shale or a phyllite. In Austerlitz, a quarter of a mile south of Redrock, the schist contains a bed of slightly chloritic quartzite, 20 feet thick, with pebbles of quartz up to an eighth of an inch in diameter.

STRATIGRAPHY.

The general structure of the strip of the Hudson formation between the Hudson River and the Cambrian boundary, in at least its narrower part, is shown at a quarry between Troy and South Troy, where an acute anticlinal core, slightly overturned to the west, forms the center of a mass of shale and grit about 400 feet wide, measured across the

[a] See pp. 303–306 of paper No. 9, p. 11, and Mon. U. S. Geol. Survey, vol. 23, pp. 182–184.

strike. At the north end of the quarry the east limb of the fold dips 60° E. and the west limb 80° E., but at the south the anticline is nearly erect. The folds in the wider part, however, are not all of this character, for at an old quarry a half mile southwest of Defreestville, or 2 miles northeast of Rensselaer, a gentle anticline of grit and shale, about 100 feet in diameter, is exposed.

The order and thickness of the Hudson beds are difficult to determine. This is in consequence not only of the frequent overturned folding, as shown above, but also because of the horizontal transition of red and green shale into each other and probably of several other members of the series, the interbedding, the possible difference in age indicated by different graptolite faunas, as shown by Ruedemann (paper No. 15, p. 11), and also the unconformities shown by the limestone conglomerates (paper No. 16, p. 11).

The following table embodies such approximations as to the order and thickness of this formation as the data, obtained during these studies and from the literature, seem to warrant:

Table showing the Hudson formation as exposed in Rensselaer County and the northeastern part of Columbia County, N. Y.

Description of strata.	Fauna.	Estimated thickness.	Age.	Metamorphic equivalent.	Estimated thickness.
Black shale with arenaceous limestone, etc.[a]	Diplogr. amplexicaulis.[b]				
Black and gray shale with interbedded grit.[c]	Normans Kill graptolite fauna.				
Similar shale with limestone and limestone conglomerate.	Trenton fauna in limestone and cement of conglomerate.[d]	*Feet.* 1,200–2,500?	Trenton.	Sericite-schist, black, green, or purple, in places with greenish quartzite up to 20 feet thick.	*Feet.* 1,000–2,000
Black, siliceous, white-weathering, "cherty-looking" shale.[e]	....				
Reddish, purplish, greenish shale, with small quartzite beds.[e]	....				

[a] See Ruedemann, pp. 535–537, stations 24, 25, 26, of paper No. 15, p. 11.
[b] See as above for other fossils.
[c] Rarely with small beds of quartzite.
[d] The pebbles of this conglomerate contain Trenton, Chazy, and Lower Cambrian fossils. See paper No. 16, p. 11, and Ford, paper No. 3, p. 10.
[e] The vertical relations of the colored shale and the black siliceous shale to each other and to the black and gray shale with Normans Kill graptolite fauna are not clear. They are all intimately associated. The greenish shale sometimes includes small limestone beds.

AREAL AND STRUCTURAL RELATIONS.

The Hudson formation, as shown on the map, occurs on both sides of the Lower Cambrian belt, and it also forms two isolated areas of more or less complex synclinal structure within and upon it. Some of its structural relations are shown in figs. 7, 13, and 15–17. The Hudson beds are frequently separated from the Lower Cambrian by a few feet of Beekmantown shale. Whether this shale always intervenes in eastern New York has not yet been determined. In any case, it is here unconformably related to the underlying formations either by the absence of the Chazy and the Middle Cambrian, very probably also of the Upper Cambrian, or by the absence of these and the Beekmantown, and in both cases possibly also by the absence of the lowest Trenton. An unconformity to older sedimentary formations is indicated by the pebbles and grains of slate, limestone, dolomite, and quartzite within the grit, as shown under "Petrography," and this has also been paleontologically corroborated by the conglomerate interbedded with the grit, the pebbles of which contain Lower Cambrian and Chazy fossils.

That the relations on the west side of the Cambrian belt are not only those of unconformable deposition but of a more or less continuous overthrust is rendered somewhat probable from the situation of the overthrust near Schodack Landing (fig. 17) and of that at Bald Mountain[a] in Greenwich, 47 miles north-northeast of the former, as well as from the general direction of the Cambro-Hudson boundary between them. It is to be noted also that at the outlet of the pond in Oakwood Cemetery in Lansingburg the black cherty beds of the Hudson underlie the olive grit (horizon F) of the Lower Cambrian, from 110 to 340 feet of the Lower Cambrian being absent either through faulting or through pre-Hudson erosion.

For these reasons it is assumed that in consequence of a westwardly overturned fold, which is frequently ruptured, the Lower Cambrian here usually overlies the Hudson—i. e., the Trenton or middle part of the Ordovician. The east-west course of the Cambro-Hudson boundary east of Van Denburg Hill corresponds roughly to a change in the strike of the Hudson beds. It is uncertain whether the overthrust follows this bend or maintains its northerly course or is interrupted.

The isolated mass of Hudson shale in Brunswick, Lansingburg, and Pittstown, amply identified by graptolite localities and by the typical black and red shale, grit, and cherty-looking beds, is almost surrounded by typical Cambrian beds with several fossil localities. It has Beekmantown beds at two points, one on either side of it. The reason for drawing the boundary here different from that on Mr. Walcott's map[b] is that the shale with small beds of quartzite which crops out north of the graptolite shale has a general resemblance to the Cambrian shale, although no Lower Cambrian fossils have as yet been found north of the latitude of Tomhannock village in the area of this map. The east-northeast to west-southwest trend of Mount Rafinesque is due to change in the strike of the Hudson shale. Less than a mile

[a] See paper No. 6, p. 11; Walcott, C. D., Am. Jour. Sci., 3d ser., vol. 35, p. 317, fig. 12. The continuation of this fault was retraced in 1902 by Mr. Fred H. Moffit, then the writer's assistant, from Bald Mountain, Greenwich, in a northerly direction 10 miles into Argyle.

[b] See Pl. III of paper No. 6, p. 11.

east of Chatham Center there is an outcrop of the black cherty-looking beds and red shale of the Hudson formation striking N. 10° E., but a mile farther southeast the gray shale of the Cambrian crops out. At Malden bridge, 4 miles north-northeast of the first of these localities, the following series is exposed in the bed of the Kinderhook: Beginning on the east, 40 feet of gray shale and grit, 24 feet of black shale and limestone, followed by over 70 feet of shale, with a few calcareous beds and coarse, gritty beds. As the age of these beds is uncertain and as the area between them and the outcrops east of Chatham Center was not explored, there may be a tongue of Hudson-Trenton extending up this valley. This area has therefore been left uncolored.

The relations of the Hudson formation to the overlying Rensselaer grit of the Silurian are shown in the section, fig. 7 (p. 21), which crosses the contact of the two formations in Nassau, near Tackawasick Pond, and on the map, Pl. I (p. 12), which shows an outlier of typical Rensselaer grit and conglomerate resting upon the Hudson schist 2 miles northeast of Spencertown, in Austerlitz.

The small mass of unfossiliferous limestone southeast of Pike Pond, in Nassau, is probably of Hudson (Trenton) age also, and immediately underlies the grit of the plateau. It may be continuous with that about 3 miles south.

RENSSELAER GRIT.

PETROGRAPHY.

With the exception of faint annelid trails at one point, no fossils have as yet been found in this formation. Its petrography has been already so fully treated in print that little need be added.[a] Its petrographic characteristics, in brief, are as follows: A dark-green, tough, generally thick-bedded, often calcareous, crystalline, granular rock, with visible quartz and feldspar grains, and traversed by veins of quartz, in places of epidote and calcite. This rock alternates with beds of purplish, reddish, or greenish slate or shale. The grit itself contains microscopical grains of quartz, orthoclase, plagioclase, and microcline feldspar, biotite, garnet, tourmaline, zircon, magnetite, ilmenite, and epidote, in a cement of chlorite, muscovite, quartz, calcite, epidote, and pyrite. In some places the grit contains beds of conglomerate up to 4 feet in thickness, with pebbles of quartz, orthoclase, plagioclase, microcline, granitoid gneiss or granite (with the same feldspars), fine-grained gneiss, and rarely chloritized diabase or gabbro, together with pebbles of the following sedimentary rocks: Quartzite (white, black, or red), greenish phyllite, siliceous shale and fine grit (carbonaceous, and sometimes calcareous, with angular grains of quartz, plagioclase, microcline, and scales of muscovite), granular

[a] See pp. 306-310 and Pl. C of paper No. 9, p. 11.

and crystalline limestone, and cryptocrystalline quartz (with grains of plagioclase, muscovite scales, rutile, calcite, and quartz veins). The diameter of these pebbles does not usually exceed an inch, but the quartzite sometimes attains 2 inches, the limestone 4, and the gneiss in one case measured 12 by 8 by 3.[a] Pl. II, *E* (p. 20), shows a microscopical drawing of the typical Rensselaer grit, and illustrates particularly the difference between its cement and that of the Hudson grit.

In the outlier, which extends from East Nassau to Old Chatham, the matrix of the grit is sometimes reddish, and where greenish the rock approaches a quartzite. Although the massive Cambrian quartzites (horizons B, D) are generally greenish and sometimes pass into conglomerates, they can usually be distinguished from the Rensselaer grit by their cement being mostly quartz and their grains and pebbles entirely quartz, with the exception of an occasional one of feldspar or slate.

STRATIGRAPHY.

The total thickness of the grits on the plateau was estimated at about 1,400 feet, but it may be a little greater. The portion of the plateau described in this paper consists of minor folds with a north or north-northeast trend. Some of these folds are exposed in the gorge of the Poesten Kill, between Barberville and a point a mile east of the village of Poestenkill.[b] Several folds are also crossed on the road leading northeast from Sandlake.

The outlier south of North Nassau consists of two masses, which at the north are separated by a swampy interval. Each of these consists of a syncline followed on the east by an anticline, but the entire outlier is probably made up of three anticlines and four synclines in alternation. (See Pl. III, Sec. *C*, p. 46.) The north end of the outlier west of East Nassau is a syncline.

The Rensselaer grit south of Alps village in Nassau strikes N. 70° E. and dips 50° to 60° NW. From this point the strikes in the adjacent Cambrian gradually curve southward for over 2 miles and in the outlier south of North Nassau resume their normal direction.

AREAL AND STRUCTURAL RELATIONS.

The relations of the Rensselaer grit are peculiar. Along the greater part of its western boundary it is bounded and underlain by the Lower Cambrian, and these relations reappear in the greater part of the large outlier in Nassau and Chatham and in the smaller one near North Nassau. In places, however, as near Tackawasick Pond (fig. 7), it overlies the Hudson (Trenton shale and limestone), and the outlier in Austerlitz lies upon the Hudson schist. Such relations signify: (1) That

[a] The dimension of 23 inches given on p. 308 of paper No. 9, p. 11, was an error.
[b] See figs. 34, 35, 36, and 37 on pp. 325–327 of paper No. 9, p. 11.

the Rensselaer grit is later than a part or the whole of the Hudson formation, and (2) that it was deposited in places upon a Lower Cambrian surface upon which the Hudson beds had never been deposited or from which they had been eroded.

That similar Lower Cambrian surfaces were above water during the deposition of the grit at no great distance is shown by the presence of quartzite pebbles within the grit. One of these conglomerate beds, with pebbles of quartzite an inch in diameter, occurs within a mile northeast of Tackawasick Pond, but the evidence from the pebbles shows that the grit was also unconformable to formations containing greenish phyllite, siliceous-carbonaceous shale or grit, crystalline limestone, and cryptocrystalline quartz. These may all have come from Lower Cambrian beds, but the black siliceous grit pebbles resemble the Hudson grit as much as they do the black pebbles of the Cambrian sandstone. In common with the Cambrian quartzite and the Hudson grit, the Rensselaer grit contains quartz, feldspar, and zircon fragments from the older crystallines. Its pebbles of granite and gneiss are still more conclusive on this point, and the large granite "pebble" shows that these older crystallines were not far distant.

Finally, two contacts along the western boundary of the grit will be described in detail. One of these is a half mile north of Hoag Corners, in Nassau, about 400 feet east of the road to Alps. A large outcrop of grit, striking N. 35° W. and dipping 40° E., is underlain by red and green shale, without small quartzite beds, and probably also belonging to the Rensselaer grit formation. About 150 feet west of the shale is the typical red shale of the Cambrian, with small quartzites, striking N. 15° E. and dipping 90°. This interval of 150 feet without outcrop may be occupied either by the Trenton limestone and shale, as it is 1¾ miles south (fig. 7, p. 21), or by the Cambrian shale. (See Pl. III, Sec. *C*, p. 46.)

The other, 11 miles north-northwest of the first, is in the town of Brunswick, where the road from Eagle Mills (Millville) toward Davitt Pond crosses the geological boundary. This contact is 3 miles east-southeast of Millville, where the road bends from a south-southeast to an east-northeast course. There are large outcrops of the red and green shale with small quartzites, with trails, etc., typical of the Lower Cambrian horizons A, C, E. At the road bend this shale dips 45°-70° E., and measures over 100 feet along the road, which crosses it diagonally. In contact with it on the east is a series of alternating small beds of reddish and greenish shale and fine-grained grit or quartzite of uncertain position. On the east side of, and in contact with, this series is a bed of typical Rensselaer grit 3 feet thick, with large pebbles of quartz, etc., dipping 90°, and followed by the usual alternations of shale and grit. The following measurements of this series of small beds, intervening between the typical Rensselaer grit beds and the typical Lower Cambrian beds, were taken, and thin sections were prepared of beds marked 1 to 7, in order to determine how nearly the Rensselaer grit approaches the Lower Cambrian. The names attached to these beds are based upon these microscopical determinations.

Measured section at contact of Rensselaer grit and Lower Cambrian in Brunswick, 3 miles east-southeast of Eagle Mills.

Thin section.	Description of strata.	Thickness. Feet.	in.
	Rensselaer grit and interbedded shale or slate	Indef.	
7	Rensselaer grit, coarse, with pebbles of quartz and feldspar	4	6
6	Rensselaer grit, coarse and fine, in small beds	3	4
	Covered space, probably greenish shale	7	6
5	Rensselaer grit	2	
	Green shale with small gritty beds	8	4
	Rensselaer grit	1	
4	Red and green shale and small beds of Rensselaer grit	3	6
3	Bed of roundish quartz grains in a cement of chlorite with some secondary quartz	1	2
	Green shale with two small quartzose beds	3	4
2	Bed of angular quartz and plagioclase grains in a cement of chlorite	0	3–4
	Red and green shale	3	6
1	Rensselaer grit, thin bedded, with some shale	5	0
	Red shale with small quartzite beds, with trails, etc., typical of horizons A, C, E, of Lower Cambrian	50	0

This piece of investigation thus shows that the Rensselaer grit, the basal part of the Silurian, lies at this point immediately upon the red shale series classed as Lower Cambrian.

Finally, attention should be called to the significance of the position of the three outliers with reference to the plateau. The northern one is opposite the eastward recession of the edge of the plateau, and the western sides of both larger outliers are in about the same longitude as the most westerly part of the plateau in Poestenkill. This indicates that the southern prolongation of the plateau once extended at least that far west, while the third outlier in Austerlitz shows that the Rensselaer grit extended at least 7 miles south-southeast of the second outlier, or 12 miles south of the plateau itself. On the west side of the first road east of Tackawasick Pond, in Nassau, there appears to be still another outlier of Rensselaer grit, but it is too small to enter upon the map.

RÉSUMÉ OF THE FORMATIONS.

In the following table all the stratigraphical results from the study of the four formations are brought together and generalized. This table differs in important respects from that on pages 332, 333 of paper No. 9, p. 11, in which the Hudson shale and the Berkshire schist were unintentionally represented as not equivalent, and in which the relations of the Rensselaer grit to the Cambrian west of the plateau were not given at all.

Tabular résumé of the formations.

Period.	Formation.	Equivalent.	General description.	Thickness in feet.
Silurian.	Rensselaer grit. (In places rests unconformably on Lower Cambrian.)	Oneida and Medina.	Dark-green metamorphic grit with interbedded reddish and greenish shale or slate and conglomerate, containing pebbles of quartzite, marble, black siliceous shale, grit, phyllite, all of Lower Cambrian age, some of them possibly of Ordovician age; also pebbles of gneiss and granite of pre-Cambrian origin.	1,400
Ordovician.	Hudson shale or Hudson schist. (Unconformity. Chazy absent, and lowest Trenton?)	Trenton.	Black, gray, greenish, and reddish shale, the black with Normans Kill graptolite fauna, and like the gray, interbedded with grit; black siliceous shale, one or several beds of limestone conglomerate, the pebbles of which carry Trenton, Chazy, and Lower Cambrian fossils. The gray shale in places with limestone having fossils of Trenton age. In the corresponding metamorphic zone sericite-schist with occasional thick beds of quartzite.	1,000–2,000+
	Beekmantown (Calciferous). (Unconformity. Upper and Middle Cambrian absent.)	Part of Stockbridge limestone.	Greenish-gray shale, with small beds of finely banded quartzite, sometimes calcareous and micaceous, carrying "*Levis graptolites*" and *Dictyonema* and *Clonograptus*.	50+
Cambrian.	Lower Cambrian.	Part of Stockbridge limestone, Greenwich slate of Washington Co., N. Y., Vermont formation of Massachusetts and Vermont.	Alternating beds of limestone, black or gray shale, calcareous sandstone; the limestone often brecciated and in places a conglomerate, all with *Olenellus* fauna. The above underlain by reddish and greenish shale with *Oldhamia* and *Hyolithes*, and these in places by an olive grit or a sandstone passing into quartzite. The lowest beds exposed are reddish and greenish shale with thin quartzite beds, carrying *Oldhamia*, etc., interbedded with two beds of greenish quartzite, each 8 to 50 feet thick.	1,225+

STRUCTURAL GEOLOGY.

STRUCTURE SECTIONS.

Section *A*, Pl. III, shows the unconformable relations between the large synclinal outlier of Hudson shale and the Lower Cambrian; also that between the Silurian Rensselaer grit and the Lower Cambrian, as well as the overthrust at the west which has brought the Lower Cambrian on to the Hudson. The section involves three periods of folding, one at the close of the Lower Cambrian, another at the close of the Ordovician, and still another which metamorphosed and folded the Silurian beds. That these last two movements were not identical, i. e., that the Ordovician beds were folded before the Silurian beds, is shown by the well-known unconformable relations between the Ordovician and the Silurian at a number of points in the Hudson Valley.[a]

As the Silurian movement in New York seems to have been confined to an emergence causing a slight retreat of the shore line, and as both Silurian and Devonian beds in conformable relations are powerfully folded at Becraft Mountain, scarcely 25 miles southwest of the Rensselaer Plateau,[b] the movement which affected the Silurian grit of Rensselaer County does not date further back than the close of Devonian time, and may have occurred as late as the close of the Carboniferous.

Section *B*, Pl. III, crossing the smaller synclinal outlier of Hudson, repeats essentially the features of Section *A*. In both it is assumed that the unconformity between the Beekmantown and the Trenton represents merely an emergence followed by a period of denudation. In both sections the minor folds in the broad Cambrian area are necessarily largely hypothetical.

Section *C*, Pl. III, shows mainly the general structure of the small outlier of Silurian resting upon the Cambrian.

GENERAL STRUCTURE.

The general structural features are: The westwardly overturned folds which mark a large part of the area; the presence of an anticline of this character, the rupture of which resulted here and there in an overthrust at the west; east of this a synclinal axis running through both of the Ordovician outliers, with a complex anticline east of it. The most important inference, however, to be drawn from the sections is the presence of three periods of folding: The Lower Cambrian one, which raised some parts of the Cambrian area above water; that at the

[a] See Davis, William M., The nonconformity at Rondout, N. Y.: Am. Jour. Sci., 3d ser., vol. 26, 1883, p. 389. Van Ingen, Gilbert, and Clark, P. Edwin, Disturbed fossiliferous rocks in the vicinity of Rondout, N. Y.: Report New York State Paleontologist for 1902, 1903, p. 1176. Darton, N. H., Preliminary report on the geology of Ulster County, N. Y.: Rept. State Geologist of New York for 1893, p. 357.

[b] See Grabau, Amadeus W., Stratigraphy of Becraft Mountain, Columbia County, N. Y.: Rept. New York State Paleontologist for 1902, 1903, p. 1030.

PLATE III.

PLATE III.

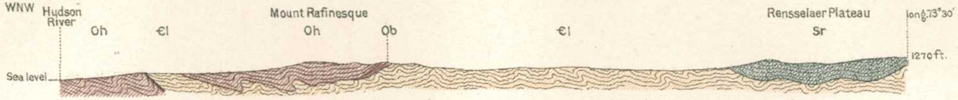
STRUCTURE SECTIONS.

A. Section from near Quackenkill, in Grafton, to the Hudson 2 miles north of Lansingburg.

B. Section from a point 2 miles east of Sandlake to the Hudson 2 miles south of South Troy.

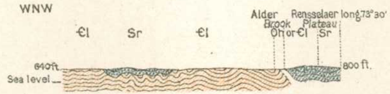
C. Section in Nassau from the western edge of the Rensselaer Plateau to a point a mile south-southeast of Burden Lake.

In these sections Єl=Lower Cambrian; Ob=Ordovician, Beekmantown; Oh=Ordovician, Hudson; Sr=Silurian, Rensselaer grit. Scale, one-half inch=1 mile.



(A)

(B)



(C)

JULIUS BIEN & CO. LITH. N.Y.

SECTIONS ALONG THE LINES A, B, AND C, PLATE I

close of the Ordovician, which not only folded the Hudson and the Beekmantown beds, but also modified and faulted the Lower Cambrian folds; and one at the close of Devonian or Carboniferous time, which folded and metamorphosed the Silurian grit, and which must also have modified both the Ordovician and the Cambrian folds. The sections also imply the existence, in places, of a Lower Cambrian land surface in Ordovician time, which became partially submerged in Silurian time.

DISCUSSION AND CONCLUSIONS.

The paleontological, petrographical, and stratigraphical observations, given in detail, and summarized in the table and the sections, speak for themselves. It remains but to discuss some of their general bearings and to draw a few brief conclusions. This will be done under separate topics.

THREE CRUSTAL MOVEMENTS.

The evidence of the crustal movement (1) at the close of the Lower Cambrian along the western side of the Taconic Range is not confined to the unconformable areal relations of the Lower Cambrian and Ordovician in Columbia, Rensselaer, and Washington counties,[a] nor to the pebbles containing Lower Cambrian fossils found by Ruedemann in conglomerates of Hudson (Trenton) age and partially confirmed by the occurrence of grains of clastic rocks in the Hudson grit, but is made conclusive by the structural unconformity of the two formations recently observed at the north end of the Taconic Range in Rutland County, Vt.[b]

The Taconic or Green Mountain movement (2), which folded the Ordovician beds at Rondout and other places in Ulster County, and also in Orange County,[c] where the Silurian beds lie on their eroded edges, also folded and faulted the Hudson shale of this part of the Hudson Valley, and folded and metamorphosed the Hudson beds of the Taconic Range.

To the post-Devonian or Carboniferous movement (3), which folded both Devonian and Silurian beds at Becraft Mountain, in Columbia County, must be assigned the folding and the metamorphism of the Silurian grit of the Rensselaer Plateau. A similar movement metamorphosed Devonian fossiliferous beds at Bernardston, Mass., on the west side of the Connecticut Valley, about 50 miles east of the west edge of the Rensselaer grit deposit;[d] and that movement may possibly

[a] For Washington County see Pl. XIII and pp. 290, 291 of paper No. 13, p. 11.

[b] See Dale, T. Nelson, The geology of the north end of the Taconic Range: Am. Jour. Sci. 4th ser., vol. 17, Mar. 1904, p. 185, and map, Pl. XI.

[c] See Ries, Heinrich, Geology of Orange County: Fifteenth Ann. Rept. State Geologist of New York, 1895, Pl. XX.

[d] See Emerson, Benjamin K., Geology of old Hampshire County, Mass., comprising Franklin, Hampshire, and Hampden counties; Chapter IX, The Bernardston series of upper Devonian rocks, and Pl. IV: Mon. U. S. Geol. Survey, vol. 29, 1898.

have extended across the Green Mountain crystalline axis and the Taconic synclinorium to the Rensselaer Plateau. Traces of a secondary crustal movement have been found here and there in the schist of the Taconic Range in the form of secondary cleavage foliations, sometimes plicated or followed by the formation of fresh sericite.[a]

THREE CONGLOMERATES.

The lowest of these occurs within the Lower Cambrian beds, and implies a temporary emergence sufficient to expose the beds to wave action and thus to form beach pebbles. The next consists of limestone pebbles within the Hudson shale. It implies a temporary emergence during Ordovician time; and the paleontological evidence obtained by Ford and Ruedemann from the pebbles shows that Lower Cambrian, Chazy, and Trenton rocks were above water during that part of Trenton time. Whether these Trenton pebbles came from a distance or from limestone beds formed in situ and then exposed to wave action, as in the case of the Lower Cambrian conglomerates, may be difficult to determine.

The third conglomerate is that of the Rensselaer grit, formed in Silurian (Upper) time. Its pebbles show that Cambrian quartzites were then above water at no very great distance; that slate, carbonaceous shale and grit, and marble, of Cambrian or Ordovician age, were likewise above water; also that detritus from coarse granites and fine gneisses was being brought into the sea near by. The distance of the plateau from the crystallines at the northwest (about 25 miles)[b] and at the east (11 miles), and the large size of one of the granite pebbles (12 by 8 by 3 inches), raise a difficulty here. Mr. G. K. Gilbert's suggestion that there may have been a pre-Cambrian mass in the center of the plateau that supplied these pebbles, which became concealed by the later beds of the grit or by drift or swamp, is valuable. Such a pre-Cambrian mass occurs at Stissing Mountain, 40 miles south-southeast of the Rensselaer Plateau and about 15 miles west of the Green Mountain crystallines. Furthermore, the presence of such a crystalline core in the plateau would help to account for the metamorphism of the grits, as the crystalline core of the Green Mountain axis accounts, in part, for the metamorphism of the Paleozoic sediments on either side of it. Such a core would furnish a buttress against which the grits have been pressed and thus metamorphosed.

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[a] See Mon. U. S. Geol. Survey, vol. 23, p. 143, Case IV; p. 151, Case VIII; also pp. 321–324 of paper No. 9, p. 11 of this bulletin; p. 564, fig. 566, of paper No. 12, p. 11 of this bulletin.

[b] See Merrill, Frederick J. H., Geological Map of New York, Exhibiting the Structure of the State as far as Known, 1901.

MINOR OSCILLATIONS.

Thus, in addition to the three main crustal movements, the Cambrian and Ordovician conglomerates indicate a minor oscillation in Lower Cambrian time and another in Trenton time. There was also an emergence at the close of Beekmantown time, for the Hudson lies in places immediately upon the Beekmantown, the Chazy being absent. The full thickness of this formation in the Lake Champlain region is estimated at 890 feet.[a] Mr. Ruedemann's doubtful determination of Chazy graptolites in a 40-foot outcrop at the Deep Kill can not suffice to substantiate the presence of a formation representing such a lapse of time as is implied in the deposition of 890 feet of limestone.

The writer in 1901 found in the town of Shoreham, in Addison County, Vt., a small anticlinal hill of Potsdam overlain by the Trenton-Utica, the Beekmantown and Chazy being absent. Such minor oscillations seem to have marked the entire Hudson-Champlain region during Paleozoic time.

ABSENT FORMATIONS.

The formation which, owing to unconformity, is not at all represented within this area, is the Middle Cambrian. The Upper Cambrian and the Chazy are also practically absent, besides possibly the lowest Trenton. Of these the Upper Cambrian, or Potsdam proper, occurs around the southern border of the Adirondack mass, 25 miles north-northwest of Troy, and the Chazy about the same distance in north-northeast and north-northwest directions, and probably also forms part of the Stockbridge limestone, 20 miles northeast and southeast of Troy. The significance of the absence of these formations is that the Lower Cambrian was here a land surface at least during Middle Cambrian time, and that the Beekmantown was also a land surface during Chazy time, and may possibly have remained so during very early Trenton time.

The absence of the Middle Cambrian fauna agrees with the structural evidence of movement, which involved the Lower Cambrian beds, in pointing to the existence of a land surface here during Middle Cambrian time. But the absence of exclusively Upper Cambrian fossils, as well as the mingling of the equivocal *Dictyonema* with Beekmantown graptolites, indicates the submergence of the Middle Cambrian land surface in Beekmantown time and the consequent immigration of Beekmantown graptolites along with the *Dictyonema* which may have survived from the Upper Cambrian. Messrs. Walcott and Schuchert, to

[a] See Brainard, Ezra, The Chazy formation in the Champlain Valley: Bull. Geol. Soc. America, vol. 2, 1891, p. 293.

whom this question has been submitted, agree in the opinion "that the data at hand are not clearly sufficient to determine whether or not the mingling of the *Dictyonema* with the Beekmantown graptolites indicates the continuance of Middle Cambrian land into the later portion of the Upper Cambrian time."

EQUIVALENT FORMATIONS.

The entire Lower Cambrian series, shown in the tables on pages 29 and 43, is regarded as the offshore but shallow-water equivalent of the Lower Cambrian conglomerate, quartzite, schist, and dolomite which border the Green Mountain pre-Cambrian axis (Vermont formation and basal part of Stockbridge limestone of Monograph XXIII). It is assumed that sediments of Lower Cambrian age forming the base of the Taconic synclinorium are continuous from Hoosac Mountain to Troy, with a possible interruption by an island of pre-Cambrian within the area of the Rensselaer Plateau, but that the character of these sediments changes with the distance from the highlands of pre-Cambrian time and with the westward decrease of metamorphism. The Lower Cambrian series is also regarded as equivalent to the Greenwich formation of Washington County, N. Y., and Rutland County, Vt., where, however, the moderate metamorphism and the regularity of the compression which attended the crustal movement at the close of the Lower Cambrian changed the shale into slate, and where also the basal part of the formation as exposed in Rensselaer County (horizons A to E of table on p. 29) does not appear to be exposed.[a]

The Beekmantown of the Hudson Valley is regarded as the equivalent of the Beekmantown part of the Stockbridge limestone. That formation represents the upper part of the Lower Cambrian, the Beekmantown, the Chazy, and the lower part of the Trenton. The Stockbridge limestone usually disappears from east to west under the Hudson schist of the Taconic Range, owing, it is now thought, to the presence of a Lower Cambrian shore line there and to the overlapping of that limestone along that shore line by the Hudson schist (Berkshire schist) during a submergence which took place in Trenton time.[b] As the fossiliferous Trenton limestone along the west edge of the plateau in Nassau is associated with shale, it probably belongs to the Hudson formation and not to the Stockbridge limestone. For these reasons the Beekmantown shale of the Hudson Valley, although equivalent to the Beekmantown part of the Stockbridge limestone, is regarded as belonging to different basins which were separated by an island (?) of Lower Cambrian.

The Rensselaer grit is regarded as the equivalent of the Oneida and

[a] See table opposite p. 178 of paper No. 13, p. 11.
[b] See op. cit. on north end of Taconic Range.

the Medina. Its estimated thickness of 1,400 feet compares fairly well with the estimates for these formations in western New York of 1,158 feet,[a] and in Pennsylvania of 1,125 feet.[b]

DENUDATIONS.

One of the marked features of the region is the repeated denudation which it has undergone. Passing by the denudation which accompanied the minor emergence that produced the Cambrian conglomerate, the first important denudation began in Lower Cambrian time and continued during Middle and Upper Cambrian. Upon the eroded Lower Cambrian surface the Beekmantown and Hudson shales were deposited. But as both the Hudson (Trenton) grit and the Rensselaer grit (Oneida-Medina) contain pebbles of Lower Cambrian age, denudation of a portion of the Cambrian surface must have gone on in Ordovician and early Silurian time. Omitting the denudation which accompanied the minor emergence implied in the Ordovician conglomerate, there is the unconformity between the Beekmantown and the Trenton, representing a time interval sufficient for the deposition of 890 feet of limestone in the Champlain region, during which much denudation must have taken place. It is uncertain, however, whether the absence of the Beekmantown shale from so large an area of Lower Cambrian is to be attributed to the denudation of Chazy time or to a later one. The next important denudation followed the Green Mountain movement and affected the Hudson shale and schist. As the Hudson shale (e. g., at Rondout and Becraft Mountain) was eroded before the deposition of the Silurian, it follows that the transition from the Ordovician to the Silurian was not simply attended by a retreat of the sea consequent upon the folding and elevation of the Ordovician beds, but that after these folded beds had been eroded there occurred a sufficient submergence to bring the sea back again over the denuded Ordovician surfaces east of the Hudson, at least as far as the eastern edge of the Rensselaer Plateau.

As the Rensselaer Plateau lies in some places upon Hudson beds and in others upon Lower Cambrian beds, it is evident that where it overlies the Lower Cambrian that surface had either been denuded of its Ordovician beds or else formed part of the Cambrian surface which had remained above water during Ordovician time and which became submerged in the Silurian transgression. It may not be possible to determine which of these two possibilities is a probability.

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[a] Prosser, Charles S., The thickness of the Devonian and Silurian rocks of central New York: Bull Geol. Soc. America, vol. 4, p. 117.

[b] Lesley, J. P., Second Geol. Survey of Pennsylvania, Final Report.

But there was also a third denudation, which began at the close of the Oneida and Medina and which eventually severed the Rensselaer Plateau from the outlying masses in Nassau, Chatham, and Austerlitz. The two outliers of Hudson, lying in the same synclinal axis, must have once been continuous. It is a question whether the denudation which removed the intervening mass of Hudson shale and thus reexposed the old Cambrian land surface was that which occurred between the Ordovician crustal movement and the Silurian transgression, or whether the post-Silurian denudation did the major part of the work. In this case, as the time interval since the post-Devonian or Carboniferous crustal movement was so much greater, it seems probable that the work was done mostly during the third period of denudation, although at the beginning of that period a certain thickness of Silurian would have to be removed before the partially eroded Ordovician surface could have again been reached.

EXTENT OF THE LOWER CAMBRIAN LAND SURFACE.

The Lower Cambrian land surface was bounded on the north and northwest by the sea which formed the Upper Cambrian (Potsdam) deposits about the Adirondack mass and on the east side of Lake Champlain, but the data require a Lower Cambrian land surface during Ordovician time not very distant from the conglomerate bed at Rysedorph Hill, nor from the Hudson grit in general. Such a surface would have to lie east of the axis of the two outliers. If the Cambrian area in Pittstown and Brunswick be followed around the northern end of the plateau it will be found to connect with one which terminates near the village of Cambridge in Washington County.[a] There appears to be a continuous Lower Cambrian surface at least from the Columbia County line to Cambridge, a distance of about 35 miles, and in width from 2 to 4 miles, which is the distance between the plateau and the Hudson outliers or masses on the west. As the northwestern part of the Rensselaer Plateau lies on the Lower Cambrian it is possible that the area west of a line running north-northwest from North Nassau under the plateau to Potter Hill, in the town of Hoosic, may have, in Ordovician time, formed part of the Cambrian land surface. In that case the width of that surface would have been 2 to 3 miles greater. But the data also require a Cambrian land surface during Silurian time on the landward side of the Rensselaer grit. As the Silurian transgression presumably came from the southwest, this Cambrian area would have to lie north of the plateau, and it would also have to be south of Cambridge. It would thus form the northern part of the area just outlined.

[a] See map, Pl. XIII, of paper No. 13, p. 11.

EXTENT OF THE BASAL SILURIAN BEDS.

The Rensselaer grit of the plateau and its three outliers must needs have been originally connected and also continuous with other Silurian deposits. The geographical relations of the Rensselaer grit to the Silurian formations west of the Hudson River are shown on the Lower Hudson, the Hudson-Mohawk, and the Central sheets of Merrill's geological map of New York.[a] It will be noticed that the northern edge of the Rensselear Plateau is in nearly the same latitude as the boundary between the Silurian (Oneida-Medina) and the Ordovician (Hudson) in Herkimer County, and that its southern part is in line with the southern continuation of the same boundary along the Kittatinny Mountain. The plateau thus lies at the apex of the angle formed by the receding shore line of Silurian and Devonian time, as indicated by the outcrops. The west-northwest and east-northeast strikes at the north end of the plateau and the east-northeast one in the Hudson shale on Mount Rafinesque are either related to the general movement which resulted in the general east-west course of the boundary between the Ordovician and the Silurian across the State of New York or else are due to transverse folding. For all these reasons it may be assumed that the grit mass now forming the plateau was near the end of the Silurian bay; but in the Taconic Range, in the northern half of Rutland County, Vt., about 57 miles north-northeast of the northern edge of the plateau, lies another mass of grit and conglomerate, also containing pebbles of Cambrian quartzite and also overlying the Hudson schist, but only about 500 feet in thickness, and covering not quite 4 square miles.[b] The bay of Silurian time may thus possibly have sent an arm up the Champlain Valley.

HISTORICAL GEOLOGY.

With the aid of these conclusions the main outlines of the geological history of this portion of the Hudson Valley may be tentatively drawn. As the presence of a core of pre-Cambrian granite and gneiss within the Rensselaer Plateau area is not yet established, geological history does not begin here until after the Cambrian transgression, and it begins with the presence of the Lower Cambrian sea, with its fauna chiefly of trilobites, brachiopods and pteropods, and a flora abounding in *Oldhamia*, if it be a plant. The sediments were alternately sandy, clayey, and calcareous-organic. The sea was shallow and there was one slight emergence of short duration during a general gradual subsidence. At the close of Lower Cambrian time a crustal movement folded these sediments, and the sea retreated northward, northwestward, and possibly in other directions. The new land surface became

[a] Op. cit. [b] See paper No. 14, p. 11.

exposed to atmospheric erosion during Middle and Upper Cambrian time. Toward the close of Upper Cambrian time, at least the western part of this Cambrian land surface became submerged and the Beekmantown graptolites, together with some surviving Upper Cambrian forms, appeared. This submergence was of relatively short duration, and an emergence took place during Chazy time which may have lasted into early Trenton time, when another submergence occurred. Another great series of sandy, clayey, and calcareous sediments was then deposited, also upon a shallow subsiding sea floor. An abundant graptolite fauna (Normans Kill) flourished, and at intervals a Trenton fauna of tetracorallia, crinoids, gastropods, polyzoa, brachiopods, trilobites, etc.[a] One or more brief emergences and submergences occurred in places during this time, resulting in the formation of conglomerates, the pebbles of which show that limestone rocks of Lower Cambrian, Chazy, and Trenton age were above water at no great distance.

At the close of Ordovician time the powerful crustal movement which formed the Taconic Range folded the Trenton and Beekmantown sediments and with them refolded and faulted the Lower Cambrian sea bottom. The metamorphism attending this movement extended to the western foot of the Taconic Range. The sea retreated southward and westward. A period of denudation set in which affected the Ordovician beds and still further eroded the Lower Cambrian areas (islands?), which had remained unsubmerged during Ordovician time. Then came the Silurian transgression, which again submerged the Ordovician areas and part of the still exposed Lower Cambian area. The Silurian sea formed a bay, the wider part of which seems to have terminated in the region of the Rensselaer Plateau. The sediments deposited at this time were alternately clayey and sandy, with occasional pebbly beds, the pebbles of which came from pre-Cambrian coarse granites and fine gneisses above water at no great distance, and also from Lower Cambrian quartzites and from slate, shale, grit, and marble of Lower Cambrian or Ordovician age. The land areas from which the Cambrian pebbles came were probably north of the plateau.

These Silurian beds may have become exposed to denudation soon after their deposition, owing to a slight emergence and the retreat of the shore line in the Silurian bay. However that may have been, at the close of Devonian or of Carboniferous time these beds were folded and somewhat metamorphosed, and this movement also affected the Ordovician sea bottom. The region has been greatly denuded since Devonian time, and this denudation was greatly facilitated by one or more uplifts and finally by glacial action. The extent of this denudation is shown by the outliers of Hudson shale and Rensselaer grit,

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[a] See p. 101 of paper No. 16, p. 11.

and still more by the isolation of the three masses of Rensselaer grit from other Silurian deposits of the same age.

This region thus shows the effects of three transgressions (Lower Cambrian, Ordovician, and Silurian), three or more minor recessions and advances of the sea (one in Lower Cambrian and one or more in Trenton), of three crustal movements (Lower Cambrian, Ordovician, and Devonian or Carboniferous), and of four periods of denudation (at close of Lower Cambrian, of Beekmantown, of Trenton, and in post-Silurian time), besides those attending the minor recessions in Lower Cambrian and Trenton time. The history of this portion of the Hudson Valley was eventful indeed.

The facts presented will also be found to have some bearing upon the geographic-paleontological theories recently set forth by Messrs. Ulrich and Schuchert. (See paper No. 18, p. 11).

ECONOMIC GEOLOGY.

The rocks of this tract have thus far proved of little economic value. The Cambrian limestone breccia, when in beds of sufficient thickness, makes a good building stone of unique appearance. The Hudson grit is used for foundations. The carbonaceous-siliceous shales of the Hudson formation, quarried near Grandview Hill, are useful for country roads, and the shales of all the formations are serviceable for application to sandy roads. The red shales of the Lower Cambrian (horizons A, C, E, of table on p. 29), quarried west of Burden Lake, and of the Silurian Rensselaer grit have been used in the manufacture of putty and paint. The coarser beds of the Rensselaer grit, with their dark-green matrix and occasional white, reddish, and bluish pebbles, become a beautiful rock when polished[a] and would answer for indoor decoration. Efforts to utilize it for outdoor purposes have failed because of the small percentage of lime in the matrix, the surface of which, under continued exposure, thus acquires a spongy texture.

But the chief economic value of these formations lies in their relation to agriculture. The greenish shale of the Lower Cambrian (horizons C, E, H), which covers so many square miles of the valley, owing to its numerous planes of bedding, cleavage, and jointing, and to the action of rain, changes of temperature, and frost, breaks up into roughly quadrangular, stick-like fragments which gradually pass into a clayey subsoil and soil. Upon this, rye, which is one of the chief products of Rensselaer County, and is cultivated as much for its straw as for its grain, thrives. Specimens of soil and subsoil of this origin, from typical rye lands in this county, were submitted in 1894 to Prof. Milton Whitney, of the United States Department of Agriculture, for mechanical analysis. The results of the analyses are as follows:

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[a] See Pl. C of paper No. 9, p. 11, for a colored lithograph of polished specimens.

Mechanical analysis of soils from Rensselaer County, N. Y.

	1721, soil.	1722, subsoil.
	Per cent.	*Per cent.*
Moisture in air-dry sample	2.48	2.02
Organic matter	8.17	6.42
Gravel (1-2 mm.)	7.03	7.71
Coarse sand (0.5-1 mm.)	4.66	4.33
Medium sand (0.25-0.5 mm.)	4.64	3.74
Fine sand (0.1-0.25 mm.)	3.93	3.59
Very fine sand (0.05-0.1 mm.)	19.47	19.00
Silt (0.01-0.05 mm.)	35.37	34.17
Fine silt (0.005-0.01 mm.)	6.51	8.21
Clay (0.0001-0.005 mm.)	8.58	10.60
Material larger than 2 mm	38.00	22.00
"Fine earth"	62.00	78.00
	100.00	100.00

Professor Whitney, in a letter to the writer, offered the following remark on these analyses:

I think it is not hard to point out the reason why this soil is considered poor and why it is not adapted to wheat and grass. If the soil were composed wholly of the fine earth and had none of the coarse material of the undecomposed shale, the soil itself would contain, according to our analysis, 8.53 per cent of clay and the subsoil 10.60 per cent. This would be much less than is necessary for a good wheat land, except in cases where there is a large amount (45 per cent or over) of silt. The samples would be considered too light in texture for wheat or grass and not sufficiently retentive of moisture. These have, however, about the same texture as good fruit land with us, especially adapted for peaches. When we consider, however, that this fine earth represents only about 62 per cent of the soil and 78 per cent of the subsoil, while the remaining 38 per cent in one case and 22 per cent in the other is coarse, inert material, it will be seen that the actual amount of clay in the soil is very much less than would be indicated by the mechanical analyses of the fine earth. Instead of there being 10 per cent of clay in the subsoil there would be very much less than this, and too little, I should say, to give the proper supply of water to the staple agricultural crops.

As a matter of observation, rye seems to have such an affinity for this Cambrian shale that the stalks will grow almost on a bare ledge of it. Under the microscope this shale is seen to consist largely of potash mica (see Pl. II, *B*), and as the ash of the grain contains 32.10 per cent and that of the straw 22.56 per cent of potash[a] there may be a slight chemical relationship between the supply of potash by the soil and its requirement by the plant, which, added to the permeability and other physical properties of the soil, makes it peculiarly favorable for the cultivation of rye.

The region also affords an illustration of the effect of the uneconomic use of geological and topographical conditions—i. e., of unwise defor-

[a] Strassburger, Noll, Schenck, and Schimper, Lehrbuch der Botanik, 2d ed., Jena, 1895, p. 147.

estation.[a] The Rensselaer Plateau is the natural source of water supply for towns along the east shore of the Hudson for a stretch of 20 miles, but it was deforested over a half century ago, with the effect of diminishing the quantity and lowering the quality of the supply.

SUBJECTS FOR FURTHER INVESTIGATION.

These geological studies indicate the directions in which further investigations are needed. These are:

(1) Very minute exploration of the Rensselaer Plateau area for a pre-Cambrian mass.

(2) The determination of the structure of the bed or beds of limestone conglomerate in the Moordener Kill, in order to ascertain whether there was more than one emergence in Hudson time.

(3) A careful search for Beekmantown graptolites in the areas mapped as Lower Cambrian, with a view to determining the exact areal extent and the thickness of the Beekmantown formation.

(4) Further search for fossils in the belt of shale with small quartzite beds which lies between Schaghticoke and Valley Falls and extends north to the Washington County line.

(5) Search for favorable points for the measurement of the Lower Cambrian shale horizons A, C, E, H, with a view to making a more nearly correct measurement of the thickness of the Lower Cambrian exposed.

(6) The extension of the areal and structural work, thus begun, into Columbia County to that point where the Ordovician areas on each side of the Cambrian meet, and also northward into Washington County.

[a] See p. 299 of paper No. 9, and a quotation from Spafford in paper No. 21, in list on p. 11 of this bulletin.

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