New York State Museum Bulletin

Published by The University of the State of New York

No. 331 ALBANY, N. Y. December 1942

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CHARLES C. ADAMS, *Director*

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PART I CAMBRIAN AND ORDOVICIAN GEOLOGY OF THE CATSKILL QUADRANGLE

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GLACIAL GEOLOGY

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M360r-Je 41-2000

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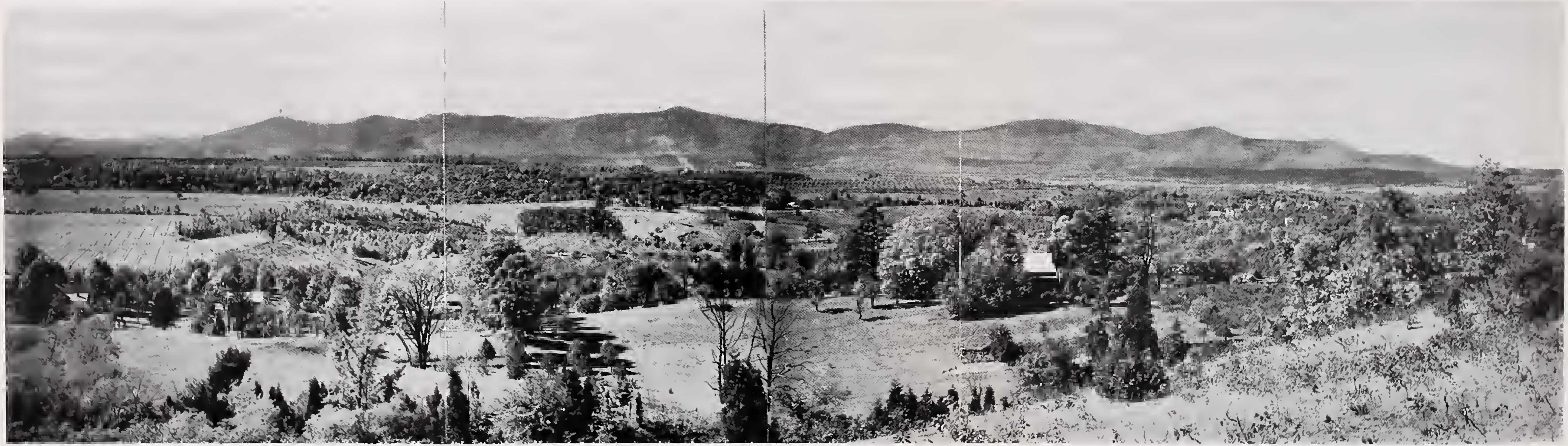

Figure 1 View across the Hudson River plain looking west from Plass hill south of Church hill. One sees in front the broad river plain (Albany peneplain), the stream bed being hidden except in the right corner. On the other side of the river plain the Helderberg plateau with the level surface of the Tertiary peneplain is seen. Above it rise the Catskills. In the river plain are wooded strips, marking rock ledges or creeks and orchards, often located on drumlins. (E. J. Stein photo)

Part I CAMBRIAN AND ORDOVICIAN GEOLOGY OF THE CATSKILL QUADRANGLE

By Rudolf Ruedemann

PREFACE

The mapping of the Cambrian and Ordovician formations of the eastern portion of the Catskill quadrangle, also of the Silurian and Devonian formation in the Becraft Mountain outlier, was undertaken at the request of Dr G. H. Chadwick who has mapped the western Devonian belt of the quadrangle, as well as the adjoining entirely Devonian Kaaterskill quadrangle. The work was also undertaken in the hope that problems that had remained undecided in the Saratoga-Schuylerville and Capital District bulletins would be cleared up by a study of the region to the south, especially as Dr Winifred Goldring had taken up the mapping of the Coxsackie quadrangle, directly between the Albany and Catskill quadrangles. It was hoped that T. Y. Wilson could at the same time map the Kinderhook quadrangle, thus completing the group of quadrangles directly south of the Capital District.

The writer has had in the mapping and study of the formations the frequent assistance of Dr Winifred Goldring and T. Y. Wilson to whom he is greatly indebted for their interest in the problems encountered. To E. J. Stein, Dr Winifred Goldring, J. W. Graham and the New York Central Railroad Company, the writer also wishes to make acknowledgment for most of the photographs.

To Dr Homer D. House, state botanist, and Dr Rogers McVaugh of the U. S. Department of Agriculture, Washington, D. C., who for several years has been studying the plant ecology of the Hudson valley the writer is under obligation for information freely given on the flora of the region. Doctor McVaugh has been kind enough to write the chapter here incorporated in the physiography. Walter J. Schoonmaker has contributed data on the fauna.

PHYSIOGRAPHY

The Catskill quadrangle extends north from 42° latitude to 42° 15′ and west from 73° 45′ western longitude to 74°. On the whole it is a sector from the Hudson River valley just east of the Catskill mountains which here rise in a 2000-foot wall to heights of more than 4000 feet not more than ten miles from the river bank. Below this great mountain massif extends the Helderberg plateau which rises from the river plain 300 to 400 feet in a steep escarpment that extends from north-northeast to south-southwest near the western margin of the quadrangle at a distance varying from one-half to two miles from the river bank. The river, here an estuary that extends above Albany to Troy, is about three-quarters of a mile wide. The river bed is entrenched about 100 feet on either side in rock cliffs and clay beds and lies in the river plain proper which extends westward with an average height of 200 feet to the foot of the Helderberg escarpment and eastward with the same average height about seven miles to the foot of a plateau that is seen in the southeast corner of the quadrangle, its edge extending southwest from Pine Hill (see Copake sheet) near Livingston through Elizaville and the Spring lakes. This plateau that, as we shall see, is largely caused by slight metamorphism resulting in greater hardness of the rocks, as well as overthrusting, and that we will therefore call the phyllite plateau, rises along the edge 300 feet above the river plain to 500 feet and gradually farther eastward beyond the quadrangle (on the Copake quadrangle) to 1000 feet.

This plateau which also strikes northeast and which is nine to ten miles wide is rather abruptly followed by a broad depression, the so-called Harlem valley through which the Harlem branch of the New York Central Railroad passes. It is three to four miles wide and averages 600 feet in height, above sea level. Beyond this rises abruptly the Taconic Mountain range in peaks above 2000 feet such as Alexander mountain (2243 feet) on the Copake quadrangle. This mountain range forms the New York-Massachusetts boundary.

The Silurian-Devonian rock series of the Helderberg plateau reached once across the river east to an unknown distance, but undoubtedly far beyond the Catskill quadrangle. An outlier known as Becraft hills in the northeastern corner of the quadrangle shows the former presence of these rocks on the east side of the river.

There are thus recognizable a series of levels, one the Hudson River lowland, 100-200 feet high, and ten miles wide, beyond this on the west side the more or less reduced Helderberg plateau rising from 400 feet above the Hudson River plain or lowland at the escarpment to 700 feet at the foot of the 2000-foot wall of the Catskill escarpment (see figure 1). In the east the Hudson River lowland extends farther to about seven miles from the river, bearing on its back in the Becraft outlier, a remnant of the old Helderberg plateau. A third level, recognizable only in the east is that of the phyllite plateau, rising from 750 feet to 1000 feet and beyond the Harlem valley and the Taconic mountains (see figure 8).

It is readily recognized that these plains and plateaus are differential erosion features. This is obvious from the fact that the plain is cut across folded and faulted rocks and that hills of harder rocks, so-called monadnocks, rise above these plains indicating former erosion levels. The Becraft Mountain outlier was mentioned already. It is a relict mountain. Distinct monadnocks are Mt Merino and Church hill south of Hudson, Blue hill south of Greendale and Mt Tom southwest of Blue hill. They rise abruptly 300 to 350 feet above the river plain (see figures 2 and 3). Mt Merino and Blue hill are due to upfolded masses of hard Ordovician Normanskill chert, Church hill and Mt Tom to hard folded beds of Lower Cambrian Nassau quartzite and Schodack limestone.

The phyllite plateau is also a differential erosion plain. It mainly projects through the greater hardness of the slightly metamorphosed Nassau, Schodack and Normanskill beds. The Harlem valley on the other hand has been sunk into the folded mountain masses by the presence of a belt of pure Cambro-Ordovician limestone (Stockbridge limestone) that is more easily dissolved and eroded than the phyllites adjoining in the west and the hard schists that form the Taconic mountains.

It is a question how much these erosion plains partake of the nature of true peneplains. The writer has distinguished in the Capital District (1930) three peneplains, *viz.,* the Albany peneplain, an incipient peneplain of the broad inner lowland extending from the Helderbergs to the Adirondacks, the Helderberg peneplain and the Catskill peneplain and tentatively referred the Helderberg peneplain to the early Tertiary (Eocene) peneplain of the Appalachians known as the Harrisburg peneplain and the Catskill peneplain to the earlier Cretaceous peneplain known as Kittatinny peneplain. It is possible that these peneplains are much younger than has been supposed and only of middle and later Tertiary age. The Helderberg peneplain rises to 2000 feet southwest of Albany and gradually descends southward around the Catskills owing to the southwest dip of the harder Devonian limestone beds which control the weathering.

FOSSIL PENEPLAIN

A plain that appears to be a most striking fossil peneplain is developed at the base of the Silurian Manlius limestone. It is well seen around the Becraft Mountain outlier. Here north-striking belts of Lower Cambrian Nassau beds and Schodack limestone and Ordovician Normanskill chert and shale are seen to disappear successively from east to west under the Silurian-Devonian outlier and to reappear in the north from under the outlier. It is therefore obvious that here Silurian beds were spread over an even surface of strongly folded beds of greatly varying ages. West of the Hudson river the Manlius limestone rests on Normanskill grit and shale. This pre-Manlius peneplain stands at Becraft mountain at 200 feet above sea level and it holds the same level in the long contact line from Catskill to the south margin of the quadrangle. It is therefore probable that this contact plain of the Cambro-Ordovician and late Silurian was originally a wide uniform plain of erosion approaching a peneplain.

There is, however, also evidence of marine erosion by the invading Manlius sea. A good exposure is that figured by Schuchert and Longwell ('32, p. 319; see also our figure 4) in the Jonesburgh quarries at the northwest side of Becraft mountain. Here Manlius rests with an angular unconformity in broad folds on much crumpled Normanskill shale. At the top of the Ordovician appear small valleys which are filled with slightly conglomeratic sandstone, indicating a somewhat irregular surface that was leveled by detritus (Rondout) before the deposition of the Manlius limestone. At the north end of Becraft mountain (see figure 48) an irregular two-foot sandstone bed separates the Manlius limestone from the underlying Schodack beds. At other places, as notably west of the river the contact is a sharp line of unconformity. It therefore seems that the advancing sea filled on one hand depressions with sand and on the other leveled the possibly hummocky surface to a large degree. This is especially suggested by the monadnocks (Mt Merino, Blue hill, Church hill, Mt Tom) which rise as much as 350 feet above the pre-Manlius erosion plain and appear by their bounding cliffs, seen especially well on the east side of Mt Merino, and steep slopes as much like early rocky islands as monadnocks of an erosion plain. It is obvious that they were there before Appalachian folding affected the Silurian and Devonian limestones and that they are not due to that orogenic agent.

Figure 2 Blue hill, a Normanskill chert monadnock seen from southeast. (E. J. Stein photo, 1935)

Figure 3 Mt Merino, a Normanskill chert monadnock, seen across the Hudson river from northwest. (W. Goldring photo, 1936)

While we thus see that the general setting of the topography of the region and, especially, the carving out of the different levels or erosion plains is controlled by the relative hardness of the rock formations, it is also readily recognized in a study of the topography and geology of the area that two other geomorphologic factors have largely contributed to the minor features of the topography. These are the folding, faulting and the resultant strike of the rocks and the action of the continental glacier.

OROGENIC FACTORS OF TOPOGRAPHY

The tectonic features of the country rock will be dealt with in another chapter. It may suffice here to state that the north to northeast strike of the Cambrian and Ordovician rocks is the controlling agent of many of the higher hills, as notably Mt Merino, and of an endless number of smaller ledges and ridges of Cambrian Nassau quartzite, Schodack limestone and Ordovician Normanskill chert and grit which partake of the nature of "hogbacks." As a glance at the map will show, these harder rocks appear everywhere above the glacial deposits where many of them are spaced out from the glacial cover by the overprint. Some are also distinctly influenced by overthrust planes as notably the long curving ridge extending south from Mt Merino through Church hill to Mt Tom.

On account of the infertility of the rocky ledges, these hills are usually wooded or bear pastures in contrast to the drumlins and eskers which are covered by orchards or vineyards.

While the smaller ledges, of which there are too many to be shown on the map, and the drumlins regularly strike from north to south, the larger hills, or monadnocks as Mt Merino, Blue hill and also Becraft mountain show a distinct north-northeast strike. It is apparent that the smaller rock outcrops were controlled in their outlines by the ice moving down the valley bottom, while the larger hills and mountains follow the strike of the hard rocks that preserved them as monadnocks.

While the multitude of north-south striking ledges of rock, mostly Normanskill grit or Normanskill chert but often also Nassau quartzite or Schodack limestone, form the wooded hills, the intervening broader fertile valleys are usually underlain by the softer shales of these formations, which were first removed in part by the advancing ice and afterward the depression filled in again with drift or alluvium. The landscape is therefore characteristically divided by wooded rocky hills, or drumlins with orchards and north-south extending valleys in which the fields and pastures are located. The roads run usually at the foot of the hills, where also the farm houses are located. Such charming and fertile farming country is especially well seen in the region extending south of North Germantown beyond Germantown to Madalin.

The left side of the river for half a mile to a mile above the steep riverbank south from Linlithgo to Barrytown and beyond is practically devoid of soil and is now a wooded region, in which the palatial homes of the wealthy New York people are located in parks overlooking the river.

The fact that in traversing the area one passes innumerable ledges of Cambrian limestone or quartzite and Normanskill grit or chert gives one the impression that these are the principal country rocks. This is, however, not the case, for the great bulk of the component rocks is shale, mostly barren, greenish gray shale, both in the Cambrian and in the Ordovician formations, which is, so to say, the matrix in which the others, especially the quartzites, limestones and grits (to a lesser degree the cherts) are carried. These great shale masses are, owing to their softness, buried out of sight in the numerous longitudinal depressions between the ridges and exposed only rarely in specially deep valleys, as for instance in the lower stretch of the Roeliff Jansen kill, where 60 feet of dark Normanskill shale without any grit are exposed. Besides the lower Roeliff Jansen valley, some other broader depressions, now filled with glacial debris are obviously also due to the erosion of underlying shales. Such an area is the broad glacial belt of good farm land extending from Cheviot past Madalin to Barrytown and coming out in North and South Bay. This shale belt is flanked on the west by the Normanskill grit belt extending above the river and is continued in Magdalen and Cruger islands, while on the east chert and grit ridges protrude, as well as drumlins that were built above rock ledges.

Also the broad valley extending south of Hudson between Mt Merino and the Becraft hills, that is now filled with morainal material and lacks all outcrops, is probably an old large preglacial valley eroded in shale.

The principal orogeny that affected these rocks was undoubtedly the pre-Silurian Taconian orogeny which in a general way followed the Precambrian grain of the continent, that is the structure of the fundamental Precambrian complex, along the east coast of North America. Its general strike is to northeast in eastern America; locally on our quadrangle it varies from north to north-northeast.

Figure 4 Unconformity at Jonesburgh quarries, west side of Becraft mountain. Valleylike depressions in crumpled Normanskill shale, filled with local Silurian (Rondout beds). View looking east. (From Schuchert and Longwell, 1932)

The Appalachian orogeny is recognizable in the folding and faulting of the Siluro-Devonian rocks of the Helderberg plateau west of the river and to a lesser degree also in Becraft mountain which forms a low syncline and has probably survived for that reason as an outlier. The influence of the Appalachian orogeny on the earlier Taconian folding is difficult to establish. It would seem that it was very superficial in this area, as otherwise the Ordovician-Silurian unconformity would be distinctly affected and not form a horizontal plane.

GLACIAL FACTORS OF TOPOGRAPHY

The glacial factors will be fully dealt with in another chapter by J. H. Cook. We shall therefore only mention here the general features.

The obvious, coarser topographic results of glacial action in this area are the erosion, the lack of original soil, the mantle of drift, the drumlins, the kettle hole lakes, the wide alluvial plains now drained by insignificant brooks and the complete alteration of the preglacial drainage as far as the minor water courses are concerned.

The *erosion* is principally recognizable in the numerous rock ledges now striking from north to south more or less with the movement of the last Wisconsin glaciation, which alone is here recognizable. They all expose the fresh rock on top because the original soil-mantle has been carried off. It is interesting to note here, however, that the *soil* has not been carried away so completely as is generally assumed. This becomes especially conspicuous above and along the ridges of Schodack limestone and ferruginous grit as in the large Cambrian inlier east of Germantown. Here the southern fingers can well be traced by the red to orange-red color of the soil on the ridges, which originates from the underlying Schodack beds, showing that the last drift was merely local to a large extent. This close relation of the deeper glacial drift with the underlying rocks, especially recognizable in the color above Schodack beds, but often also in the black shale debris above Normanskill, had already been noticed on the Saratoga-Schuylerville quadrangles (1914) and in the Capital District (1930). It is possible that it points to the very last stages of the glaciation. The drift mantle of typical moraine is conspicuous in many areas and sometimes, as along the lower Roeliff Jansen kill it reaches the great thickness of a hundred feet or more. It therefore has been most effective in filling former preglacial valleys to the general country level as in the case of that creek.

Larger glacial *boulders* are, on the whole, rare in the area, probably because much of the original drift is covered by later postglacial deposits. One large boulder of very fossiliferous New Scotland limestone, 30 feet long and 15 feet wide, was seen in a pasture, three-quarters of a mile southeast of Livingston and another large block of Nassau phyllite standing upright in the alluvial plain of Roeliff Jansen kill.

The latest stages of glaciation produced under the ice the numerous rounded longitudinal hills known as *drumlins*. They are composed of more or less unstratified material. Some are shown south of the Greendale road, west of the Precambrian inlier. Most distinct and regular drumlins arise in a row from east to west southwest of Viewmonte (see figure 8). Another double east-west row is seen east of Madalin. The northern row proved especially interesting, as the road leading east from Madalin, in being straightened and macadamized, had been cut into the north ends of these drumlins and there exposed rock cores of Normanskill grit, which obviously had furnished the starting points for the drumlins. Unfortunately the slumping of the overlying material and the building of walls for the protection of the roads have later covered these rock cores again, but the map shows the exposures by the overprint along the road. There is another group around Elizaville and a very peculiar rounded one a mile east of Blue Stores.

The opposite of the drumlins are the *kettle holes* which form a number of charming lakes in the eastern area of the quadrangle (see figures 5 and 6). These are Bell pond, at the northeastern edge of the quadrangle, the Twin ponds north of Elizaville and Warackamac lake near the southern edge. The near-by Spring lakes are bounded by rock on one side but had the same origin.

The kettle hole lakes are surrounded by glacial drift, mostly moraine, and, quite obviously, mainly due to the filling in of material around iceblocks that remained for a time when the ice finally withdrew and melted away.

A most striking feature is the wide *alluvial plains* which extend between the hill regions as notably southeast of Becraft mountain, west of Livingston, along the Roeliff Jansen kill from Blue Stores south to Elizaville and an especially large area extending north from Elmendorf along the upper reaches of Stony creek to near Viewmonte. To what extent these fertile, very flat alluvial plains are old bottoms of lakes that were left after the glaciation and have since been drained or were formed by frequent inundations from brooks or damming of brooks is a subject for the specialist.

Figure 5 Twin pond in kettle hole near Elizaville. (E. J. Stein photo, 1936)

Figure 6 Warackamac lake near Cokertown, a typical kettle hole in glacial drift. (E. J. Stein photo, 1936)

Some of these alluvial plains, as that of Stony creek, mentioned above, that are not entirely level, but are slightly graded downward, were probably gradually built up along the creeks by successions of beaver dams. The early settlers called many of these places "beaver meadows," being well aware of their origin. Most of these alluvial plains are usually considered as old late glacial lake bottoms.

It is obvious that these rich bottom lands were the earliest to be chosen by the mostly Dutch settlers that spread northward through the Hudson valley and some families became prominent in early days by their rich lands, as the Livingstons on the alluvial plains near the present village of Livingston. The richest orchard and fruit-raising district of New York extends north and south of Hudson over these alluvial bottoms and the deep morainal soil.

A most interesting group of deposits of the latest glacial stage are the *varved clays* covering the bordering lowlands of the river up to about 200 feet and forming in some localities as around North and South bays near the southern edge of the steep grit, banks reaching 140 feet above the river. They extend away from the river to various distances. These clays, which distinctly show the varved structure that is a regular alternation of lighter and darker layers deposited respectively in winter and summer, are by these varves recognized to have been deposited in quiet fresh water. They were formerly supposed to have been deposited in one extensive body of water, Lake Albany, extending on both sides of the present river from the region of Kingston to the neighborhood of Saratoga and Schenectady (Woodworth, 1905). More recently there has been brought forward (Cook, 1930) evidence that suggests that instead of one lake there was a series of bodies of water at slightly different levels along the river held in place by residual ice tongues in the river valley.

While the coarser features of the topography have resulted from the general erosion of the country that is controlled principally by the rock structure, the finer and final details of the land sculpture have been worked out, according to the studies of John H. Cook, by the stagnant ice at the end of the glacial period. This fascinating chapter of the physiography of the region will be fully dealt with in a separate chapter by Professor Cook.

DRAINAGE

The present drainage is the last conspicuous and also the most complex result of the glacial period. It is well known that the enormously thick body of moving ice with its great eroding, transporting and crushing power everywhere completely altered the preglacial drainage by filling in valleys in one place, eroding deeply in softer rocks in other places, thus creating channels for later rivers and lakes. The glacialists are still busy all over northern North America trying to trace the preglacial drainage and many a great river of today is found to be nothing but a composite of former and very different drainages. Such a river is the Ohio.

The *Hudson river* existed long before the glacial period. It is even known to have extended 90 or more miles beyond New York at the present bottom of the ocean and to have had already excavated a tremendous canyon through the Highlands and far above to the Albany district before glacial time, facts which indicate a much greater elevation and farther extension of the eastern coastal section of the continent.

The history of this fine scenic and historic river is probably very long, going back to the time when this section of the continent last emerged from the sea; that is, towards the end of the Paleozoic period. Considering the enormous amount of erosion that has been accomplished by the river in digging its bed to present sea level through the 4000 feet of sandstones and shales that now build up the mural front of the Catskill mountains and once extended across the valley to the Rensselaer grit formation, and that it sunk even way beyond present sea level in a deep canyon that has been found below the river channel, it is seen that the history of the river must be enormously old. This gorge extends hundreds of feet down (more than 500 feet in the Highlands and about 300 feet at the site of the Poughkeepsie bridge) and was formed when this part of the continent stood thousands of feet higher than now. The near-vertical rock walls of the present stream bed are therefore only the upper lips of the old gorge, which according to Cook is not very deep through the Catskill quadrangle. Where these walls are broken down as at the North and South bays and varve clay forms the riverbanks, preglacial tributaries must have reached the stream.

There is little doubt that the Hudson river carried out this erosional work in Mesozoic and Tertiary time beginning its course on top of the beds that now compose the Catskills and possibly even higher on beds of Carboniferous age that must have extended northward from Pennsylvania. The stages by which this great river was developed are still clothed in mystery as is evidenced by the fact that widely opposing views are held by different writers. While Davis (1892), the pioneer in this field, held that the Potomac, Susquehanna, Delaware and Hudson are now abnormal in flowing from the Allegheny plateau (and Adirondacks) across the inner lowland and out through the oldland to the Atlantic, Johnson (1931) has thought to account for this abnormality by the ingenious hypothesis of an extensive coastal plain cover, extending 125-200 miles back into the country on a very ancient peneplain of pre-Schooley (or pre-Kittatinny) age, from which the rivers were let down in their present courses on the buried irregular topography of mountain folds, and held their original consequent courses.

The writer (1932) on the other hand has tried to explain the drainage of the Susquehanna, Delaware and Hudson rivers in the Catskill and surrounding nearer regions by assuming that the Susquehanna (see figure 7) was the original consequent river flowing southwest with the dip of the general surface towards the sea and that later the Delaware and Hudson took advantage of their shorter courses and steeper gradients to behead the upper branches of the Susque-

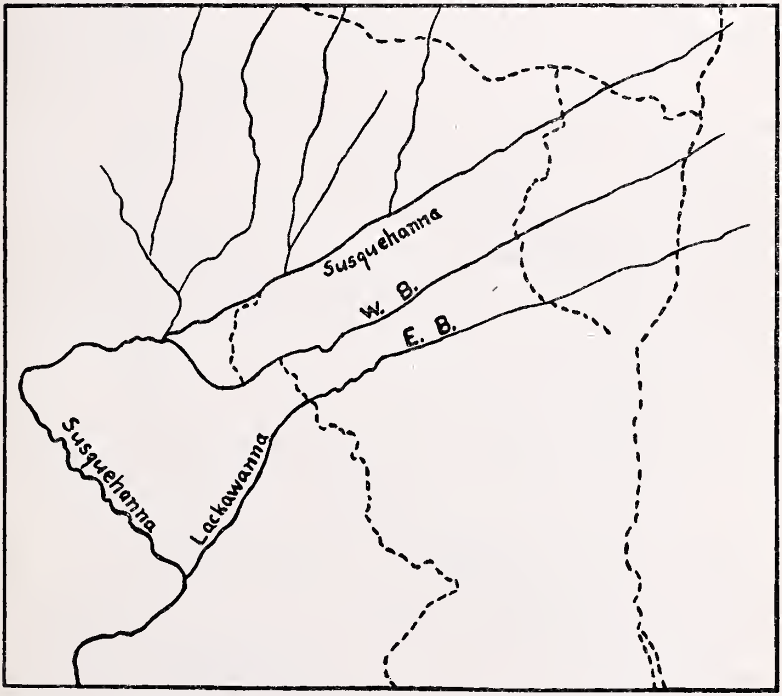

Figure 7 Early stage of Susquehanna drainage in Mesozoic time. Susquehanna headwaters reach upon the Adirondack plateau and eastern Appalachian Mountain regions. Present drainage (Hudson and Delaware rivers) dotted. (From Ruedemann, 1932)

hanna in the east and develop straight north-south courses largely by piracy, at least in their upper reaches as indicated by the diagrams.

Recently Meyerhoff and Olmsted (1936) have advanced the view that the original trunk rivers were headed southeast in conformance with the southeast dip slopes of overthrust folds, thrust sheets and Paleozoic formations that have been removed. These streams are inferred to have been flowing in Triassic and early Upper Cretaceous times and to have been altered later by the irregularities of topography induced by the differential hardness and structure of the underlying formations.

There is no doubt that the Hudson river has held its preglacial course through the various glacial and interglacial periods, and that it thus reaches back at least to Cretaceous times or, taking the end of the Mesozoic era as a measure, some 73-75 million years according to Holmes and Lawson's lead-ratios in the calculation of ages of radio-active minerals (1927).

If we now turn to the *tributaries* of the Hudson river on the Catskill quadrangle, (see figure 8) we find on the west side the Catskill and the Esopus creeks which both have their entire courses in the Devonian rocks, mostly of the Catskill mountains and only their mouths in the Ordovician. They, therefore, lie outside of our field of investigation. On the east side there are also only two creeks of notable size, the Taghkanic creek which in the northeast corner flows into the smaller Claverack, the latter continuing its name until it reaches the Kinderhook creek north of our quadrangle. The most notable creek is the Roeliff Jansen kill which derives its name from an early Dutch settler. Arising in the Harlem valley at the foot of the Taconic Mountain range in a latitude to the north of the upper margin of our quadrangle, it flows south in the Harlem valley for about two-thirds of the quadrangle, swings to the southwest into the phyllite plateau turning sharply northwest just beyond the southeast corner of the Catskill quadrangle to pursue a northwest course to the edge of the phyllite plateau and then flows north-northwest to the Hudson. The creek has thus a most remarkable angular course with a reversal in the second half (see figure 8). A glance at the map shows that the Taghkanic follows an exactly parallel course, also with a reversal in the phyllite plateau. And the Kinderhook creek to the north of our quadrangle also has a somewhat similar course in arising behind the Rensselaer grit plateau and breaking through the phyllite plateau in a curve. It, however, swings then to the southwest.

The courses of these creeks, especially the retrograde parts, indicate

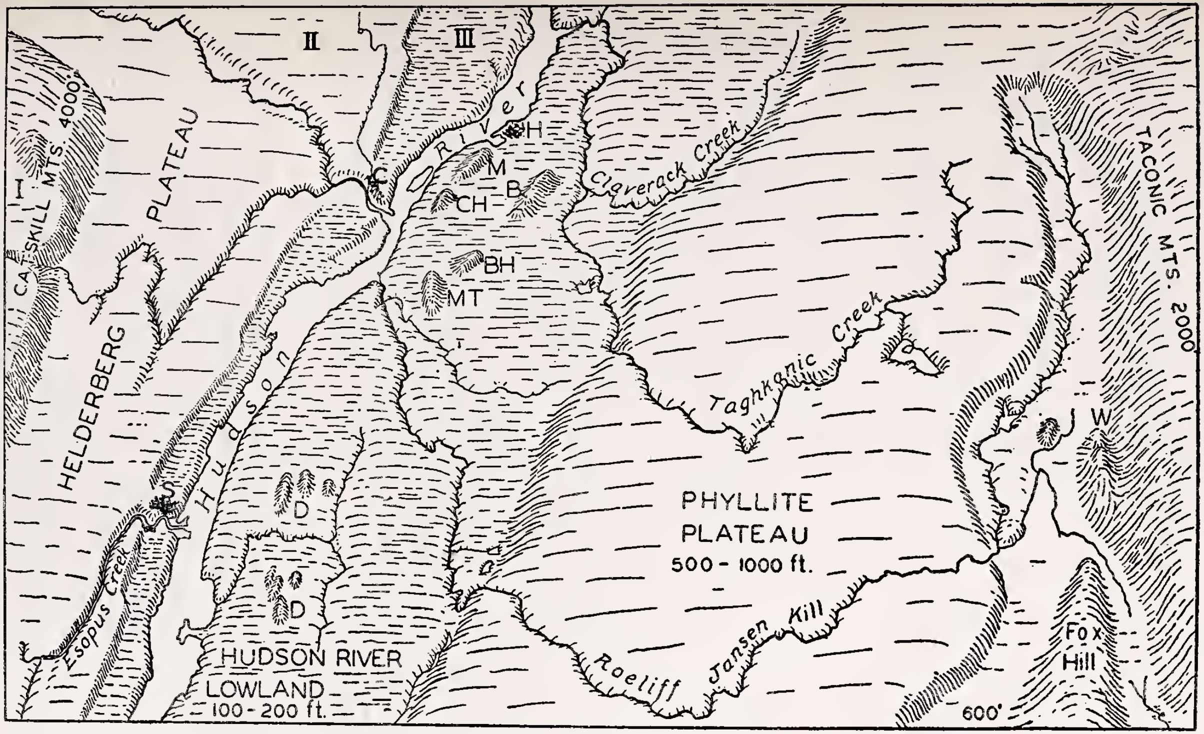

Figure 8 Diagram of Hudson valley and adjoining regions of Catskill quadrangle. Shows the Hudson valley (Albany peneplain). Above it the Helderberg plateau west of the river and the Phyllite plateau east of it, both corresponding to the Tertiary peneplain, and rising above the latter the Catskill and Taconic mountains. H=Hudson; C=Catskill; S=Saugerties; M=Mt Merino; CH=Church hill; B=Becraft mountain; BH=Blue hill; MT=Mt Tom; D=drumlins. **(E. J. Stein)**

that they have a very complex history, and Professor Cook holds that they are composites made up from sections of various preglacial rivers. There as yet are not sufficient data at hand to elucidate their history, but Professor Cook will present some provisional conclusions.

It is a remarkable fact that the Roeliff Jansen kill sinks in its lowest course into a 100-feet deep drift mantle, reaching Normanskill shale and grit bedrock at the bottom. It obviously has discovered there an old preglacial river course, but it reaches this by breaking through a grit ridge west of Blue Stores*.

Stony creek drains a wide alluvial plain east of Madalin and leaving this breaks also through a prominent grit ridge and reaches the Hudson river at a steep grade.

ANCIENT BEAVER MEADOWS

Alluvial plains of the type of the fertile Stony Creek plain east of Madalin have currently been considered as old postglacial lake bottoms. More recently (Ruedemann and Schoonmaker, 1938) the fact has been recognized that these level valleys, which show a gentle grade downstream and are strikingly horizontal from bank to bank owe their configuration to the activity of beavers, who by building dams in the valleys for thousands of years in postglacial time gave the valley bottoms an even grade down the valley and a horizontal surface from one side to the other. The Stony Creek alluvial plain is one of the most striking examples of a valley formed from ancient "beaver-meadows" by the aggrading activity of beavers. This alluvial plain evenly declines from 216 feet A. T. at the upper end to 164 feet at the outlet. The Sawyers Kill alluvial plain running northward from Saugerties is another distinct example of aggradation by beavers.

RELATIONS OF GEOLOGY AND TOPOGRAPHY TO FLORA, FAUNA AND HUMAN CULTURE OF REGION

The great charm of the section of the Catskill quadrangle east of the river arises from the great diversity of the physiographic features, from the multitude of north-south stretching mountains, hills and narrow ridges or single ledges, which are densely wooded or as in the case of the drumlins bear orchards and vineyards, while between extend fertile valleys, nearly all with brooks flowing lengthwise in the valleys. Here and there the valleys expand to larger

* Probably a simple diversion for this short stretch. The valley seems to have run northwest from Blue Stores (Cook).

alluvial plains which are prosperous farming regions. The region altogether gives the impression of a fertile, yet not monotonous country.

The flora has of course been largely restricted to the ridges and gorges, but owing to the great diversity of underlying rocks it exhibits considerable variety.

According to Bray ('30, p. 69) the Hudson Valley region belongs to the much favored zone B of the vegetation zones of New York, only Staten Island and southern Long Island which belong to zone A having a longer growing period and more favored climate. Zone B which extends up the Hudson valley and through the Mohawk valley to the Lake Ontario-Erie belt and is also found in the Delaware, Susquehanna and Allegheny drainage valleys, is characterized by the dominance of oaks, hickories, chestnut, tulip trees etc. in the woods. Its indicator species are red cedar (*Juniperus virginiana*), black walnut (*Juglans nigra*), butternut (*Juglans cinerea*), the hickories, bitternut or swamp hickory (*Hicoria cordiformis*), shag-bark (*H. laciniosa*), white-heart hickory (*H. alba*), small fruited hickory (*H. microcarpa*), pignut hickory (*H. glabra*); numerous oaks, *viz.*, red oak (*Quercus rubra*), swamp or pin oak (*Q. palustris*), scarlet oak (*Q. coccinea*), gray oak (*Q. borealis*), black oak (*Q. velutina*), white oak (*Q. alba*), post or iron oak (*Q. stellata*), mossy-cup or burr oak (*Q. macrocarpa*), swamp white oak (*Q. bicolor*), rock chestnut oak (*Q. prinus*), chestnut oak or yellow oak (*Q. muhlenbergii*); further the sweet birch (*Betula lenta*), the chestnut (*Castanea dentata*), the hackberry (*Celtis occidentalis*), red mulberry (*Morus rubra*), cucumber tree or mountain magnolia (*Magnolia acuminata*), the tulip-tree or yellow poplar (*Liriodendron tulipifera*), the paw paw (*Asimina triloba*), the sassafras (*Sassafras sassafras*), the wild hydrangea (*Hydrangea arborescens*), the American crab-apple (*Malus (Pyrus) coronaria*), the sycamore (*Platanus occidentalus*), the red-bud (*Cercis canadensis*), the Kentucky coffee tree (*Gymnocladus dioica*), the honey locust (*Gleditsia triacanthos*), the prickly ash (*Xanthoxylum americanum*), the flowering dogwood (*Cynoxylon (Cornus) floridum*), tupelo (*Nyssa sylvatica*), great laurel (*Rhododendron maximum*), mountain laurel (*Kalmia latifolia*).

This list of the characteristic trees and bushes of zone B is a wonderful array of beautiful plants which depict a rich tree flora hardly duplicated in any other country of equal temperate climate and most certainly not in Europe with its small tree flora, because it became woefully depauperated by the glacial period which extinguished the multitude of trees that could not withstand the cold and could not escape over the latitudinal mountain ranges of the Pyrenees, Alps, Carpathians and Caucasus. How many of these magnificent trees and bushes as the red oak, black walnut, tulip tree, the honey locust, the great laurel or the mountain laurel, however, does one still see in the woods of the Hudson valley? Man has done there his nefarious work of destruction of wild life only too well.

The small herbaceous plants show a similarity in richness. Of these Bray cites the following as indicator species: white dogtooth violet (*Erythronium albidum*), lizards tail (*Saururus cernuus*), American lotus or water chinquapin (*Nelumbo lutea*), golden seal (*Hydrastis canadensis*), wild sensitive plant (*Chamaecrista* (*Cassia*) *nictitans*), partridge pea (*Ch. fasciculata*), shooting-star (*Dodecathion meadia*), Virginia cowslip or blue bells (*Mertensia virginica*).

Several areas in the quadrangle are botanically of greater interest because of their geologic structure and the divergent character of the rocks which lead to particular florulas.

Dr Rogers McVaugh of the U. S. Department of Agriculture, Washington, D. C., who for several years has made a special study of the botanical ecology of the Hudson valley, has kindly written the following note on the flora of the principal mountains (and the Hudson estuary):

These hills are covered with a growth of trees, including mostly oaks (*Quercus spp.*) and sugar maple (*Acer saccharum*), with dense stands of juniper (*Juniperus virginiana*) covering considerable areas, especially on Becraft mountain. As the stony nature of the soil, combined with the steepness of the terrain, has made agriculture, in the main, impossible, many of the steep shaly hillsides support a characteristic and interesting vegetation, which is not to be found elsewhere in the vicinity, and which includes numerous species more abundant southward.

Among the junipers and chestnut oaks (*Q. prinus*) are found numerous individuals of the dwarf chestnut oak (*Q. prinoides*) and the scrub oak (*Q. ilicifolia*), while the hackberry (*Celtis occidentalis*), is found in abundance. On the dry open hillsides in the spring one finds the bright yellow flowers of the early buttercup (*Ranunculus fascicularis*), and in the more calcareous places the purple virgin's-bower (*Clematis verticillaris*). Later in the season the visitor finds the showy purple penstemon (*P. hirsutus*) and on Mt Merino the well-known colony of the prickly pear (*Opuntia vulgaris*), which was reported at least as early as 1825 and represents the most northerly known station for this species in the Hudson valley. Late summer brings out on Blue hill and Mt Merino the brilliant deep yellow flowers of the rare goldenrod (*Solidago *rigida*) as well as the white ones of the milkweed (*Asclepias verticillata*). The crimson stamens of the tall grama grass (*Bouteloua curtipendula*) also attract the eye, while the botanist might find the interesting but rather less conspicuous false pennyroyal (*Isanthus brachiatus*), the small mosslike plants of the rock selaginella (*S. rupestris*) and the green milkweed (*Acerates viridiflora*).

On the exposed shale ledges of these hills grows the rusty woodsia (*Woodsia ilvensis*), while on the limestones of Becraft mountain and Mt Merino are to be found other ferns, including the purple cliff brake (*Pellaea atropurpurea*), the wall-rue spleenwort (*Asplenium rutamuraria*) and occasional patches of the walking fern (*Camptosorus rhizophyllus*).

While the surrounding country has been almost completely altered, since the coming of the white man, by the operations of agriculture, the steep rocky sides of these hills, undisturbed except for occasional cutters of firewood, probably give us a fairly good picture of the original conditions prevailing on them.

The rocky gorges, cut into the hard shales of the Hudson valley by small streams entering the river, often afford suitable living conditions for plants which are rarely found in this region except at higher altitudes. Examples of such gorges are to be found south of Tivoli, at Cheviot, at Greendale and other points, including the larger one formed by the Roeliff Jansen kill. The most conspicuous plants found in these situations are the white birch (*Betula papyrifera*), the striped maple (*Acer pennsylvanicum*) and the mountain maple (*A. spicatum*), the leatherwood (*Dirca palustris*), the stiff gentian (*Gentiana quinquefolia*), the fly honeysuckle (*Lonicera canadensis*) and the yellow touch-me-not (*Impatiens pallida*).

The dry shale bluffs and banks along the river also support a characteristic vegetation. Here the traveler finds the arbor vitae (*Thuja occidentalis*) in abundance; it is found also in the tidal swamps of Rogers island. Along with the arbor vitae grows the often-cultivated ninebark (*Physocarpus opulifolius*), the bladdernut (*Staphylea trifolia*) and several interesting herbaceous plants, including the so-called yellow pimpernel (*Taenidia integerrima*) and another goldenrod (*Solidago squarrosa*) whose large showy flowering spikes make it very noticeable.

Of special interest in Doctor McVaugh's account appear to us those plants which are of southern habitat and reach in the relatively warm Hudson valley their farthest northern station. The most interesting of these in the Catskill area are the green milkweed (*Acerates viridiflora*) which grows on the slopes of Blue hill and the prickly pear (*Opuntia vulgaris*) which is found on top of Mt Merino, on Church hill and in the woods at the eastern foot of Mt Merino in a few prosperous colonies (see figure 9). It is usually found on outcrops of chert or Normanskill grit, which seem to supply the dry and easily heated soil the plant requires. The pretty patch here reproduced was found surrounded by dense and moist woodland on a little knoll of Normanskill grit. This is the northernmost occurrence in New York State. On the west side of the river the cactus is also seen on Esopus grit northwest of the West Shore Railroad station (fide Chadwick) at Saugerties.

Also the juniper (*Juniperus virginiana*), popularly known as red cedar, prefers ridges of chert or grit and it grows in great numbers where pastures on these rocks are returning to woodland, as shown in figures 10 and 11.

The fauna, according to information given me by W. J. Schoonmaker, assistant state zoologist, is strongly divided between that of the wooded lands of the phyllite plateau and Taconic mountains and the open cultivated plains to the west of them.

The little settled woodlands along the southeastern edge of the quadrangle and beyond and especially the Taconic mountains are inhabited by deer and wild cats, red and gray foxes, red and gray squirrels, the pine mouse, the short-tailed shrew, smoky shrew and the masked shrew, Brewers mole, the star-nosed mole and the interesting flying squirrels. Muskrat, mink and raccoon are found along waterways and in wooded swamps of the region. Beavers have been extinct for a long time in this region but they have left physiographic records in the "beaver-meadows," alluvial plains now extending along some of the creeks (see page 26).

Both in the woods and cleared lands occur the cottontail rabbit, the skunk, the small brown weasel and the New York weasel. Ruffed grouse are common in the woods and pheasants in the open land, while along the Hudson river one may see, during migration, thousands of wild ducks. Wild black ducks live and breed in great numbers along the river, where the wild rice of the river swamps supplies them with plentiful food.

Rattlesnakes and copperheads or moccasins occur on the rocky ledges of the less settled areas. I have seen water snakes repeatedly in the Roeliff Jansen kill as well as black snakes, and one day I saw a small flock of egrets in one of the wild rice swamps.

The river valley was settled early as the river formed the most important highway from New York to the interior for more than two hundred years, and as Brigham (1928) has emphasized it formed together with its extension through the Champlain valley northward to Montreal the most strategic and important road of the early history, especially in the Revolutionary War, which until the battle of

Figure 9 Northernmost station of prickley pear (*Opuntia vulgaris*) in Hudson valley. The plant grows on small outcrop of chert which provides a warm, dry soil surface. Eastern foot of Mt Merino. (J. W. Graham photo, 1935)

Figure 10 Ledge of white-weathering Normanskill chert (white areas) east of Blue hill, showing growth of red cedar (*Juniperus virginiana*). (W. Goldring photo, 1936)

Figure 11 Young forest of red cedar appearing upon Normanskill chert plateau, east of Blue hill. (W. Goldring photo, 1936)

Saratoga, turned for a long time about the possession of this strategic road.

Owing to this strategic position early flourishing settlements grew along the river, the most important of which on our map are Hudson on the east side and Saugerties and Catskill on the west side. Hudson is located on a bluff of Normanskill chert jutting out into the river between two (former) bays, and Catskill and Saugerties are located at the mouths of large creeks (Catskill and Esopus respectively) which furnished both water power and convenient harbor facilities. As the river is an estuary large ships could reach these ports in early times and it is known that several prominent pirate captains had their headquarters in Hudson in the old days; even Captain Kidd is believed to have lived there sometime and buried his treasure somewhere near the river. It is thus seen that romance and history are not foreign to these shores, from which the section that harbored Rip Van Winkle can be clearly seen. Also some of the villages, as Germantown which was founded by the palatinates, have a long history.

The river is still a highway of traffic both on water where ply the largest and most luxurious river steamers of the world and along its banks, where close along the east shore the New York Central Railroad, one of the principal systems of the country, sends its fast passenger trains and huge freight trains over four tracks and on the other side of the river the West Shore Railroad supplies another outlet for the enormous freight being shipped to and from New York. The opening of the port of Albany at the head of navigation has even brought ocean steamers into the river and one may now see the flags of foreign countries flying over the placid waters of this great estuary.

We have already mentioned the prosperous farming population that inhabits both the east and west sides of the river lowland, as far as the phyllite plateau which has today even fewer inhabitants than it had in olden days and has mostly returned to woodland. The rich land of the glacially filled valleys is given up to fruit farming (trees and berry bushes) on a large scale, the rich alluvial land to dairy farming. This industry is greatly helped by the nearness of the great market of New York and the excellent transportation facilities both on water and land.

The presence of Devonian limestone that is suitable for the manufacture of Portland cement in Becraft mountain and in the Helderberg plateau on the west has provided the material for the most important eastern New York cement industry that is flourishing at Hudson, Alsen and Malden and that, as well as the brick manufacture in the valley which is dependent on the Albany clay, is greatly aided by the cheap river transportation to distant ports.

The river, freezing over in the winter, formerly supplied New York City with ice and the riverbanks were lined with unsightly icehouses. This industry has vanished owing to the unsanitary condition of the water. A few of the icehouses have remained and been readily adapted to a new industry for the region, that of mushroom raising.

A very clear view of the exceptional natural advantages of the Hudson Valley region in general and the sector of it in the Catskill quadrangle here under discussion is obtained by a perusal of the report of the New York State Planning Board, submitted to the Governor and transmitted to the Legislature in January 1935.

It is there seen from the charts that submarginal farm and idle lands are found only on the phyllite plateau and are entirely absent in the Hudson Valley lowland; that the latter is located in the most favored "valley belt" of the State which extends up the Hudson river and west through the Mohawk valley and the Lake Ontario plain and contains six of the seven great metropolitan centers of the State and, though containing only 16 per cent of the land area, includes 84 per cent of the population; that it lacks larger areas of excessive slope, unfit for farming, the only exceptions being the large monadnocks; that in soil productivity it ranks medium to high; that the U. S. Soil Erosion service found only slight sheet erosion with occasional gullies (in clay beds) in the western part and moderate sheet erosion without gullies in the eastern part; that the population density is high (in spite of the prevalent farming), being 30 to 50 a square mile in the eastern part and over 50 in the western part near the river. Corresponding to these facts also the value of real property a square mile moves in the highest brackets in the area, 50 to 100 thousand dollars and over 100,000 closer to the river, while, correspondingly the percentage of State aid of total town revenues is very low, 0 to 25 per cent, in the western part near the river and 26 to 50 per cent farther east. In spite of these advantages and the closeness of the metropolitan markets of New York and Albany the agricultural population has shown a slight decrease from 1900-30 in the area as in all agricultural regions except close to the metropolises.

DESCRIPTIVE GEOLOGY

The Cambro-Ordovician belt of the Catskill quadrangle contains formations of the Lower Cambrian (Taconian), Canadian and Ordovician systems. All of these were deposited in the eastern or Levis trough of the Appalachian geosyncline while the formations that belong to the western or Chazy trough series and are known from the western Saratoga and Capital Districts are buried under the Catskill mountains, but reappear in New Jersey and Pennsylvania.

CAMBRIAN SYSTEM

The mapping on the Catskill quadrangle has brought out a much wider distribution of Lower Cambrian (Taconian) rocks than was expected. The latest State Geological Map (Merrill, 1901), ends the Lower Cambrian belt of northeastern New York at Stockport, north of Hudson and shows from the latitude of Hudson to the southern edge of the quadrangle only "Hudson river" and "Hudson river metamorphosed" to the limestone belt of the Harlem valley, with the exception of a very narrow short strip south of Elizaville. Nor do later maps, as in plate I of the 16th International Geological Congress guidebook 1, show any indications of the presence of large areas of Cambrian rocks.

As in the Capital District the older Lower Cambrian rocks (the Nassau beds) are again distributed in the east, the younger ones in the west. Walcott (1888, plate 3), on the other hand, referred on his map the entire belt as far as the eastern limestones, except a very narrow strip along the river, to the Cambrian, extending this Cambrian belt to the northern boundary of Columbia county.

The present map shows a wide distribution of Lower Cambrian rocks also south of Hudson and we have observed on occasional field trips that the Lower Cambrian rocks extend southward through the slate belt to the Highlands and into the valley behind them and eastward into the metamorphosed belt along the Massachusetts line.

In the Capital District (1930, p. 25) we have distinguished in the Lower Cambrian the following formations (oldest at top):

1 Nassau beds
2 Bomoseen grit
3 Diamond rock quartzite
4 Troy shales and limestones
5 Schodack shales and limestones

Of these only the Nassau beds and Schodack shales and limestones are well developed on the Catskill quadrangle as mapable formations and the Bomoseen grit is present as a narrow, more or less transitional horizon and the Troy shale is not well enough distinguishable from the Schodack shale and limestone to be mapped separately. The Diamond rock quartzite has not been noticed.

To these must be added the Zion Hill quartzite Ruedemann (Ferruginous quartzite Dale) which though not noticed in the Capital District, is, if a thin, at least a distinct member of the Lower Cambrian south of Hudson.

Nassau Beds

The Nassau beds (Ruedemann, 1914) were first distinguished by Dale (1904, p. 29) as the beds A-E of his Lower Cambrian series as exposed in Rensselaer county and part of Columbia county. These beds were in ascending order:

	Description of strata	Fauna	Thickness estimated in feet
E	Greenish, or reddish and greenish shale with small quartzite or grit beds.	Casts of impressions	65-535
D	Massive, greenish quartzite, in places very coarse.	....	10-50
C	Reddish and greenish shale with small beds of quartzite or grit (rarely up to five feet thick).	Casts of impressions, Oldhamia	30-80
B	Massive greenish quartzite, in places very coarse.	....	8-40
A	Reddish and greenish shale with small beds of quartzite or grit, from 1-12, and rarely, 24 inches thick.	Casts of impressions, Oldhamia	50-80

Most of these divisions are recognizable in the Catskill quadrangle in southern Columbia county, although mostly so involved by folding as to be difficult of separation. The largest division E composed of an endless repetition of greenish gray shales with thin greenish quartzite bands (from an inch to half a foot) is best exposed in the phyllite plateau in the southeast corner of the map, where the rock is slightly metamorphosed into phyllite. Figures 12 and 13 well illustrate this alternation as exhibited in a new road cut near Jacksons Corners (just beyond the southeast corner of the quadrangle).

Figure 12 Nassau phyllite near Jacksons Corners at southeast corner of map. Shows quartzite bands (white) in broad anticline, intersected by steeply dipping fracture cleavage. (J. W. Graham photo, 1935)

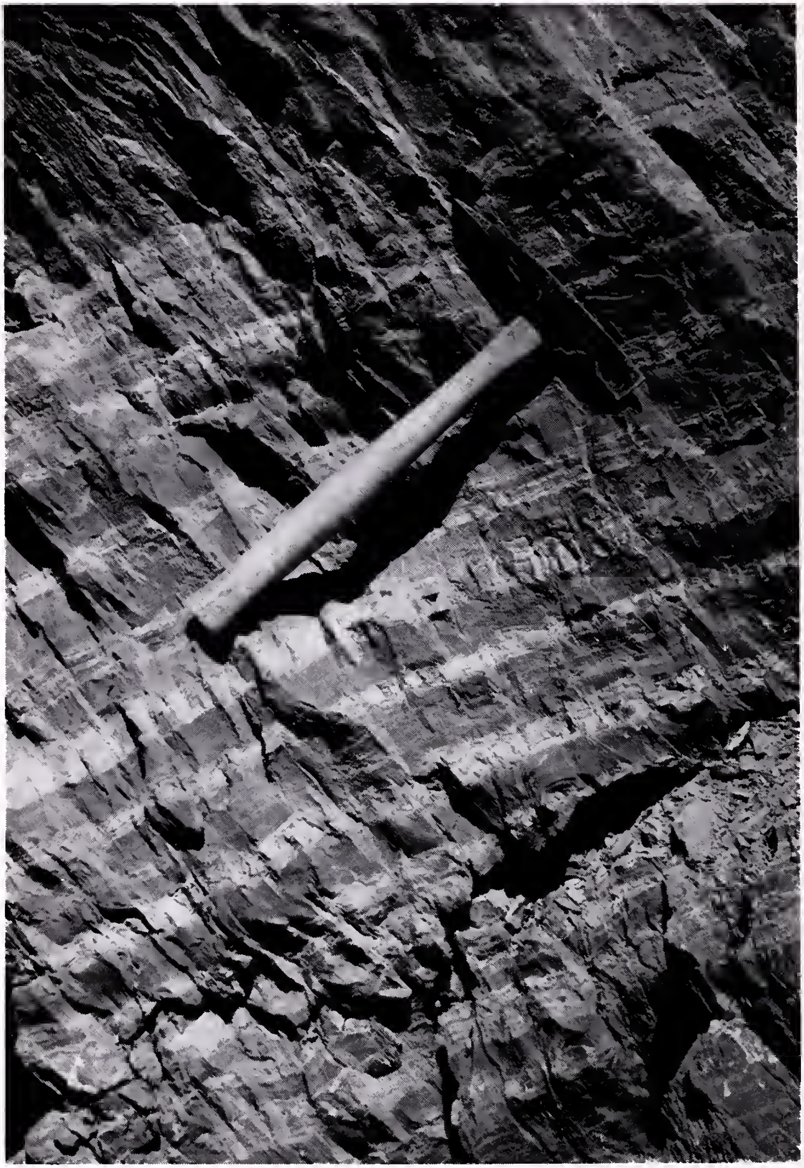

Figure 13 Further enlargement showing alternating phyllite and quartzite bands. (J. W. Graham photo, 1935)

A continuous fine series of outcrops of Nassau beds is exposed along the new road from Elizaville to Jacksons Corners along the Roeliff Jansen kill (see figures 56-59). No section is obtainable there, however, as the same beds are repeated in a series of three flat anticlines (see below p. 145). Thicknesses of 40 feet and more of the alternating greenish gray shale and thin greenish quartzite beds were observed southeast of Becraft mountain and in the Roeliff Jansen kill. Dale's divisions *B* and *D* of massive greenish quartzite, in places very coarse, which are well exposed in the Capital District, were not observed on the Catskill quadrangle; they are, however, present directly north on the Coxsackie quadrangle. Also black shale occurs with the thin quartzite near Elizaville.

Dale ('99, p. 178) has estimated the maximum thickness of the Lower Cambrian at two places (Mt Hebron and east of North Granville) and obtained a maximum figure of 1400 feet, which, however, is probably exceeded, as the base of the Nassau beds is not known. Of these 1400 feet the Nassau beds with a maximum of 785 feet occupy the major portion. Dale adds in a footnote that a recent measurement of the Lower Cambrian quartzite on the Green Mountain range opposite Bennington exceeds 1500 feet. It is therefore apparent that the thickness of the Lower Cambrian amounts to 2000 feet or more. Only a small portion of the Nassau formation is apparently exposed on the Catskill quadrangle, namely the uppermost division *E,* but it is often repeated in folding.

An elaborate description of the *petrographic character* of the Nassau beds has been given by Dale (1904, p. 16-17).

"The greenish shale, occasionally slightly reddish or blackish" is described as being under the microscope "a very fine-grained aggregate of muscovite and chlorite scales, angular quartz grains, rarely plagioclase grains, with brownish dots which are probably limonite." It is added that "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."

Regarding "the greenish coarse and fine quartzite beds" interbedded with the red and green shale bearing *Oldhamia occidens,* it is stated that these differ little from the other quartzites of the Lower Cambrian beds "except in the occasional abundance of chlorite or chlorite schist areas or fragments."

"The reddish shale associated with all these quartzite beds varies much in the amount of its hematite and, therefore, the intensity of its color." "The green shales owe their color to chlorite, the purplish ones probably to chlorite and hematite, and the blackish ones, naturally, to carbon."

It is a remarkable fact that the great mass of Nassau beds has never afforded any fossils save the Oldhamia impressions. This absence of preservable organic life is to some extent in favor of the view that this formation may be a very late Precambrian or a transitional one from the Precambrian to the Cambrian (see below p. 58).

Oldhamia occidens Walcott, was described originally as a calcareous alga from the beds of the Troy quadrangle (Walcott, 1894). Later the organic nature of Oldhamia was denied by Roemer ('80, p. 130), Sollas ('86) and the paleobotanists Solms-Laubach (1891), Seward (1898), Potonié and Gothan (1921), but its algal nature reaffirmed by Ruedemann (1929).

Recent collections of fine material of *Oldhamia occidens* in the eastern slate belt of New York and a restudy of the British types of *Oldhamia radiata* and *antiqua* have led to the discovery that all these remarkable impressions, both in the shale and in the quartzite, are radiating feeding trails of worms such as have been fully described by Richter both of recent and of fossil occurrence. The writer has given a fully illustrated account of these interesting fossils in Bulletin No. 281, of the New York State Museum (1929).

As *Oldhamia occidens* is thus found to be an actual fossil and occurs only in the Nassau beds, it is a good index fossil of these beds.

NOTE. The Nassau beds were placed by an unfortunate slip in the printing of the table of formations in the Capital District (1930, p. 27) in the middle of the Lower Cambrian, instead of at the base, although distinctly considered in the text as belonging there. This error has crept also into Miss Wilmarth's elaborate correlation table of the New York formations (northeastern New York column).

Bomoseen Grit

This name was proposed by Ruedemann ('14, p. 69) for Dale's "olive grit (division F)." It is defined by Dale as "olive grit, metamorphic, usually weathering reddish; absent at south." It is given in Rensselaer county a thickness of 18 to 50 feet. It is a very prominent member of the Lower Cambrian series in southern Vermont and Washington county of New York and there reaches a thickness of 200 feet. The writer found it still a striking formation along the eastern edge of the Schuylerville quadrangle and it is also well shown in the Capital District where a belt passes through the eastern portion of and back of the city of Troy and east of Lansingburg, the belt striking over to the northeast towards Raymertown. In all this area the ledges of either fresh olive-green or weathered pale brick-red rock are easily observed from the road.

This is not the case farther south. Directly south of the Capital District, on the Coxsackie quadrangle, it is still recognizable as a transitional band between the Nassau and Schodack beds, and it appears also as such between the Nassau and Schodack beds on the Catskill quadrangle, in the west at the southeast corner of Mt Tom as a distinct narrow belt, and again at the south end of a small inlier of Lower Cambrian rocks, a mile east of Mt Tom and finally also in a road cut south of Bell pond and on top of a ridge west of it. In all these localities it outcrops close to the Schodack thin-bedded and brecciated limestones, ferruginous quartzite etc. All these occurrences are repetitions of the same beds in an east-west succession produced by folding. The full thickness of the Bomoseen beds or olive grit has not been obtained, but it is apparently not more than 20 feet. South of Elizaville we found 10 feet exposed, 15 feet below ferruginous quartzite and resting on thin-bedded quartzite.

A careful petrographic description of this peculiar rock has been given by Dale (1899, p. 179) from which we quote:

A greenish, usually olive-colored, very rarely purplish, more or less massive grit, generally somewhat calcareous and almost always spangled with very minute scales of hematite or graphite. Under the microscope it is seen to consist mainly of more or less angular grains of quartzite, with a considerable number of plagioclase grains, rarely one of microcline, in a cement of sericite with coarse calcite and small areas of secondary quartz. . . . The scales of hematite, sometimes graphite, can be made out with a magnifying lens.

We are especially interested in this brick-red-weathering rock, because it carries a steady, though small iron content (hematite) and because it holds the horizon of the iron beds in Columbia county between the Nassau and Schodack formations (see below).

Fossils are extremely rare in the Bomoseen grit and we have made no special efforts to collect any. Walcott ('12, p. 188) has reported specimens of *Obolella crassa* from the formation.

We have mapped the narrow strips of Bomoseen grit with the Schodack formation into which the grit appears to grade and of which it may be a local facies or basal member.

Burden Iron Ore

We will designate here as the Burden iron ore a formation that is found as limonite and siderite iron ore between the Nassau and Schodack beds in a belt extending from the southern base of Mt

Tom (Mt Thomas) to Church hill, about four miles in all. Here ore was mined until 1901 in the Burden mines at Mt Tom and in other mines in Plass hill (now Church hill). Altogether four separate "basins" were distinguished by Kimball (1890, p. 157), separated by barren rock (see chart, figure 14). Kimball constructed a series of

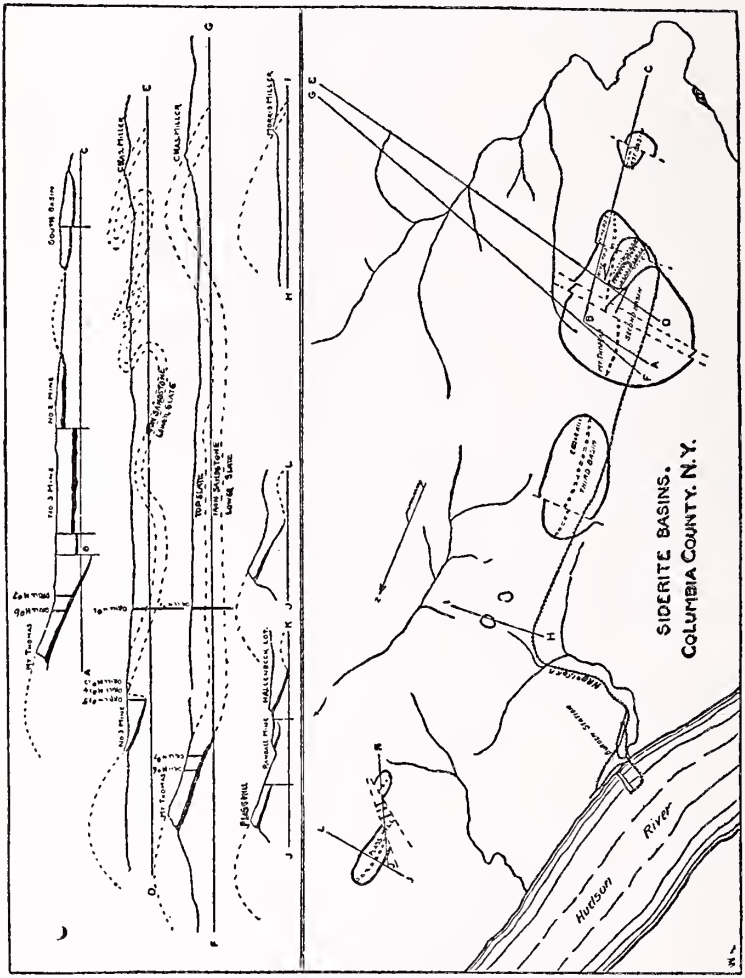

Figure 14 Chart showing locations and vertical sections of the iron mines near Hudson. (From J. P. Kimball)

sections (see chart), in which he considered the iron ore beds as the eastern limbs of anticlines that are continued eastward as small synclines and anticlines. We shall see that the regular easterly dip of the ore beds is not so much the result of folded, as of overthrust structure, the ore bed being overthrust with the rest of the Lower Cambrian on Normanskill grit. Nor are there separate basins of iron ore for it is a continuous horizon, that is folded and faulted out in the intervening stretches. The iron-stained deep red rock and soil is continuous on top of the ridge from Mt Tom to Church hill, where the old Plass Hill mines were. A very instructive section across this ridge, where before it showed very little indication of iron ore, has been made by the new road cut (see figure 18) on the road from Greendale Station to Greendale. Here on the south side of the road, an ore bed 18 feet six inches thick, resting directly on Nassau quartzite and shale is well exposed, while directly across on the north side this ore bed is again faulted out and only the red-stained adjoining rocks and a crush zone are exposed. It is obvious in this section that much slipping and faulting has disturbed the relative original thicknesses of the beds; one fault passing through the overlying Schodack limestones and another separating the Schodack and overlying Deepkill beds, with a small wedge of ferruginous quartzite caught in the fault. Kimball's chart of the iron basins (see figure 14) also shows various transversal faults which offset the outlines of the basins, especially strongly so at the Plass Hill mine and his longitudinal sections *BC* and *JK* show distinctly the interruption of the basins by folding and faulting, South basin being separated from Second (Burden) basin by an eroded anticline.

The typical outcrop of the Burden iron ore is at the old adit of the Burden mine. Here the following section was found (see plate and text figure) in descending order:

1 20 feet brownish-weathering, very heavy quartzitic limestone.
2 5 feet shaly, thin quartzite.
3 13 feet heavy-bedded gray quartzitic limestone.
4 6 feet thin-bedded quartzitic limestone.
5 25 feet iron ore, conglomerate with calcareous matrix, full of rounded quartz-grains.
6 Shale with thin quartzite beds. Nassau, forming base of section.

At the Church Hill iron mine, which is now filled in, the writer found, when he first came there, in descending order:

1 10 feet limestone full of rounded sand grains.
2 2 feet limestone.
3 1½ feet thin-bedded quartzite.
4 7 feet iron ore exposed.
Foot wall not exposed.

The iron ore beds in both the Church Hill and the Burden mines contain layers of limestone breccia, in the Church Hill beds apparently of the nature of a crush breccia.

The Nassau shale and quartzite is exposed on the slope of the hill directly below the mine adit (see figure 15), at the western brow of the hill. A most significant observation made at the time of the first inspection of the mine was that of the presence of slabs, a foot in diameter, of greenish Nassau quartzite in the iron ore bed which was a breccia with limestone pebbles. This left little doubt that the Burden iron ore bed rested directly on the Nassau, probably with a disconformity.

Age of Burden iron ore. The exact age of the iron ore was not known to the earlier writers. The ore was cited in the literature as being probably of the age of the Hudson River shales (Smock, 1889, p. 14; Eckel, 1905). The Hudson River formation itself was a rather nondescript terrane, which proved to contain a variety of formations. The writer, when first visiting the iron ore belt of the Catskill quadrangle in a preliminary survey of the region, discovered graptolites on both sides of the iron ore belt and thereby arrived at the conclusion that the iron ore must be of Normanskill age (Ruedemann 1931, p. 136). Careful mapping in later years with the assistance of T. Y. Wilson revealed the underlying beds as belonging to the Nassau formation and the overlying to the Schodack formation, as well as the presence of a great overthrust fault by which the Lower Cambrian rocks had been pushed from the east upon the Normanskill formation, hence the graptolites close to the west. Some of this material was even later found to have been dumped there and in time overgrown, thereby forming an apparently natural outcrop. Toward the east the series is much abbreviated and the thickness decreased by many small thrust faults, producing a shingle block or sliced structure and bringing the Normanskill shale up on the eastern brow of the ridge. The series, though abbreviated, is, however, a normal one from west to east as seen along the Greenfield road (see figure 21) save for the Bomoseen grit which is hardly suggested in the section. The series begins with the Normanskill grit, passes through the main overthrust fault, the Nassau beds, the Burden iron ore, the Schodack limestone and breccia, the Deepkill shale and the Normanskill shale and chert, the latter being the oldest division of the Normanskill.

It is thus apparent that the Burden iron ore is a bedded layer holding a horizon near or at the base of the Schodack formation and

Figure 15 Adits of the old Mt Tom mine. The ore bed reaches to the roof of the adit on the left and to the projecting point in the side wall of the other. The overlying beds are calcareous grit. (E. J. Stein photo, 1935)

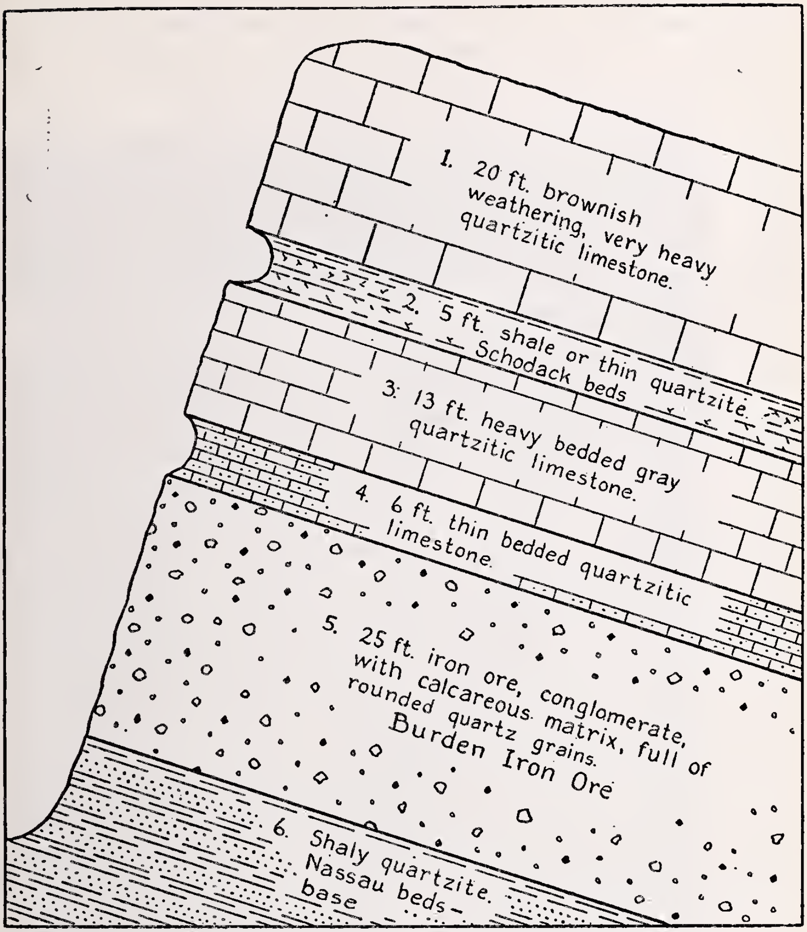

Figure 16 Diagram of section at Mt Tom Burden mine

above the Nassau beds. Its thickness is variable, partly because of the slip-planes, as we saw before, and partly perhaps due to rapid variation of original deposition. Smock reported a thickness of 41 feet including a thin bed of sandstone at the Burden mines (mines No. 3 and 2) southeast of Mt Tom; on Cedar hill a thickness varying from eight to 30 feet, in the Livingston mine east of Cedar hill 18 feet and in the Plass Hill openings ore ranging between 10 and 16 feet with a footwall of drab-colored shale.

The Burden iron ore is, as was early recognized by Dana (1884) and his successors in the study of the iron ores of eastern New York, of the same type as the iron ore of the great belt in the Harlem and

Stockbridge valleys along the New York-Massachusetts line in the Taconic area. There is everywhere a capping of brown ore, the limonite which was mined and which at greater depths passed into siderite, the "white horse" or "dead head" of the miners. Altogether there are some 40 or 50 mine openings in this belt extending from Pittsfield, Mass., south along the interstate boundary to near Pawling, N. Y., in the two limestone belts on either side of the Mt Washington ridge. The age of these limestones, the Stockbridge limestone and the adjoining phyllites and schists is not exactly determined on account of the metamorphosed condition of the rocks.

A hasty survey of the mines on the New York side with Dr D. H. Newland, however, gave evidence that the schists close to at least some of the mines are metamorphosed Nassau beds and the limestone metamorphosed Schodack beds, in part at least; the iron ore holding a place approximately between the two. This is especially apparent at Amenia, "one of the few places where the ore and wall rocks are well exposed; the succession across the dip from footwall to hanging wall is: limestone-ore-mica schist; with limestone repeated again to the east, above the schist" (Newland, 1936, p. 146). It was at Amenia that Doctor Newland and the writer were strongly impressed with the similarity of the schist with the Nassau beds of the unmetamorphosed belt and of the limestone with the quartzitic limestone of the Schodack formation farther west.

Further, more accurate age determination of the eastern metamorphosed beds will therefore probably prove that the Burden iron ores and the eastern iron ores not only have a like composition but also a like stratigraphic position and are parts of an identical horizon. It is in this connection interesting to observe that the eastern iron ore belt is interrupted north of Copake exactly opposite or directly east of the Burden-Church Hill belt by a stretch of about the same length as the latter belt that has no iron pits and apparently no iron. It is then quite possible that the Burden-Church Hill belt is a sector torn out of the eastern belt and carried farther west by about 15 miles on the overthrust plane that is exposed along the western slope of the ridge. The fact that east of the Lower Cambrian iron ore belt the Normanskill chert of Lower Normanskill age is exposed in contrast to the Upper Normanskill grit, that underlies the overthrust plane in the west, lends strength to this assumption of a possible far transference of the iron ore belt and is further supported by the appearance of the overthrust plates of Lower Cambrian between the eastern and western iron ore belts.

Figure 17 Abandoned workings in the ore bed and former adit on Plass hill, now filled in. The ore bed extends from the bottom to the projecting bed of calcareous grit. A stratum of shale in the ore bed is seen above the figure at base of outcrop. (E. J. Stein photo, 1929)

Figure 18. Contact, marked by hammer, of Nassau shale and quartzite on right and massive Burden iron ore on left. Cut in Greendale Station—Greendale road, looking south. (J. W. Graham photo, 1935)

Origin of the iron ore. Besides the problem of the age of the Burden iron ore, another moot question is that of the origin of the iron ore.

Various attempts have been made to answer the question. The ore consists of siderite and limonite, but it is generally understood that the limonite is an alteration product of the siderite, as the latter alone is found in the deeper and fresher portions of the ore bed. The problem revolves therefore about the origin of the siderite. Newland (1936, p. 151) gives the following resumé of the views expressed on the origin of the ore:

Dana regarded the siderite as a primary ore mineral and the deposits to be part of the sedimentary succession, closely related to the Stockbridge limestone. Besides siderite, which seems to have withstood decomposition to a marked extent, the original ore bodies may have contained isomorphous mixtures of iron, magnesia and lime carbonates, combinations that would more readily succumb to weathering attack. The age of the sediments is held to be Ordovician.

Kimball explained the siderite ore near Hudson, which he recognized to be conformably interbedded in the stratified series, by deposition of ferric oxide in the evaporating waters of inshore basins along with organic matter and detritus. Later burial, with reduction of the ferric oxide in the presence of hydrocarbons, led to the formation of an interbedded layer of siderite; this mineral perhaps also replaced the wall limestone to some extent. He was the first, apparently, to recognize the possible relation of organic matter to the ore deposition.

Smock remarked the presence of iron carbonate in the deeper workings of some of the Taconic pits. He considered the carbonate to be the source of the hydrous oxides.

Eckel, in an introductory paper, not since extended, considered siderite the chief source of the limonite. Of the origin of the siderite he remarks that it was "deposited from solution and as a replacement of the limestone and not deposited in a basin contemporaneously with the inclosing rocks." Certain deposits where siderite is not visible in the pits (*e.g.*, Davis mines, Lakeville, Conn.) may have been formed by direct deposition of limonite from circulating underground waters.

Hobbs developed the replacement idea further by considering the limonite and the carbonate as separate depositions, the one as replacement of the Berkshire schist and the other as replacement of the Stockbridge dolomite. The iron, in his view, came from some outside source, not from alteration of the ferruginous minerals in the immediate wall rocks, carried in solution as ferrous carbonate and sulphate. The time of ore deposition was probably late Glacial or post-Glacial. On that point no convincing evidence is provided and it is difficult to find any in the field.

Chance, in a broad generalization on the origin of the Appalachian limonites—a thesis which leaves out of account most particulars about their geology and mineralogy—characterized them as gossans, the weathered outcrops of buried pyrite bodies. It is hard to find any factual support for the explanation from occurrences anywhere in the Taconic belt, although it is known of course that some deposits of the gossan type are found in the Appalachian region, notably in Virginia, North Carolina and Tennessee. Such, however, have quite different features from the usual run of Appalachian limonites, so as to be differentiated without much difficulty when they are explored or mined.

Kimball's view prevailed until recent time. The writer (1931, p. 144) from a study mainly of the conditions surrounding the iron ore beds and the gross characters of the ore arrived at the view that the siderite may be an alteration product produced under the influence of the chemical mass action of the surrounding calcite upon magnetite that was brought down from the Precambrian heights in the east, which are a continuation of the Hudson highlands, where magnetite is still present in great abundance as in the 40-foot bed of the Tilly Foster mine. This magnetite was considered to have been deposited along the shore similar to the magnetite deposits found today along ocean shores and thereby to have produced the very elongate ore beds.

A grant which the writer received from the Penrose fund of the Geological Society of America for the study of the iron ores* and chert beds of the Hudson River terrane allowed the manufacture of a series of thin sections of the limonite and siderite ore which were turned over to Doctor Newland for study. He arrived at the view expressed in the following summary (Newland, 1936, p. 152-54):

Microscopic examination, together with other information here brought out, gives new insight into the relations of the Taconic iron ores and the conditions of their origin. It may be remarked that the present study covers the occurrences in New York, Massachusetts and Connecticut, but not those of Vermont, for which appropriate material has not been available.

The limonitized ores have a common heritage of characters due to their derivation from siderite as the principal source mineral. Siderite upon weathering yields rock limonite, which, like the former, occurs in bands or lenses intercalated conformably in the series of limestone and schists. The soft or wash ores are a step removed, as they consist for the most part of the reworked outcrops of the hard limonite, supplemented to some extent, perhaps, by iron derived from leaching of pyritic bands in the schists. Between unaltered siderite at one extreme and the thoroughly oxidized ore at the other, every stage in

* An article on the age and origin of the Burden iron ore, delivered to the Geological Society in March 1935, has not been printed and most of the facts here presented are taken from that article.

Figure 19 Picture continuous with preceding figure. Outcrop of Schodack limestone, partly brecciated, overlying the iron ore. Small steep fault in center. (J. W. Graham photo, 1935)

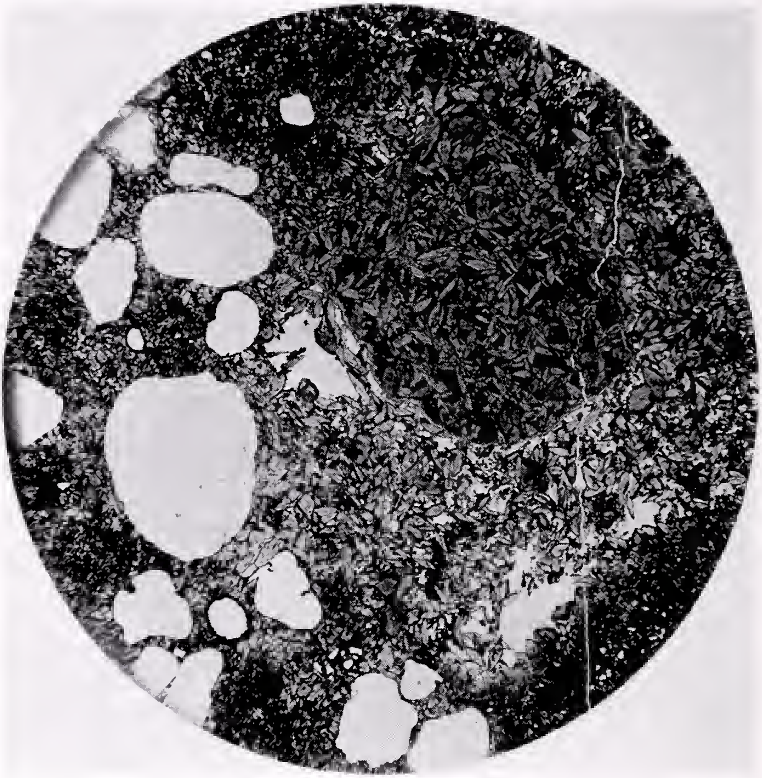

Figure 20 Thin section of Burden iron ore, showing idiomorphic siderite crystals, forming a nodule at upper right and rounded, frosted quartz grains (white). (E. J. Stein photo)

the progress of weathering may be observed in samples collected from the mine pits. Rock limonites, owing to their inheritance of textural patterns and incidental mineral components of the originals, lend themselves to petrographic analysis for mutual comparisons and deductions as to origin.

Of the nature of the siderite bodies the evidence is conclusive for the Hudson occurrences in the western part of the Taconic belt. There the ores have been deposited as contemporaneous sediments of probably early Cambrian age. They have a stratified structure which extends to the finer layering of constituents. The siderite is in uniform crystal shapes and is associated with amorphous silica and plentiful organic matter in the form of diffused hydrocarbon, which latter produces a resemblance to black-band ore when concentrated, as it sometimes is, in definite beds. Well-rounded quartz, feldspar cleavages and silt compose the clastic sediment.

Definite sedimentary traits of texture and structure are rarely discernible in the eastern part of the ore belt because the deposits have shared the more intensive compression and metamorphism which characterize that area. It is obvious from this circumstance that the deposition of the siderite preceded the Taconic upheaval. Further, they show so many similarities—mineral, chemical and other—with the western deposits that little doubt arises that the eastern bodies are actually members of the same group formed under similar conditions. Mineralogically, the lack of amorphous silica and the presence of secondary sericite constitute the only distinctive features of the eastern ores, as compared with those found near the Hudson river.

Brecciation, mashing and metamorphism become more manifest as one crosses the Taconic belt from west to east. The ores follow the country in that respect. The clay shales of the western area give place to phyllites and to mica schists on the New England border.

The manner in which the iron was collected and precipitated in the known associations and traits is a problem by itself. The occurrence of euhedral siderite with amorphous silica and organic matter in the described relations has few counterparts among the better known iron ore deposits. The nearest analogy seems to be with the clay ironstone and black-band ores of the Carboniferous. There is little to be found in literature, at least within the writer's acquaintance, about the microscopic features of those ores, but it is inferred that the iron ore occurs as crystallized siderite with primary relations. Small amounts of manganese and traces of lead and zinc (rarely copper, nickel and cobalt) are indicated by analyses. So far, the resemblance is close. But the Taconic ores have only a minor content of clay and locally, at least, contain substantial amounts of colloidal silica. Further, the Taconic siderites attain a thickness of fully 40 feet, possibly more, in a single bed, much greater than the run of ironstones or black-band ores of our coal measures.

The deposition of the siderite took place most likely in lagoons or in-shore basins, which received wash from the land from time to time, as well as a steady influx of iron in solution. That the iron was carried as ferrous bicarbonate seems probable. The abstraction of the solvent carbon dioxide by organisms, probably vegetable, caused precipitation, and the presence of free hydrocarbon has been one of the factors in preserving the iron in ferrous form. That the siderite crystallized before and not after precipitation is surmised from its relations with the silica.

Abundant stores of iron in the form of silicates and oxides were released by erosion of the crystalline formations in late Precambrian time. The ferruginous minerals were largely decomposed and the iron taken into solution, for they do not appear to any notable extent as mechanical ingredients of the Cambrian sandstones and shales. Antecedent conditions, thus, may be held to have been favorable to the accumulation of chemically precipitated iron ores in the early Cambrian.

The relation of the Taconic district to the rest of the Appalachian district from the standpoint of the origin of the limonites is a subject for future examination. The outcome may be important for stratigraphy as well as economic geology. For the present it suffices to refer to the many striking comparisons between Taconic and other ore occurrences available in the published records, suggestive of a community of physical and chemical features hardly realizable from the operation of mere chance.

We thus see that the final microscopic analysis of the siderite ore supports Dana's original view of the siderite, being a primary ore mineral. The presence of numerous sand grains floating in the matrix at the Burden and Church Hill mines, as well as of numerous angular pebbles making a breccia of part of the ore indicate the deposition in water that was advancing and receiving also wind-blown material from the land. The large Nassau-quartzite slabs incorporated in the ore and mentioned before suggest that the sea advanced over old land with Nassau beds exposed on the surface.

It is very probable that the appearance of the iron ore between the Nassau and Schodack beds has a much greater significance than would appear from the mere local occurrence in eastern New York. Doctor Newland has already hinted in his closing chapter at "the many striking comparisons between Taconic and other ore occurrences available in the published records, suggestive of a community of physical and chemical features hardly realizable from the operation of mere chance."

An attempt at a correlation of the Lower Cambrian formations of the entire Appalachian geosyncline from Newfoundland to Alabama brings out the fact, as was pointed out to the writer by Dr Charles E. Resser, a leading student of the American Cambrian faunas and stratigraphy, that the base is everywhere formed by quartzitic beds, pure quartzite or quartzite and shale and that this

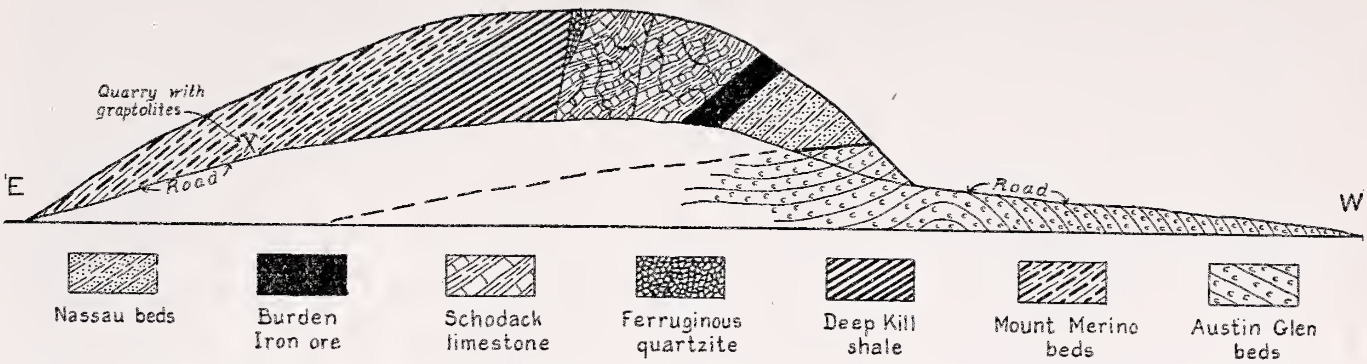

Figure 21 Diagram of Greendale Road section shown in figures 18 and 19. Scale 1 inch = 63 feet horizontally, 12 feet vertically

is later followed by Lower Cambrian calcareous beds or frequently by limestone and shales.

It thus appears that the quartzites and shales which we have called Nassau beds and Diamond Rock quartzite (Troy quadrangle) and the limestones, dolomites and limestone breccias with shales which we have termed Schodack and Troy beds (which will be united, see later page) may well be continued as Cheshire quartzite at the base and the overlying Plymouth marble and Plymouth breccia in southeastern Vermont, or Cheshire quartzite and Rutland dolomite and Cheshire quartzite with overlying Monkton quartzite (fossiliferous), Winooski marble and Mallett dolomite above in northwestern Vermont. We do not cite in this connection the smaller members of less wide distribution, as the Bomoseen grit and the Mettawee slate which will be considered as members of the Schodack formation in a later chapter (see page 65). The Cheshire quartzite extends to Vermont (see Wilmarth correlation table of Vermont) and the series can be recognized in Canada and Newfoundland, where the Nassau beds are represented by the Random terrane of Walcott (fide Resser). The Random terrane was considered by Walcott (1900, p. 3-5) as of Algonkian age and is still placed with the Precambrian. The importance of this correlation will be understood when it is remembered that the Nassau beds, as well as the Cheshire quartzite and other basal quartzites have thus far utterly failed of affording any fossils save the Oldhamias in New York, which are but feeding trails of soft-bodied animals (supposedly worms) and might equally well occur in Precambrian beds of the Beltian type.

T. H. Clark ('21) has also found barren beds (slate, dolmite and graywacke) below the Cheshire quartzite in southern Quebec and north of Vermont. It is possible that also these beds are Precambrian in age.

Also southward from the Hudson valley the sequence of the basal quartzite and shale and superjacent limestones and shales is preserved. The Nassau quartzite is continued southward in the Poughquag quartzite of the Highlands and the Cheshire quartzite of the Taconic range which there is followed by the lower Stockbridge limestone. South of New York in New Jersey the base is formed by the Hardyston quartzite with the Lower Cambrian (Olenellus) fauna in the upper part which is overlain by the Kittatinny limestone, that has Upper Cambrian fossils above the middle and is barren in the lower part. The Hardyston series of quartzites (with various members, Loudoun formation, Weverton sandstone, Harpers schist with Montalto quartzite member) and the overlying Antietam sandstone in central southern Pennsylvania and the corresponding basal Chickies quartzite with Hellam conglomerate member at bottom in northeastern Pennsylvania are followed by Lower Cambrian limestones (Tomstown dolomite).

In Maryland and northern Virginia we find again the Loudoun, Weverton, Harpers, Antietam quartzite and shale series overlain by the Tomstown dolomite, while in central and southwestern Virginia these formations appear in slightly different character but the same general succession in ascending order as Unicoi sandstone, Hampton shale, Erwin quartzite, Shady dolomite and Watauga formation or shale (Rome formation in west, upper part Middle Cambrian), while in the Blue Ridge province of North Carolina the typical Unicoi formation (a 1500 to 2500 foot massive white sandstone, feldspathic sandstone, and quartzite, with interbedded shales in upper part and conglomerate arkose and graywacke in lower part) is followed by the Hampton shale, Erwin quartzite and Shady dolomite and their differently named correlatives, and the Piedmont plateau contains corresponding metamorphics (Kings Mountain quartzite, Blackburgs schist and Gaffney marble). The succession can be followed to Alabama, where the barren Weisner quartzite, Shady limestone and Rome formation (shales) represent the Lower Cambrian series.

If in the Lower Cambrian of the Appalachian geosyncline a general succession of basal quartzites and shales and overlying limestones and shales can be established, as is indicated by the preceding survey, it is equally probable from information the writer has received from students of the Lower Cambrian, as Dr Charles E. Resser, and of its economic products, as Dr D. H. Newland and Professor A. F. Buddington that the siderite-limonite iron ores are usually found in the quartzite-limestone interval of the formations.

We may add that this work may receive still greater significance from the possibility that the iron ore horizon may mark the end of the Precambrian era. This is suggested by several facts, first of which is the absence of fossils in the Nassau quartzite and corresponding basal quartzites; further the apparent transition of undoubted Precambrian beds into the basal quartzite series, as in the Random terrane, and finally the fact that widely-spread iron ore deposits are beginning to be considered as evidence of long preceding continental emergence and erosion, which furnished the iron-solutions to the continental and littoral waters. This view is especially prevalent among European students of sedimentation problems, as Johannes Walther (1893) and Hermann Schmidt (1935).

If the Nassau beds, like the supposedly correlated Random beds of Newfoundland, should prove to be of Precambrian age (Resser) the Burden iron ore horizon would be on the actual boundary of the Precambrian-Cambrian eras (Lipalian interval) and in a true position to be regarded as the result of the washing out of the regolith of the widely emerged continent. In case the Nassau beds should prove, however, to be of earliest Lower Cambrian age, it would still be possible to consider the iron ore of a like origin, as also in Lower Cambrian time the largest portion of North America was still widely emergent.

It is in this connection important to remember that the Bomoseen grit which holds about the same horizon as the Burden iron ore, is a peculiar arkosic rock, a coarse grit, full of hematite scales and with a considerable number of plagioclase grains. This rock with its iron and feldspar content points also to a continental surface with much granite as the source of the material, presumably also a Precambrian surface and suggests even the character of a continental regolith similar to the Brayman shale.

Schodack Formation

In Bulletin 169 (Saratoga-Schuylerville quadrangles, 1914, p. 69) the writer proposed the following names for recognizable larger units of the Lower Cambrian in the Schuylerville area:

The Lower Cambrian Series as Exposed in Rensselaer County and Part of Columbia County, N. Y.

Name of formation	Serial letter	Description of strata	Fauna	Estimated thickness in feet
Schodack shale and limestone	J	Greenish shale.		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.	Olenellus fauna	*a* 20-200
Troy shale	H	Greenish, reddish, purplish shale, in places with small beds of more or less calcareous quartzite.	Oldhamia, annelid trails Hyolithes and Hyolithellus	25?-100+
Diamond Rock quartzite	G	Granular quartzite, in places a calcareous sandstone.		10-40
Bomoseen grit	F	Olive grit, metamorphic, usually weathering reddish; absent at south.	Traces of?	18-50
Nassau beds	E	Greenish, or reddish and greenish, shale with small quartzite or grit beds.	Casts of impressions, *b* Oldhamia	65-535
	D	Massive greenish quartzite, in places very coarse.		10-50
	C	Reddish and greenish shale with small beds of quartzite or grit (rarely up to five feet thick).	Casts of impressions, Oldhamia	30-80
	B	Massive greenish quartzite, in places very coarse.		8-40
	A	Reddish and greenish shale with small beds of quartzite or grit, from one to 12 and, rarely, 24 inches thick.	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, 1225+.

For the sake of completeness the following terms were proposed: Mettawee slate for Dale's Cambrian roofing slate, Eddy Hill grit for his Black patch grit and Zion Hill quartzite for the ferruginous quartzite. These were not found far south of the New York-Vermont line and apparently are absent in the Schuylerville area.

On the Troy and Cohoes quadrangle of the Capital District (Bul. 265, p. 79, 1930) the writer recognized in descending order:

Schodack shale and limestone
Troy shale and limestone
Diamond Rock quartzite
Bomoseen grit
Nassau beds

It was, however, very difficult, owing to the intricate folding, to separate the Schodack, Troy, Diamond and Bomoseen formations on the map and therefore not undertaken. They were, therefore, united into an upper division in distinction to the lower or Nassau division and these two divisions were mapped.

The Diamond Hill quartzite is only a very local formation that has been seen only in one outcrop. It may be, as suggested to me by Doctor Resser, the result of a hot spring that flowed in Schodack time and be in line with similar thick local quartz deposits farther south in the Appalachian geosyncline.

On the Catskill quadrangle it was possible to distinguish in descending order:

Zion Hill quartzite
Schodack shale and limestone
Burden conglomerate Grabau
Bomoseen grit
Burden iron ore
Nassau beds

Again the Zion Hill quartzite, the Schodack shale and limestone, the Burden conglomerate and the Bomoseen grit were so intimately connected and interfolded that it would require much more detailed work than the writer could give to the quadrangle and a larger scale map to attempt to separate these divisions.

In a conference with Doctor Resser it was found that it would be more practicable to extend the term Schodack formation so as to include as members the beds that occur associated or even interbedded with it such as the Zion Hill quartzite and the Burden conglomerate, and also the Troy shale and limestone, which is for the most part a mass of greenish, reddish and purplish shale in places with small beds of more or less calcareous quartzite.

This formation can then be correlated with the larger upper units of the Lower Cambrian north and south of New York, which also consist of limestones and shales. Prindle and Knopf (1932, p. 277) have been able to distinguish on the Taconic quadrangle (including the Berlin and Hoosick quadrangles east of the Capital District) the Mettawee slate, the Schodack formation and the Eagle Bridge quartzite which they consider as probably identical with the ferruginous quartzite (horizon C) of Dale (Ruedemann's Zion Hill quartzite), but name separately as the correlation is not certain. Doctor Resser would unite Ruedemann's Mettawee slate, Schodack shale and limestone and the Eagle Bridge quartzite (Zion Hill quartzite) into the Schodack formation and correlate this with the ever-present upper limestones or dolomites and shales of the Lower Cambrian, that is with the Parker shale and Mallett dolomite of Vermont, the lower Kittatinny limestone of New Jersey, the Tomstown dolomite of Pennsylvania and northern Virginia, the Shady dolomite and Watauga formation (Rome formation in west) of North Carolina, known as the Shady limestone and Rome formation of shales as far as Alabama.

Doctor Resser would also correlate the Bomoseen grit and Diamond Rock quartzite with the Antietam quartzite and Erwin quartzite of the South. In his last publication ('38, p. 6) the Antietam quartzite is considered as represented in New Jersey by the Hardyston quartzite and in New York by the Poughquag quartzite and the Bomoseen grit of the Hudson valley. We have already pointed out, in the chapter on the Burden iron ore, the importance for general paleogeographic conclusions that this uniform series of shales and quartzites, followed by shales and limestones, has in the Appalachian geosyncline.

It is worth noting that the Shady dolomite of Georgia and Virginia, as well as the Mallett formation of Vermont are remarkable for the beautifully developed reefs of Archaeocyathinae with which is usually associated a rich fauna. No such reefs were clearly seen in the Schodack formation of the Catskill district, but they may well be present and only have failed to be exposed as a result of the scanty outcrops.

Zion Hill quartzite member (ferruginous quartzite). The ferruginous quartzite is exposed as a deep iron-red quartzitic sandstone in many localities on the Catskill quadrangle. It is one of the most striking rocks of the Lower Cambrian there. Dale (1899, p. 183) gave a careful description of this formation as it appears in the New York-Vermont slate belt. It may reach there 74 feet in thickness, but is more often between 10 and 30 feet thick and lies between the Lower Cambrian black slate and the Ordovician black slate. It appears in the central and southern part of the slate belt as a massive quartzite, which "is vitreous with brown limonite specks in the cement, probably from the alteration of a siderite. It there is identical in composition and appearance with the quartzite of Horizon A (Bomoseen grit). In other places, however, it is a bluish calcareous sandstone, the grains being quartz (with a few of plagioclase and microcline) and the cement calcareous and sideritic. The rock is traversed by numerous quartz veins, sometimes very thin. In weathering the calcite carbonate is dissolved away, the siderite ($FeCo_3$) passes into limonite, giving a rusty color, and the rock gradually crumbles back into quartz sand, while the quartz veins remain."

It is interesting to note that Dale considers it identical in composition and appearance with the Bomoseen grit which lies at the base of the Schodack formation. On the other hand it is so similar to the Burden iron ore, that Kimball in his section of the siderite basins (see figure 14) continued the Burden iron ore horizon eastward to outcrops of ferruginous quartzite (sections D and F on Charles Miller's farm, section H-1 on Morris Miller farm). In its composition of quartz grains, and a matrix of calcite and siderite it is to be considered as a reappearance of the conditions that produced the Bomoseen grit and in their fullest development the Burden iron ore.

That the ferruginous quartzite is actually a weathered gray to white quartzitic limestone is well shown in outcrops about a mile southeast of Germantown, where in the woods vertical ledges of this hard fresh rock were found with weathered crusts two to three inches thick of typical ferruginous quartzite*. The bed is here found between 20 feet of compact limestone and gray slate. In most cases, however, it is closely associated or alternated with calcareous breccia; west of Bull pond it was found intergraded with breccia, the section being there in descending order:

3 feet gray quartzite with ferruginous quartzitic walls
2 feet breccia
4 feet ferruginous quartzite
gray quartzite

On Claverack creek, at the southeast corner of the Becraft Moun-

* A very similar case of alteration of a rock that has been only recently recognized in its true nature is described by P. Dorn (1936, p. 289). He found that rock exactly identical with the deep red *Eisensandstein des Dogger B* (ironsandstone of Dogger), a widely spread iron ore and a good Jurassic counterpart of the ferruginous quartzite, originates from pyritiferous calcareous sandstone and dark clay shales by decalcification and oxidation of pyrite.

tain outlier one sees the following section from the top of the hill down to the creek (47 feet)

Greenish gray shale with many thin quartzite bands
Ferruginous quartzite and red soil
Breccia 5+ feet thick, forming waterfall
Greenish gray shale in creek below fall

The breccia was described by Grabau (see page 76) as Burden conglomerate.

Outside of the Catskill quadrangle just south of the village of Claverack a coarse conglomerate is found in Schodack beds that contains numerous ferruginous quartzite pebbles and other limestone pebbles. This bed which is incorporated in greenish gray siliceous slates with numerous black worm-tubes represents a horizon above the Zion Hill quartzite or ferruginous quartzite and indicates that this member in this area does not form the top of the Schodack formation, but is only a member near the top.

Very interesting sections were found on the road leading south from Elizaville. Here at a farmhouse were noticed in descending order (see figure 22):

Thin-bedded limestone
½ foot conglomerate
3 feet ferruginous quartzite
10 feet thin-bedded limestone and shale
10 feet + greenish gray and black shale and thin quartzite

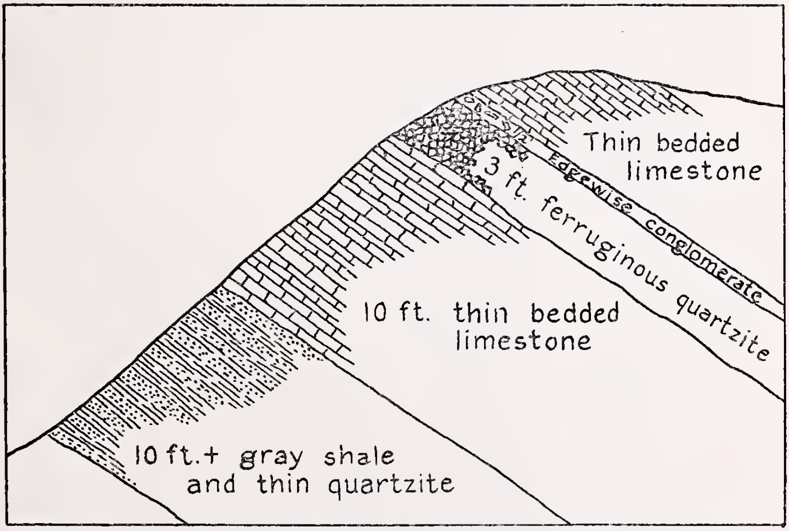

Figure 22 Section of Schodack beds along road south of Elizaville

A quarter of a mile farther north there were found on the hillside:

2 feet ferruginous quartzite
15 feet covered
10 feet olive grit, weathering reddish
Thin-bedded quartzite
Thin-bedded limestone and black shale

On the ridge east of the New York road, half a mile southeast from the southwest corner of the Becraft Mountain outlier three feet of ferruginous grit is exposed on top of a 12-foot bed of Schodack conglomerate and the ferruginous grit is well shown in the quarry on the opposite side of the road, half a mile south.

Along the north-south road one and one-fourth miles southwest of Bingham Mills a most instructive section was found in nearly vertical beds going from west to east in the following order (see diagram, figure 23):

Whiteweathering chert (west of road)
Black shale with graptolites (east of road)
Breccia
Ferruginous quartzite
Heavy limestone
Ferruginous quartzite
Breccia

Here in a small anticline the incorporation of ferruginous quartzite between heavy limestone and breccia is distinctly shown.

One and one-fourth miles southeast of Germantown near the east-west road a succession of 10 feet of conglomerate and breccia, six feet of ferruginous quartzite and six feet of drab quartzite with some intervening shale was found. A similar succession was observed a mile farther east.

Finally in the Greendale section about 75 feet of Schodack limestone breccia and conglomerate are exposed between the Burden iron ore and a small wedge of ferruginous quartzite caught in a fault that separates the Schodack from the Deep kill (see figure 21).

It is thus obvious that near the top of the Schodack formation is a series of limestone beds, breccias and conglomerates and one or two beds of quartzitic limestone, weathering into ferruginous quartzite.

The basal beds of the Schodack series are exposed at the Burden iron mine, where as we saw before (see figure 16) the Nassau quartzite is overlain by 25 to 40 feet of iron ore, 6 feet of thin-

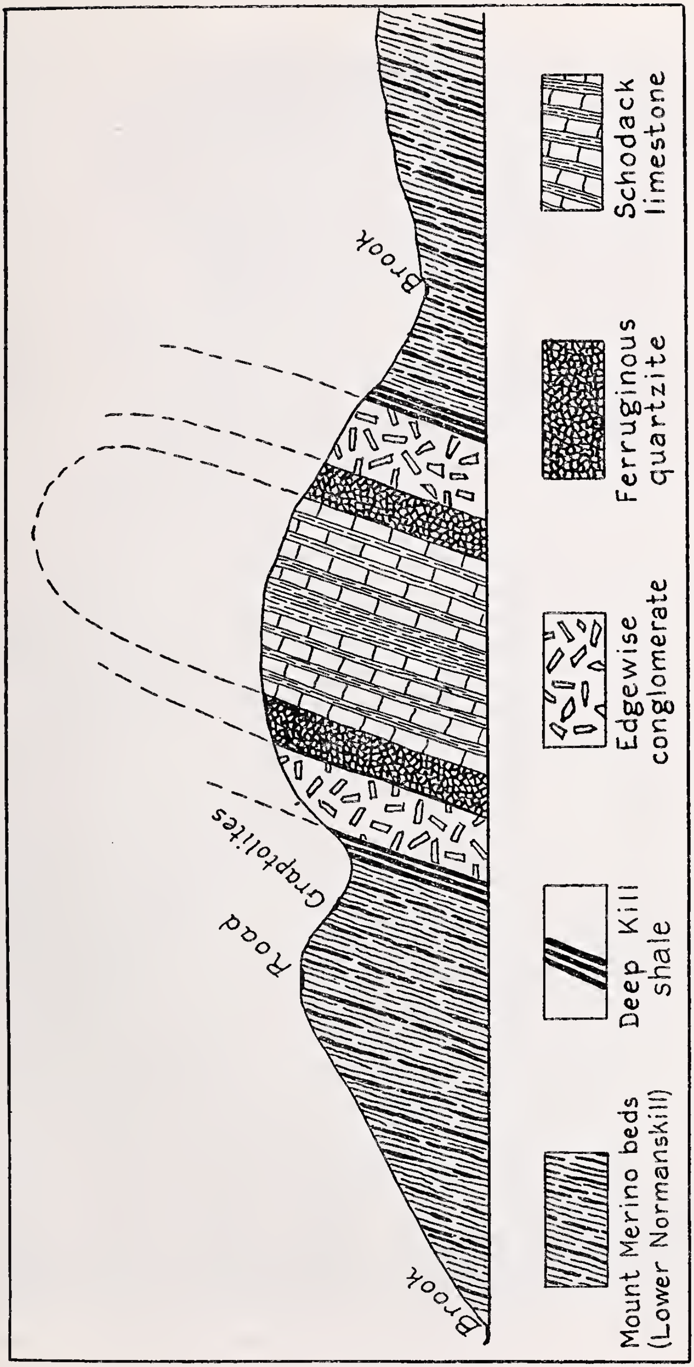

Figure 23 Section along road southwest of Bingham Mills, showing relation of edgewise conglomerate and ferruginous quartzite to Schodack limestone and shale

bedded quartzitic limestone, 13 feet of heavy-bedded gray quartzitic limestone, 5 feet of thin-bedded quartzitic limestone and 20 feet of brownish to orange weathering very massive quartzitic limestone. These beds are also exposed in the Greenfield road cut with considerable breccia.

There is very much greenish gray shale intercalated between the basal limestone and these rocks at the top. These shales often contain many thin limestone beds. Fine exposures of this middle portion of the Schodack beds are found along the new road cut of the New York road (Route 9E) just south of the Becraft Mountain outlier and in Fisher's quarry (one and one-half miles due southeast of Germantown (see figures 24-28). The cut along Route 9 gives a fine exposure of the series of rocks, beginning at the left with alternating black shale and thin limestone bands. This series up to five feet thick, is usually capped by a heavier limestone bed (about one foot) that is followed by black shale (two to five feet thick), upon which rests again the thinly bedded alternating shale and limestone. The diagram (figure 28) shows clearly that we have here a fourfold regular upward succession of black shale, black shale with thin limestone bands and a heavy limestone bed. This series indicates regularly and slowly proceeding changes from muddy water to clear water, which is abruptly filled with mud again. Whether these first gradual and later abrupt changes are due to a change of shore currents, or merely of their velocity or indicate the oscillation of a barrier is difficult to establish from the data at hand.

One of two facts which are suggestive in this connection is the presence of lenses of edgewise conglomerate on top of the heavy limestone beds. Five of these lenses can be discerned in the section. The lenses consist of angular, little, crowded, more or less erect slabs of thin limestone, forming thus a typical edgewise conglomerate or rather breccia. These lenses indicate that submarine slumping took place at the bottom of a gently sloping seacoast, involving recently hardened calcareous mud beds. The repeated presence of these lenses at the same horizon, *viz.*, at the top of the heavy limestone, followed by black shale, points to the recurrence of violent interruptions by storms, earthquakes or other agents that caused the slumping and new inrush of muddy water.

Such lenses of edgewise conglomerate are also seen in Fisher's quarry (see figures 24 and 25), here again on top of a heavy limestone bed, a foot thick, that is followed by very thin-bedded black shale and limestone, which is directly followed again by heavy limestone,

Figure 24 Schodack beds in Fishers quarry, two miles southeast of Germantown. Heavy limestone beds alternating with black shale are exposed. The figure in the middle points to a lens of edgewise conglomerate, that has formed in thin-bedded limestone and shale. See next figure. (E. J. Stein photo, 1935)

Figure 25 Enlargement of lens of edgewise conglomerate, Fishers quarry, showing it resting upon a heavier bed of limestone, along which slipped the mass of shale and thin limestone bands. (E. J. Stein photo, 1935)

Figure 26 Road cut on Highway 9, one mile southeast of south end of Becraft mountain. Shows alternating thin limestone strata and black shale; also lenses of edgewise conglomerate; some above the figure on the right, another behind the figure on the left and one in the middle. Schodack beds. (J. W. Graham photo, 1935)

Figure 27 Enlargement of two lenses. The brecciated character of the limestone is more distinct in the upper lens in this picture. (J. W. Graham photo, 1935)

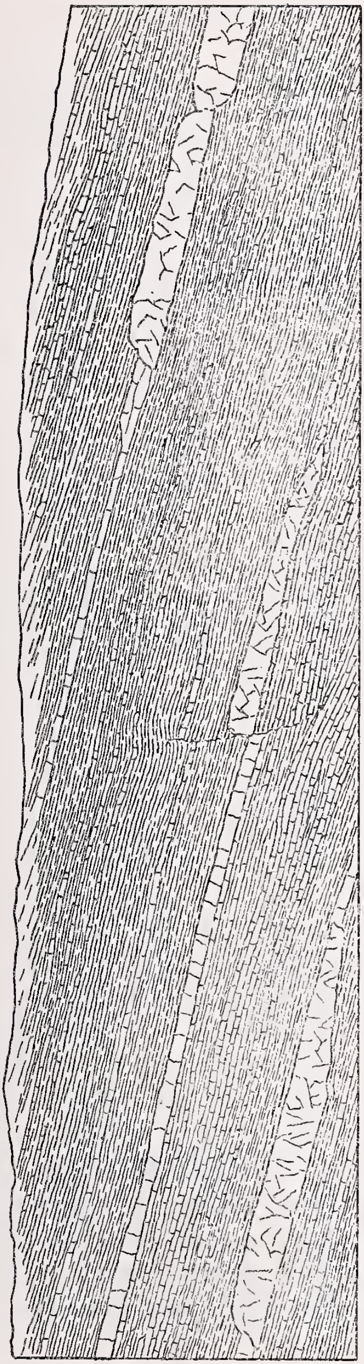

Figure 28 Diagram of figure 26 to indicate location of lenses

the black shale bed being absent in this case, but present above and below the horizon of the lenses.

Identical lenses of edgewise conglomerate are also known from the Deadwood formation (Upper Cambrian) of the Black hills. It is considered by Schuchert and Dunbar ('33, p. 157) as made up of the shingled-up fragments of mud-cracked layers.

The more extensive beds of edgewise conglomerate, described before by Dale and Prindle and by the writer from the Schodack limestone beds in Albany and Washington counties, may in part at least have originated on tideflats where such beds are seen forming today when partly consolidated thin limestone beds are again broken up as Häntschel ('36, p. 350) shows from the German coast of the North sea.

On the other hand, lenses of edgewise conglomerate as those in Fisher's quarry and south of Becraft mountain that clearly represent a slipping at times on a firmer bed, if they can be found over a wider area at the same horizon—as those at the two mentioned localities may be—suggest seismic activity that caused sudden slipping of portions of the slanting sea bottom that were in more labile condition.

Another fact worthy of notice here is the presence of numerous rounded sand grains in the limestone and also in the breccia. These sand grains are nearly always smoky or black quartz and Doctor Newland tells me that very little smoky quartz occurs in the Adirondacks but that it is found farther east (see Emerson). We therefore seem to have here an indication that these sand grains were blown in from the east and that the deposition of the beds took place along the eastern shore of the geosyncline, a conclusion that agrees exceedingly well with the presence of the Schodack limestone only in the eastern or Levis trough of the Appalachian geosyncline. Incidentally it may be mentioned that the Rensselaer grit also contains much smoky quartz, indicating its derivation from areas east of the Adirondacks. The Lower Cambrian beds of limestone, breccia and edgewise conglomerate all contain numerous rounded grains of quartz, mostly of the smoky variety. The presence of this quartz has been fully described before by Dale and the writer.

Burden conglomerate. The limestone breccia beds of the Schodack formation attain considerable thickness, beds measuring 12 feet having been seen. Still greater thicknesses were observed in Vermont and northeastern New York. Grabau (1903, p. 1034) has described this conglomerate which he correlated with the Normanskill as follows:

This name is proposed for a calcareous conglomerate in which the pebbles are chiefly limestone embedded in a silicious sand, which in turn is held together by a more or less calcareous cement. The limestone of the pebbles is in part a gray, compact rock (calcilutite) not unlike the Manlius limestone and in part a more granular mass (calcarenite [Grabau]). The matrix is generally stained with iron hydrate and at the Burden iron mine this rock is in intimate association with the iron ore.

Davis described this rock, assigning to it an age "apparently younger than the Helderberg series, and certainly much older than the drift." He thought that the limestone fragments "seem to correspond with the several subdivisions of the Lower Helderberg." He found it at two localities, one in the meadow south of Academy hill and one in the fields a quarter of a mile south of the southern end of the mountain. It is well exposed on a little stream which enters Claverack creek at a point about east of that where fault 16 strikes the eastern bounding road of the mountain. The stream lies on a fault line. It has cut back some distance from Claverack creek and forms a fall over the hard conglomerate, which fall has been utilized as a site for a dam and mill. The conglomerate bed is about 10 feet thick at the fault. It dips northeastward and abuts against what are probably the Normanskill shales, which have a similar dip. The conglomerate increases in thickness away from the fault and forms a prominent hill between the road and the stream. It is underlain by shales similar to those on the opposite side of the fault.

The age of this conglomerate is unknown. That it belongs to the Hudson River series is undoubted, but whether older or younger than the Normanskill shales, has not been ascertained. No fossils have been noted in the pebbles of limestone, though some search has been made for them. The position and character of the bed indicate that the rock is older than the beds composing Becraft mountain, for all these beds with the exception of the Manlius are highly fossiliferous and easily recognizable. It may correspond to the Trenton conglomerate of Rysedorph hill described by Ruedemann, or it may be of still earlier date. Its areal relations seem to indicate that it is older than the Normanskill beds of Mt Moreno. Boulders of this rock have been found on Becraft mountain in such a location that they could not well have been derived from any known outcrop. They therefore suggest other outcrops to the north or northeast of Becraft mountain.

It follows from his description and our field work that he has united under the name Burden conglomerate the beds at the Burden iron mine of earliest Schodack age with those of later Schodack age found at Claverack creek and north of Becraft mountain. All are, however, of Schodack age and not of Normanskill age.

The Rysedorph conglomerate with which Grabau correlates the Burden conglomerate is also well represented on the Catskill quadrangle and outcrops in great thickness north of Elizaville. It is of Middle Ordovician age (see page 116).

The full *thickness* of the Schodack formation on the Catskill quadrangle has not been ascertained. As usually only the limestone beds or the alternating limestone beds and shales are exposed, while the greenish gray and black shales which reach considerable thickness remain hidden, the thickness of the formation is undoubtedly greater than would appear by piecing the various outcrops together. Outcrops of 25 to 50 feet of limestones with intercalated shales and representing different horizons, as do the outcrops at the Burden mine, Fisher's quarry and the road cut at Route 9 with the hill-section behind it indicate nearly a hundred feet of limestones with shales. To this can be added more than a hundred feet of greenish gray and black shales, which are seen in several places, especially on the quadrangles north of the Catskill quadrangle.

The *fauna* of the Schodack formation has been fully dealt with in the geology of the Capital District (Bul. 285). As the fossils proved rare and fragmentary in the shales and limestones, where the conglomerate is the main carrier of them, it was not deemed necessary to make a special effort to collect them.

We add here the list of the forms reported from the Capital District:

Sponges:
- *Archaeocyathus rarus* (Ford)
- *A. rensselaericus* (Ford)

Brachiopods
- *Acrothele nitida* (Ford)
- *Acrotreta sagittalis taconica* (Walcott).
- *Bicia gemma* (Billings)
- *B. whiteavesi* Walcott
- *Billingsella salemensis* (Walcott)
- *Botsfordia caelata* (Hall)
- *Lingulella schucherti* Walcott
- *Micromitra (Paterina) labradorica* (Billings)
- *Obolella crassa* Hall
- *Obolus prindlei* (Walcott)
- *Yorkia washingtonensis* Walcott

Mollusks:
- *Hyolithellus micans* Billings
- *Hyolithes americanus* Billings
- *H. communis* Billings
- *H. communis emmonsi* Ford
- *H. impar* Ford
- *Scenella retusa* (Ford)
- *Stenotheca rugosa* (Hall)

Trilobites:
- *Elliptocelphala asaphoides* Emmons
- *Microdiscus connexus* Walcott
- *M. lobatus* (Hall)
- *M. schucherti* Walcott
- *M. speciosus* Ford
- *Olenoides fordi* Walcott
- *Protypus hitchcocki* (Whitfield)
- *Solenopleura nana* Ford

CANADIAN SYSTEM

The Canadian System is represented in the eastern shale belt, or the eastern (Levis) trough of the Appalachian geosyncline in New York by some limestone (Bald Mountain limestone), the Schaghticoke graptolite shale (Ruedemann, 1903) and the Deepkill series of graptolite shales (Ruedemann, 1902). The graptolite shales are well represented in the Capital District and their type localities are found on the Cohoes quadrangle. (The northeastern sheet of the Capital District map.)

The Bald Mountain limestone was discovered on the Schuylerville quadrangle (Cushing & Ruedemann, 1914) and not noted in the Capital District. A small outcrop has since become exposed by erosion on top of Rysedorph hill, but no exposures were found on the Catskill quadrangle and the limestone belt probably is intermittent, but is continued in the Wappinger limestone south of the Catskill quadrangle.

The Schaghticoke shale is characterized by the presence of *Dictyonema flabelliforme* (Eichwald) var. *acadicum* (Matthew) and *Staurograptus dichotomus* (Emmons) var. *apertus* Ruedemann. This important guide horizon, which is now considered in America and most of Europe as marking the base of the Canadian (Beekmantown formation) or Ordovician (sensu lato) was formerly held to be the last Cambrian horizon and is still considered so by authors in Great Britain. The horizon has not been observed on the Catskill quadrangle, which, however, by no means indicates its absence there, as the relatively small thickness of the beds (minimum measured 30 feet at Schaghticoke, probably considerably more) will serve to obscure their presence in the much folded mass of shales.

Deepkill Shale

The Deepkill shale and its faunas have been fully described by the writer in 1904; the type section at the Deep kill in Rensselaer county in 1902, and the outcrops and faunas of the formation in the Capital District in 1930. From the last record we quote the paragraphs here of interest:

> In 1902 the writer described as the Deep Kill shale the graptolite shales of Beekmantown age which he had discovered along Deep kill in Rensselaer county, N. Y., exposed in a continuous series of rocks. This splendid outcrop begins a quarter of a mile above the hamlet of Grant Hollow in the creek bed, and extends to the dam of the reservoir of the Troy waterworks in the Deep Kill gorge. It has been very fully described in New York State Museum Bulletin 52 (also Volume 55, Report of the New York State Museum for 1901, p. 546-605, 1903), because it is the only complete section through the Beekmantown graptolite shale known as yet south of that at Point Levis, near Quebec. . . .
>
> It was estimated by the writer that the rocks of this section must have attained a total thickness of 200 to 300 feet. Dale ('04, p. 33), who has recorded some other outcrops of Beekmantown shale

in the Capital District, roughly estimated the thickness in these localities at 50 feet, but considers it a possibility that some of the green shales without banded quartzites and without fossils belong to this formation and therefore he holds his estimate to be a minimum.

The Deep Kill shale is most characteristically represented by finely banded quartzite beds that in places are very calcareous and are associated with greenish and grayish shales, resembling the lower Cambrian shales. Along the Deep kill we have the following succession of rocks (the letters refer to the figure):

b Limestones (more or less silicious) with shaly intercalations	4′ 0″
c Sandy shales and grits	2′ 8″
d Greenish siliceous shale and black graptolite shales	0′ 8″
Graptolite bed 1	
e Thin-bedded shales, grits and limestones	1′ 8″
f Greenish silicious shale and black graptolite shale	1′ 9″
Graptolite bed 2	
g Greenish silicious shale	2′ 9″
h Thin-bedded, dark gray limestone	14′ 3″
i Greenish silicious beds and black graptolite shale	2′
Graptolite bed 3	
j Greenish silicious beds and sandy shales (two thin seams of bluish black shale with graptolites)	5′ 5″
k Dark gray thin-bedded limestone layers	5′ 9″
l Greenish silicious beds and black graptolite shale	7′ 4″
Graptolite bed 4	
m Thin-bedded limestone with shale partings	16′
n Covered	8′ 9″
o (Quarry) Two to three-foot banks of hard, fine-grained thin-bedded layers (banded greenish gray and lighter). Many tenuous graptolitiferous partings of black shale	52′
Graptolite bed 5	
q Covered (distance of 825′)	(100′+)
r Exposure at north side of dam, 135 feet long, mostly greenish gray quartzite, with some brecciated layers and some thin bands of gray limestone	(70′+)
Graptolite bed 6 (3′) *and graptolite bed 7* (2′)	

Worth noting in this section is the appearance of a breccia and coarse-grained sandy shale in *c*, the uneven surface of the limestone layers in *h*, and the still more undulating or interlocking surfaces in *k*, and limestone breccia in *l*. Still more important is the distinct alternation of calcareous beds and siliceous and graptolite shales, indicating at least five cycles of deposition between *b* and *o*, either due to oscillations in the depth of the trough, or to changes in currents.

The writer ('03) divided the Deepkill graptolite shales as exposed at the type locality, into three main zones, namely,

a Tetragraptus zone, comprising graptolite beds 1 and 2

b Zone of *Didymograptus bifidus* and *Phyllograptus anna*, graptolite beds 3, 4 and 5.

c Zone of *Diplograptus dentatus* and *Cryptograptus antennarius*, graptolite beds 6 and 7.

Later ('19, p. 119), the writer found it advisable to divide each of the zones into two subzones, since the graptolite faunas of the two or more graptolite beds of each zone show differences in their faunal composition that correspond to those recognized in other regions, notably Great Britain and Sweden. Furthermore, another zone below the deepest Deepkill zone exposed at the Deep kill is indicated by an occurrence, discovered by L. M. Prindle on the road between Defreestville and West Sand Lake (Dale, '04, p. 30). This contains forms of the Clonograptus zone of Quebec and Europe. We have accordingly distinguished the following subzones in ascending order. ('19, p. 121):

I. Zone of *Clonograptus flexilis* and *Tetragraptus* II. Zone of *Tetragr. quadribrachiatus*	Tetragraptus beds
III. Zone of *Didymograptus* *a* Subzone of *D. nitidus, D. patulus* *b* Subzone of *D. extensus, Goniogr. thureaui*	Didymograptus beds

IV. Zone of *Didymograptus bifidus*
- *a* Subzone of *Goniogr. geometricus, Phyllogr. anna*
- *b* Subzone of *Didymogr. similis, Phyllogr. typus*

V. Zone of *Diplograptus dentatus*
- *a* Subzone of *Climacogr. pungens, Didymogr. forcipiformis*
- *b* Subzone of *Phyllogr. angustifolius, Retiogr. tentaculatus*
- *c* Subzone of *Desmogr.* and *Trigonogr. ensiformis.*

Deepkill shale has been found in the Catskill quadrangle in five places. It is, however, undoubtedly present in more localities, or along all the Cambrian-Ordovician boundaries, but fails to be recognized by being infolded with the Normanskill beds or broken up into slices by the faulting. The five localities are a long strip, one and three-quarters miles long along the eastern foot of Mt Merino; another narrow strip in the section exposed in the road cut on the Greendale station to Greendale road; a third a mile farther south, probably the continuation of the outcrop in the road cut, along the Schodack-Normanskill line, directly west of Blue hill; a fourth on the west side of the narrow southeastern finger of the Germantown inlier of Lower Cambrian rocks, beginning half a mile west of Bingham Mills (Baker Mills on older maps) and extending south for one and one-half miles, and finally a small outcrop on the southwest corner of the long middle finger of the Germantown inlier beginning a mile south-southeast of Viewmonte and traceable half a mile southward.

The Deepkill shale is recognizable in all these localities by its lithologic characters, the alternations of greenish gray more or less siliceous limestone and black shale; the siliceous layers usually marked by numerous black worm trails and burrows.

Fossils were found in the third and fifth outcrops that indicate the lower Deepkill horizons, *viz. Didymograptus nitidus* (Hall) in the third and *Tetragraptus similis* (Hall) in the fifth locality.

The only larger fauna was obtained in the *Ash Hill quarry* horizon, extending from Ash Hill quarry near the south shore of South bay at Hudson along the east foot of Mt Merino to the southeast corner of the mountain, where it is separated from the Normanskill by a fault.

The Ash Hill quarry exposure (see figure 29) and its fauna were described by Ruedemann ('04, p. 499-500), from whom we quote:

Transitional subzone. The fortunate discovery of a *Phyllograptus* in the shales of the Ashhill quarry at Mt Merino near Hudson, by Prof. A. W. Grabau, has led to the finding there of a fauna which is a blending of the typical forms of the zone with *Diplograptus dentatus* with some species of the preceding zone. It, therefore, appears to happily fill, to a great extent, the gap in the continuity of the graptolite horizons, caused by the interruption of the outcrops between graptolite beds 5 and 6 of the Deep kill section (zones with *Didymograptus bifidus* and *Diplograptus dentatus*).

The lithologic character of the beds at the Ashhill quarry is strikingly similar to that of the Deep kill beds, the bands of black graptolite shales being also intercalated in thicker masses of greenish, silicious shales.

The Ash hill quarry has furnished the following forms:

Dendrograptus sp.	r
Ptilograptus plumosus Hall	c
Goniograptus perflexilis sp. nov. mut.	rr
Tetragraptus quadribrachiatus Hall	rr
T. taraxacum sp. nov.	rr
T. pygmaeus sp. nov.	r
Didymograptus forcipiformis sp. nov.	c
D. filiformis Tullberg	r
D. gracilis Törnquist	r
D. cuspidatus sp. nov.	rr
D. spinosus sp. nov.	r
Phyllograptus angustifolius Hall	c
Diplograptus dentatus Brong	cc
D. laxus sp. nov.	c
Climacograptus pungens sp. nov.	cc
Glossograptus hystrix sp. nov.	r
Trigonograptus ensiformis Hall	rr
Retiograptus tentaculatus Hall	r

While the typical species of the zone with *Diplograptus dentatus* prevail, both in number of species and individuals, thus characterizing the beds as belonging to that zone, the congeries contains still a

Figure 29 Ash Hill quarry at northeast corner of Mt Merino. Shows chert and siliceous slate beds.
(E. J. Stein photo, 1929)

Figure 30 Deepkill chert, along road at east foot of Mt Merino. (E. J. Stein photo, 1935)

goodly number of species met only in the deeper horizons at the Deep kill, namely, *Goniograptus perflexilis, Tetragraptus taraxacum* and *T. pygmaeus, Didymograptus filiformis* and *D. gracilis.* The Ash hill quarry beds represent hence a very early or initial phase of the zone with *Diplograptus dentatus* not met with at the Deep kill, but whose existence was surmised on account of the considerable break in the rock succession at that place. The Dendroidea which constitute so large a portion of the fauna of the horizon at the Deep kill are here represented only by a species of *Ptilograptus* and a few fragments of a *Dendrograptus;* but, as they also fail to be present in this zone in other countries, they may represent but a local element.

A notable feature of this faunule is the considerable number of species not observed elsewhere, or in the preceding and succeeding horizons. Some of these forms, as *Didymograptus cuspidatus* and *D. spinosus,* represent moreover peculiar types and have no closely related congeners. Other species, as *Diplograptus laxus* and *Climacograptus pungens,* which are new and very rare in the Deep kill beds with *Diplograptus dentatus,* appear here in great profusion. These facts characterize the fauna as constituting a distinct subzone of the zone with *Diplograptus dentatus.*

It is worth noting that since the Ash Hill fauna was described *Didymograptus forcipiformis* has also been found in the Deepkill fauna at the Deep kill associated with *Didymograptus nitidus, Phyllograptus anna* mut. *ultimus* and *Climacograptus* sp. nov., thus indicating the presence of the Ash Hill quarry horizon or a subhorizon, immediately preceding it, in the Deepkill section.

In the Ash Hill quarry and above are exposed about 50 feet of alternating thin siliceous limestone bands and greenish gray hard siliceous slate with few very thin black shale bands with graptolites. The quarry has not been worked (for road metal) in many years and no graptolite layers are accessible at present. The beds form a westward overturned anticline, the principal body of the slate dipping east on both flanks. The new New York road south from Ash Hill quarry has opened various small outcrops of Deepkill shale. In one of them just below a farmhouse, a mile southwest of Ash Hill quarry, a characteristically rufous or rusty-brown weathering siliceous-calcareous slate contained:

Climacograptus pungens Rued.
Cryptograptus antennarius Hall
Trigonograptus ensiformis Hall (large specimens)

A rich graptolite bed was found at the southeast corner just before the end of the Deepkill strip (see figure 30), abutting there against the Normanskill chert. Here the formation consists of siliceous gray slate with few intercalated thin seams of black graptolitiferous slate, the slate grading into quartzite bands, followed by gray crystalline limestone beds, half an inch to an inch thick. These also carry on the bedding plane scattered graptolites and brachiopods. Some of the gritty beds have the bedding planes covered with small, round greenish mud-pebbles, giving them a conglomeratic appearance. These surfaces carry scattered specimens of *Climacograptus pungens* and *Cryptograptus antennarius.*

The outcrop is especially marked by one bedding plane densely covered with *Phyllograptus angustifolius* Hall. The faunule consists of:

Dendrograptus gracillimus nov.
Didymograptus cuspidatus Rued.
D. cf. *nitidus* (Hall)
D. patulus (Hall)
Tetragraptus quadribrachiatus (Hall)
T. (*Etagraptus*) *lavalensis* Rued.
Phyllograptus angustifolius (Hall)
Cryptograptus antennarius (Hall)
Climacograptus pungens Rued.
Diplograptus dentatus Brongniart
Trigonograptus ensiformis (Hall)
Glossograptus hystrix Rued.
(brachiopod)

A most interesting biotic element of this fauna was found in two small eurypterids:

Dolichopterus antiquus Rued.
Pterygotus (?) *priscus Rued.*

Hitherto only one eurypterid *Pterygotus deepkillensis* (Rued.) was known from the Canadian system. These new forms must be counted therefore among the oldest eurypterids known, as the Cambrian has afforded, with one exception, only types of Walcott's order Limulava of the Merostomata.

The composition of the graptolite faunule is distinctly the same as that of the Ash Hill quarry fauna and it is thus apparent that this horizon is strongly developed on the Catskill quadrangle; it would seem almost to the exclusion of the others, but in the intensely folded and faulted beds preservation at the surface is too much subjected to accidents to be a reliable indicator of the presence or absence of a formation.

Furthermore, the outcrop of Deepkill shale at the Stuyvesant railroad cut, only ten miles farther north has afforded a small fauna, apparently comprising all the Deepkill horizons below the Ash Hill beds, so that a full series of the Deepkill shales undoubtedly is present in this sector of the Hudson River valley below the Capital District. The Stuyvesant fauna comprises:

Goniograptus thureaui (McCoy) *postremus* Rued.
G. geometricus Rued.
Phyllograptus angustifolius Hall
Tetragraptus fruticosus (Hall)
T. pendens Elles
T. taraxacum Rued.
T. quadribrachiatus (Hall)
Didymograptus nitidus (Hall)
D. patulus (Hall)
D. bifidus (Hall)

Besides these graptolites the brachiopods *Lingula quebecensis* Billings, *L. philograptolitha* Rued., and *Orbiculoidea scutulum* Rued. were collected at Stuyvesant.

A very interesting feature of the Deepkill beds, as seen from Ash Hill quarry southward along the foot of Mt Merino, is that the hard siliceous slate becomes so fine-grained and compact that it assumes the character of dark green to gray chert. This character of the rock is already noticeable in Ash Hill quarry and still more distinctly at the south end of the belt (see figure 30) where typical chert appears in the Deepkill section.

It is still more interesting that these chert beds carry radiolarians exactly as the Normanskill chert beds do. Ruedemann and Wilson ('36) have described the following forms from the Deepkill chert:

Cenosphaera antiqua R. & W.
Choenicosphaera multispinosa R. & W.
Xiphosphaera parva R. & W.
Acanthosphaera minuta R. & W.
Heliosphaera venusta R. & W.
Haliomma antiquum R. & W.
Dorydictyum minutum R. & W.
Doryplegma priscum R. & W.
Spongotrochus primaevus R. & W.

Many of these earlier Deepkill radiolarians are markedly smaller than the Normanskill forms.

Apparently associated with the *Phyllograptus angustifolius* beds and practically adjoining it, are exposed two *conglomerate beds* of striking appearance along the Mt Merino road (see figure 45). These beds prove to be of much younger (Trenton) age than the adjoining Deepkill graptolite shale and of the character of the Rysedorph Hill conglomerate. They are in angular contact with the Deepkill graptolite shale and separated by a fault plane from it. They will be described under the Rysedorph conglomerate (page 123).

ORDOVICIAN SYSTEM

Normanskill Formation

The Normanskill formation, usually termed the Normanskill shale, consists of chert, grit and shale, the first predominating. The name "Normanskill shale" was used by Ruedemann in 1901 for beds typically exposed at the Normanskill at the southern outskirts of Albany, at Kenwood. The petrographic character of the rocks ("Hudson shale, grit and chert") was elaborately described by Dale (1899, 1904), the fauna fully listed by Ruedemann (1908, 1930).

Dale ('99) in his table (facing p. 178) of Cambrian and Silurian formations of the slate belt of eastern New York and western Vermont, assigns to the Hudson grits 500+ feet ; to the Hudson white beds 400 feet or less; to the Hudson shales 50+ feet; to Hudson red and green shale 100+ feet. We had an opportunity to make some estimates on the west side of Willard mountain on the Schuylerville quadrangle (Ruedemann, '14, p. 91), as follows: grit, 500± feet; white (chert) beds, 400± feet; shale, 100± feet. This estimate is probably a minimum estimate and largely surpassed, for Ruedemann and Wilson (1936, p. 1542) estimated a total thickness of chert of about 600 feet on the southwest spur of Mt Rafinesque and found that the chert locality east of Fly summit, Washington county, measures about 400 feet. There were further found a hundred feet of black shale exposed on the lower Roeliff Jansen kill. These observations suggest greater thicknesses than had been conjectured before. Considering the width of the Normanskill belt, attaining ten miles, with a further large portion buried under the Helderberg plateau on the west and the fact that only part of the shale is exposed, as owing to its incompetent character it is usually deeply eroded and buried by drift, it is probable that more shale is connected with the formation than appears on the surface.

Dale ('04, p. 37) gave the following succession in descending order:

1 Black and gray shale with interbedded grit—Normanskill graptolite fauna
2 Similar shale with limestone and limestone conglomerate—Trenton fauna in limestone and cement of conglomerate
3 Black, siliceous, white-weathering, cherty-looking shale
4 Reddish, purplish, greenish shale with small quartzite bands

The writer ('14, p. 89), mainly from the apparent synclinal structure of Willard mountain on the Schuylerville quadrangle, came to the conclusion that more probably the grit was near the base. Also Dale remarked that he would have placed the grit at the base were it not for the fact that it is not always in contact with the Georgian, and the writer pointed out that the position of the grit in a western belt nearest to the younger Snake Hill shale and of the chert in the eastern belt nearer to the Cambrian on the Schuylerville quadrangle would indicate younger age for the grit. The apparent evidence of Willard mountain, however, was accepted as more weighty.

The close study of the relationships of the chert in connection with the chert paper (1936) has afforded clear evidence of the older age of the chert and the younger age of the grit, although here again the structure of Mt Merino would suggest the opposite. In both cases the overturning of the syncline has produced a misleading appearance (see below page 146).

The two belts, the western grit belt and the eastern chert belt are even more distinct and sharply separated on the Catskill quadrangle (see figure 35) than on those to the north. As the two divisions of the Normanskill formation are not only distinct in their lithologic character but to some extent (see page 115) also in their fauna, we will distinguish the two members as:

Mt Merino chert and shale and
Austin Glen grit and shale

and describe them separately.

The most important facts concerning the mutual relations of the two members are the eastern position of the chert belt, adjoining the Lower Cambrian belt, and the western position of the grit belt adjoining the Snake Hill formation, north and south of the Catskill quadrangle. Where the Deepkill shale is exposed, it is either infolded with the Mt Merino beds as at Mt Merino or found in strips between the Mt Merino beds and the Schodack beds, as west of Blue hill on the iron ore ridge, or west of Bingham Mills and southeast of Viewmonte (see map).

Another important clue is given by the presence of green and black chert pebbles in the arkosic layers of the grit, as at the Broomstreet quarry at Catskill. These pebbles leave no doubt of the presence of already consolidated chert in the sea when the grit was deposited.

A third indication of the older age of the Mt Merino beds is given by the graptolite faunas, those of the Mt Merino beds containing the older elements, as *Nemagraptus gracilis,* indicative of the lower Normanskill beds, while those of the Austin Glen beds do not carry these forms that have been recognized in the homotaxial beds of Great

Britain as marking the older horizon. Future work will probably lead to the distinction of more refined horizons of graptolites in the Normanskill beds.

It is true, the two belts are not always sharply separated and there appears a belt of chert in the grit belt south of Glasco and scattered small belts of grit in the chert belt, as west of Blue Stores. This has to be expected from the folded and thrust-faulted condition of the region. On the whole, however, the boundary between the two belts is distinct and where the two come close together as along the road south of Glasco the grit is found to be calcareous and fine-grained, thus indicating transitional conditions. The grit and chert are certainly nowhere interbedded on a large scale.

a Mt Merino chert and shale. The Mt Merino chert was described by Dale as "white-weathering chert" of the "Hudson shales" and found by Ruedemann (1914) to be a most characteristic constituent of the Normanskill formation. It has been fully described by Ruedemann and Wilson (1936) in all its lithologic, structural and faunal characters and the conclusion been reached there that for the larger part it is a deep-sea deposit formed in the abyssal depths of the bottom of the middle of the Appalachian geosyncline. This conclusion (1936, p. 1563) is based on the presence of but small amounts of clastic material in the chert, the occurrence of the chert only with pure graptolite shales, the presence of fossil radiolarian genera, today characterized by deep-water habitat, and the presence of zones of radiolarite. This radiolarite, composed of chert and radiolarians, is compared with the radiolarian ooze found today only at depths of 12,000 feet, or greater. The silica content is believed to have been derived from volcanic activity in the Ordovician sea mainly to the north.

The chert beds through their competent character to erosion form the backbone of the most prominent hills of the Normanskill belt, as notably Mt Merino and Blue hill. It seems that chert becomes especially prominent in anticlinal cross folds, a fact observed already by Mather ('43, p. 396) who wrote:

> They (chert outcrops) are generally situated on or near the transverse axes of disturbance, and at or near intersections of these northwest and southeast axes with the principal north-northeast and south-southwest axes of fracture and upheave.

In these minor cases, as at the Van Wies point, it is possible that the cross fold has raised the chert beds to an especially high level, even through the grit beds and thus exposed them. The occurrence

Figure 31 Green Normanskill chert from Glenmont. Photomicrograph (slide 2) showing dolomite rhombs precipitated with the silica. Crossed Nicols, x 20. (E. J. Stein photo)

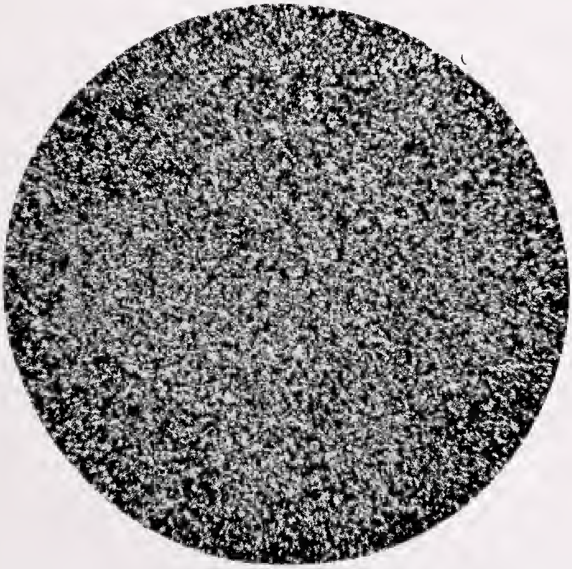

Figure 32 Deepkill chert from Stuyvesant Falls (slide 6), which is crystallized by metamorphism into fine-grained quartzite. Crossed Nicols, x 20. (E. J. Stein photo)

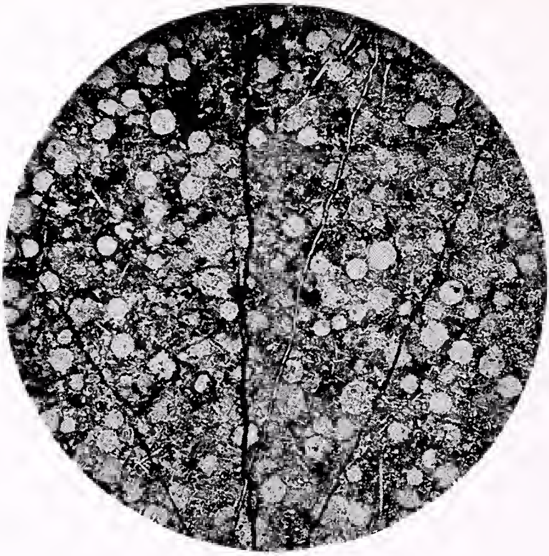

Figure 33 Normanskill red chert with radiolarians. From a point a mile west of Ghent (slide 50). Photomicrograph showing packing of Radiolaria to form radiolarite. Dark parts of section are hematite stain. Ordinary light, x 20. (E. J. Stein photo)

Figure 34 Crushed brecciated radiolarite. From a point a mile west of Ghent (slide 51). Photomicrograph showing large number of detached radiolarian spicules. Ordinary light, x 20. (E. J. Stein photo)

of chert beds in cross folds may explain a few irregularities in the distribution of the chert and grit.

There are numerous good outcrops of the Normanskill chert on the Catskill quadrangle. The largest are upon and around Mt Merino and Blue hill. On Mt Merino the white-weathering chert is seen on top of the mountain, in the quarry on the north brow and especially well exposed along the New York road at the south end of Mt

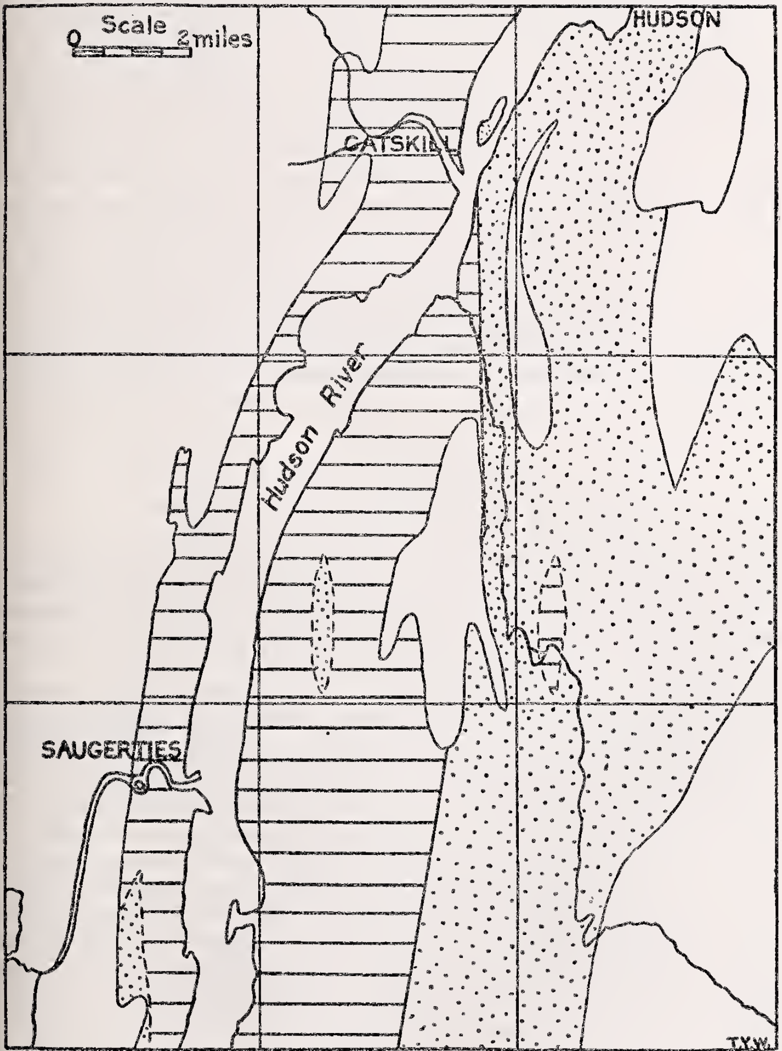

Figure 35 Diagram showing distribution of Normanskill grit (Austin Glen member—lined) and Normanskill chert (Mt Merino member—dotted) on Catskill quadrangle. (From Ruedemann and Wilson, 1936)

Merino (see figure 30) and still farther south towards the approach to the Rip Van Winkle bridge (see figure 54). Thickness of the exposed chert reaches here 40 feet. This chert belt reappears north of South bay at the west end of the city of Hudson where it forms the high cliffs along the railroad. Just north of the station one gets an excellent view of the massive chert beds from the train. On Blue hill the chert is associated with much red shale; on the eastern foot of the mountain, just south of Greendale the chert is quarried for road metal. Twenty feet of solid chert are exposed here. It is considered as excellent road material for its hardness and known as "buckwheat" to the roadmasters. Fine exposures of chert are found south of Glasco along the road in road-metal pits and surrounding country, where 55 feet of heavy-bedded green chert and fine-grained thin-bedded calcareous grit are observable. The chert is here seen in one place to grade into greenish gray shale. Cliffs of white-weathering chert are also seen in the phyllite region at the eastern edge of the quadrangle three miles due east of Blue Stores and very fine ledges of white-weathering chert are exposed around Viewmonte. Along the road southeast of Germantown beds of white-weathering chert and shale were noticed which contain a two-foot bed of concretions of red chert.

The petrography of the chert has been fully described by Ruedemann and Wilson ('36, p. 1542), from whom we quote:

The mineral constituents of the cherts, as determined by petrographic analysis, are few. Because of the somewhat metamorphosed condition of the rocks of the eastern New York shale belt, original composition is often masked by alteration products. However, certain pertinent facts stand out.

In every section of chert studied, silica is the main constituent. With the exception of some material from Glenmont and the locality south of Glasco, truly amorphous silica is rare. Most of the chert is definitely cryptocrystalline. In some instances, for example, the Deepkill chert of Stuyvesant Falls, crystallization of chert, has produced good quartzite. Ordinary light usually causes the radiolarians to appear in thin sections like windows in a darker wall (see figure 33). In some, ordinary light shows them stained by carbon. The black Normanskill chert of Stuyvesant Falls, which is interbedded with graptolitic shale, shows this feature. Under cross nicols, the fossils are seen to be minutely cryptocrystalline, suggesting that the originally chalcedonic silica of their tests, being purer, crystallized more readily than the silica of the matrix.

Thin sections of chert from Mt Rafinesque, from a mile south of Becraft mountain, and from just north of Mt Tom, show mass polarization, extinction occurring parallel to and also at right angles to the bedding. This is probably the result of mineral parallelism, effected during crystallization and producing a foliation parallel to the original microscopic bedding. This is purely a pressure effect.

Opaque material in some of the sections seems to be carbon, derived from organisms and strung out in small masses along the bedding. In other sections, it appears to be argillaceous material, probably representing original colloidal clay, the sericite needles in some of the darker chert probably representing original colloidal clay. . . . Chert from Mt Rafinesque exhibits a very little pyrite, which may be secondary.

All of the Deepkill and much of the Normanskill chert contains dolomite rhombs up to two millimeters in length (see figure 31). The Deepkill is especially rich in carbonate, a fact that may assist in correlation, where fossils are absent.

The red chert, or jasper, is rich in hematite in ultra-microscopically fine grains, irregularly disseminated throughout the siliceous matrix, producing a clouded appearance.

In the chert, clastic material is extremely scarce but is found in thin beds as subangular quartz fragments.

The fact that only chemical and colloidal precipitates make up the chert, whereas continent-derived material accounts for less than one per cent of the bulk, lends weight to the belief that the chert represents a sediment of the deeper sea, more or less remote from any continental platform.

Color

The chert is of various colors. The Deepkill chert is everywhere gray-green and is commonly characterized by discontinuous black markings which may be worm trails. The Normanskill chert is found in associations of black and green, red and green, as well as black alone and green alone. The most common is green, although in Washington county, large thicknesses of red are associated with green. Black chert is found in great quantity at Stockport and at Van Wie's point, in both places, somewhat argillaceous and carrying graptolites. Masses of red chert are found between Glasco and Kingston, between Ghent and Chatham Center, on Mt Rafinesque, and in Washington county in the slate belt.

Several studies have brought out the fact that colloidal silica has the property of absorbing considerable quantities of other substances. Silica seems to have particular affinity, in this respect, for carbon. The thin sections show that, as a general rule, the black chert is actually green chert in which there is a considerable amount of absorbed carbon. The blackest chert is that of the Stockport-Van Wie's point type, which contains carbonized graptolite remains. Thus the color is probably due, in part, to carbon derived from organisms, absorbed by the colloidal hydrous silica. Some slides show radiolarians darkened by carbon so as to set them apart from the matrix.

Although carbon has a darkening effect, much of the black color of the chert is imparted by argillaceous material, which was probably originally colloidal and admixed syngenetically with the colloidal silica.

It can be seen in the sections of banded black and green chert from Stuyvesant Falls and Chittenden Falls that the black is like the green except for larger amounts of opaque (carbon) material, strung out in lenses along bedding planes.

Davis has shown that many, but not all, green and gray cherts are the result of discoloration of cherts originally red. Red cherts, where iron oxide is dissolved out by circulating water, become leached and of greenish color. Greenish cherts, therefore, often show residual cores of red chert.

This conclusion of Davis is of considerable importance as indicating the original existence of much greater quantities of red chert than are now observed in the sections. There may have been much more radiolarite originally than is now indicated.

The white-weathering property, which generally characterizes the Normanskill chert, was believed by Dale to be due to the kaolinization of "a fine feldspathic cement." A study of the thin sections does not establish the presence of such a cement. At more than a hundred localities visited, it was found that only the surfaces of chert exposed to the light had become white. This phenomenon is true of both bedrock and loose blocks. Hence, it is possible that the whiteweathering of the chert is, in part, a bleaching or photochemical effect, if it is not merely the result of selective weathering, which produced a porous condition (as proven with a touch of the tongue when the specimens are dry). Smith has concluded that the white patina of the Kineo rhyolite is of similar origin, likewise the result of bleaching. In the August 21, 1936, issue of Science, Leon P. Smith, in an article on "The weathering of flint artifacts," stated that "the more attractive jaspers are undoubtedly affected by actinic rays, but a loosening of their silicic binding material occasionally exceeds the bleaching."

The origin of chert has been much discussed and there is no doubt that it originates in various ways. The theories of the origin of chert fall into three groups:

1 Chert is a secondary replacement by silica, of some sediment not essentially siliceous.

2 Chert is a result of organic metabolism.

3 Chert is a true sediment, deposited on the sea floor.

Dale ('99, p. 186) calls it "a siliceous and feldspathic slate," formed probably from "a feldspathic mud, with quartz fragments, and muscovite scales." Cushing and Ruedemann (1914) and later Ruedemann (1930) considered the chert to be indurated shale.

This view had to be given up by Ruedemann and Wilson (1936, p. 1545) after a closer study of the stratigraphy, petrography and fauna of the chert, in favor of the primary origin of most of the chert. They give the following argument:

Recently, it has become usual to infer the origin of a particular chert from the nature of its associates, notably the associated sediments.

The cherty shales and cherts present a series, ranging from shale through shaly chert to chert. Were this a gradual change from bed to bed, it would be reasonable to assume, as has previously been done, that the change is the result of a silicification or replacement of originally argillaceous material. However, field study shows that many beds of massive chert are separated by shale partings that exhibit no indication of silica replacement. Just east of Fly summit, Washington county, Wilson measured a 400-foot section of chert. Many of the beds are two feet thick and are separated by an eighth of an inch, or slightly thicker, black argillaceous shale beds. At the south end of Mt Merino, south of Hudson, there are four-inch and five-inch beds of solid chert, separated by as thick, or thicker, argillaceous strata. Similar outcrops are numerous.

A true induration, where shale, which is characterized by thin bedding, is replaced by silica, would show the original bedding preserved in pseudomorphic detail. Actual observation, however, demonstrates that many of the chert beds show no thin banding within. It must be admitted, on the other hand, that many beds do show a fine, even microscopic, banding. Hence, if the unbanded beds can be accounted for, it might be argued that the banded beds are indurated shale. It is significant that thin sections of chert from Stuyvesant Falls show chert with intercalated thin bands of very fine-grained quartz, clearly in its original form, leaving no doubt that, in this case, both the quartz and the chert must be of syngenetic origin.

At several localities just west of the Taconic range, the chert beds are cut by quartz veins in such a way that the quartz is clearly seen to be of a later generation. These same veins intersect beds of shale and chert alike, and the shale is not silicified.

The locality at the south end of Mt Merino exhibits an intraformational conglomerate or breccia, which is composed of fragments of chert and limestone in a calcareous matrix. This is repeated in several beds, separated by shale and chert beds. It is evident that here the chert pebbles within the conglomerate are of original chert. Secondary replacement by silica can not be so selective. A similar occurrence is to be found one and one-fourth miles north of Athens, on the west shore of the Hudson.

At Troy, on the Rensselaer Polytechnic Institute campus, Ruedemann found a fault breccia of post-Ordovician (Taconian orogeny) age, separating the Lower Cambrian and the Ordovician at the great thrust plane ("Logan's Line"). This Poestenkill fault breccia is replete with fragments of Ordovician limestone (Bald mountain), grit (Normanskill) and black chert. There is no chert known from the Cambrian of the region; hence, that of the breccia must be Ordovician, and essentially in its Ordovician lithologic condition.

[We may add here also the occurrence of green and black chert pebbles in the Normanskill grit arkose at the Broomstreet quarry at Catskill mentioned before.]

The presence of radiolarians in the chert is the best evidence that the chert is not secondary, as Paleozoic radiolarians are completely siliceous organisms and require silica for the construction of their tests. There must have been a sufficient amount of silica present when the radiolarians lived. Furthermore, radiolarians are rare in any except siliceous sedimentary rocks. This indicates that they are practically restricted to cherts and siliceous shales and that they have not simply drifted into siliceous deposits from elsewhere.

Small amounts of chert in more or less isolated patches may be accounted for by the secretion of silica by organisms. Some cherts contain so many radiolarians that they are termed "radiolarites." Sponge spicules are found in some chert, especially in the nodular variety. But all chert is not characterized by such fossils.

Radiolarians are present in the Normanskill chert to a varying degree. It is impossible to ascertain their relative abundance from less than several thousand systematically collected rock specimens. However, it is apparent that, although some sections are replete with radiolarians, or nearly composed of them, others are completely barren. This condition is proof that the radiolarians are incidental and that the chert is not a result of their decomposition (Pl. 3, fig. 1). The fact that 27 out of 51 chert slides showed radiolarians suggests that the latter may be found in all chert beds and that all this chert is of similar origin.

Owing to the small amounts of silica in seawater, the view that thick chert beds were deposited as silica gel meets serious obstacles, as fully discussed by Davis, for, even though it is fully recognized that electrolytes tend to cause the coagulation of colloids, it is necessary to provide for the silica, which, for instance, is brought by rivers in greater quantities into the sea rich in strong electrolytes, some mechanism capable of concentrating it into definite areas of sedimentation.

This difficulty has led many (among them, Davis) to the view that submarine volcanic exhalations or submarine springs producing magmatic water are necessary to explain the great deposits, hundreds of feet thick, as in the Franciscan group. This hypothesis seems well supported by the presence of volcanic rocks, both intrusive and extrusive, in connection with the more important chert deposits in many parts of the world.

From a comparison of graptolite faunas, it appears that, during Normanskill time, there was marine connection between eastern New York, across Newfoundland, to the North Atlantic and Great Britain. All these sections of Normanskill age contain chert and Newfoundland together with New England and Great Britain have an associated igneous chapter in their histories. It is not impossible that the Canadian eruptives contributed such an excess of silica to the geosyncline in its northeast portion that the effects of it were reflected, farther south-southwest as deposits of chert.

Ruedemann and Wilson found further that time is an important factor of deposition of the chert, deposition having probably taken place at a very slow rate. They arrived at the following conclusions:

At Stuyvesant Falls, Columbia county, are two distinct sets of chert. One is composed of light-grayish rocks, whose textures range from cryptocrystalline or cherty to quartzitic. In fact, there are some beds that are hard to classify according to ordinary terms. They may be termed grainy cherts or fine-grained quartzites. These fine-grained quartzites are obviously derived from amorphous chert that was deposited by colloidal silica, but, owing to a slight or beginning metamorphosis, they have been altered into an extremely fine-grained quartzite, the angular grains of which fit closely together. European authors have, for some time, recognized the fact of the metamorphism of amorphous chert into fine-grained quartzite.

The other set of chert at Stuyvesant Falls is stratigraphically above the first and is composed of material quite different in appearance. Here, the chert forms beds up to six or eight inches in thickness, which, in turn, are composed of alternating black and dark green bands of exceedingly fine, crystalline material. These beds are separated by black graptolite shale.

The alternation of chert and shale, both of which are composed of colloidal material, seems to indicate that long times of almost pure water were interrupted by epochs of relatively large and rapid supply of clay matter, at times either colloidal or detrital.

The extremely fine microscopic bedding of some of the chert, with fine black organic films on the bedding planes, is proof that some of the chert was deposited slowly. Moore and Maynard have pointed out that silica is deposited at a slow rate by electrolytes and that time is, therefore, an important factor in the precipitation from dilute solutions. On the other hand, the amorphous chert from Glenmont (Pl. 2, fig. 1) contains authigenic dolomite crystals, fairly evenly distributed in the chert and clearly syngenetic with the chert, thus leaving little doubt of the chemical precipitation of that chert, which, as bedding is not discernible, may have taken place more rapidly and from a more concentrated solution.

From these facts, the writers conclude that the Deepkill and the Normanskill cherts represent consolidated, dehydrated marine deposits of colloidal silica (plus smaller amounts of other deposits). The silica was probably contributed to the sea, through submarine or continental volcanic activity, in particles of colloidal dimensions.

The principal outcrops of the Mt Merino beds are at Mt Merino, south of Hudson. Here a road-metal pit on the north brow of the mountains since expanded into a large quarry on the land of the

Reverend Claw was worked by the writer in 1901 and furnished the following fauna (see Ruedemann '08, p. 13):

Thamnograptus capillaris (Emmons)
Corynoides gracilis mut. *perungulatus* Rued.
Didymograptus sagitticaulis (Hall) Gurley
D. subtenuis (Hall)
Azygograptus? simplex Rued.
Leptograptus flaccidus mut. *trentonensis* Rued.
id. var. *spinifer* mut. *trifidus* Rued.
Nemagraptus gracilis (Hall)
id. var. *linearis* Rued.
id. cf. var. *nitidulus* (Lapworth)
Dicellograptus gurleyi Lapworth
D. sextans (Hall)
id. var. *exilis* Elles and Wood.
id. var. *perexilis* Rued.
Dicranograptus nicholsoni var. *parvangulus* Gurley
D. ramosus (Hall)
D. spinifer Elles and Wood.
id. var. *geniculatus* Rued.
Diplograptus (*Orthograptus*) *incisus* Lapworth
D. acutus Lapworth
D. angustifolius Hall
D. (*Glyptograptus*) *euglyphus* Lapworth
Glossograptus ciliatus Emmons
id. var. *debilis* Rued.
G. whitfieldi (Hall)
Cryptograptus tricornis (Carruthers)
Climacograptus modestus Rued.
C. scharenbergi Lapworth
C. bicornis Hall
Lasiograptus mucronatus (Hall)
L. bimucronatus Nicholson

This list contains half of the some 60 species of graptolites from the Normanskill beds of New York and it has since been enlarged by further collecting in the quarry which offers at present the best collecting ground for Normanskill graptolites in the State. Collections at the place were made under Hall and the locality recorded under its old name of "Mt Moreno," a name which has been superseded by the more correct name Mt Merino.

Also the brachiopods (see Ruedemann, '34, p. 79 ff.) *Paterula amii* Schuchert, *Leptobolus walcotti* Ruedemann and *Schizotreta papilliformis* Ruedemann and the sponge *Pyritonema rigidum* Ruedemann (Bul. 262, p. 37) have been described from the Normanskill shale at Mt Merino. *P. rigidum* consists of bundles of long straight rhabd-like bodies. Recent collecting by Clinton F. Kilfoyle has added a new sponge *Teganium merino* and a new graptolite *Lasiograptus pusillus*.

There were altogether 13 graptolite localities found in the Mt Merino beds, as opposed to but two in the Austin Glen beds (to which are to be added several around Catskill found by Professor Chadwick). Among these may be mentioned the quarry to the south of the Greendale road beyond the cut which contains as the most common forms *Dicellograptus sextans, Dicranograptus ramosus* et al. and the shale east of the iron ridge at the next crossroad which has afforded *Corynoides gracilis, Didymograptus sagitticaulis, Dicellograptus exilis,* as the prevailing types. In a road cut one and one-half miles southwest of Elizaville black shale associated with chert contained *Didymograptus subtenuis, Climacograptus parvus, Cryptograptus tricornis* and *Diplograptus* (*Glyptograptus*) *euglyphus.*

Another locality where graptolites occur in chert is in a road cut one and one-fourth miles west of the Twin ponds. It has afforded *Corynoides gracilis, Didymograptus subtenuis* and *Climacograptus caudatus.* A small collection (*Diplograptus* sp., *Climacograptus parvus* etc.) was found in a quarry a mile west of Upper Red Hook. A whole series of graptolite localities were seen in the new road cut of the road from Burden to Livingston, though not any proved prolific. *Corynoides* sp., *Didymograptus serratulus, D. sagitticaulis, Climacograptus parvus, C. eximius, Diplograptus angustifolius* were found. Also the presence of infolded Deepkill was suggested by the appearance of some of the shale and the presence of *Didymograptus* cf. *filiformis* and *Phyllograptus* cf. *anna.*

An important biotic element of the Normanskill formation was discovered by Ruedemann and Wilson ('36) in the *Radiolaria.* These have been described in the Bulletin of the Geological Society of America cited above. The following species were reported from the Catskill quadrangle:

Cenosphaera pachyderma Rüst.—Glasco
Stylostaurus hindei R. & W.—Glasco (sole locality).

Much larger faunas were found in the radiolarite from Fly summit, Washington county, and from an outcrop a mile west of Ghent, Columbia county, and northeast of our quadrangle. Altogether 23 species of radiolarians were described from the chert of the Normanskill formation, but there is no doubt that this is only a fraction of the radiolarian fauna that could be extracted from the chert by more extensive, systematic search.

The bearing of this radiolarian fauna on the question of the origin of the chert has been fully discussed by Ruedemann and Wilson (1936, p. 1557). They concluded that the presence of radiolarite, a rock composed of chert and radiolarians (see figures 33 and 34), and the occurrence of radiolarian genera (*Staurosphaera, Halycalyptra, Stylostaurus*) that today do not occur above 12,000 feet indicate, with the view that the radiolarite is to be correlated with the recent radiolarian ooze, a depth of formation for some of the chert of more than 12,000 feet. This view is in agreement with the writer's conclusions, arrived at in the study of the graptolites, that these comprise a plankton fauna of the open ocean (1934). A corollary of this conclusion is again that the Appalachian geosyncline formed at earlier Normanskill time a wide open sea of suboceanic dimensions (see page 180), at the bottom of which the Mt Merino chert was formed as syngenetic deposit probably under the influence of volcanic eruptions under some part of that sea.

b **Austin Glen member.** The Austin Glen member of the Normanskill formation has been named from Austin Glen in the Catskill valley close to the village of Catskill. The grit with thin shale intercalations is here magnificently exposed in the bed of the creek (see figure 36). It forms a north-south striking anticline, giving an outcrop of 355 feet length across the strike and exposing beds of grit of various thickness, some 12 feet thick. The Manlius rests here back in the woods flat on top of the anticline.

Another still more instructive outcrop is seen in the Broom Street quarry in South Catskill (see figure 37). Here a section of a broad syncline with a thrustplane in the middle has been uncovered showing grit beds from below upward with thicknesses of 35, 5, 27, 4, 20, 15+ feet and thin shale intercalations, giving a most imposing view of the massiveness of the grit beds. In the upper left-hand corner of the quarry is seen an exposure of gray and black shale with intercalated thin grit beds that is separated by a cross fault from the grit and has afforded a combined fauna of graptolites and eurypterids (see page 115). Most interesting features of this quarry are several arkosic conglomeratic beds composed of small mud pebbles, but also pebbles of black and green chert. The arkosic conglomerate contains besides the mud and chert pebbles large rounded quartz grains, some calcareous matrix in places and feldspar crystals (both monoclinic and triclinic), and small green bodies, probably hornblendic.

There are red and brown streaks in the grit several inches thick composed of rounded grains of smoky and clear quartz and a clayey matrix with hematite and limonite. The aspect of these streaks is deceivingly like that of some of the Burden iron ore; the iron content, however, is very small, amounting for the most part to no more than a staining of the clay (fide Newland).

When traced laterally the conglomerate beds were found to form lenses two to three feet thick and 12 to 20 feet wide. A little farther north this arkosic conglomerate forms small lenses, a few inches long, that are scattered through the grit.

These occurrences give the impression that the mud pebbles forming the conglomerate, were piled up by small eddies or crossing waves on the sandy bottom of the sea. Some of these pebble layers are found on the bedding planes (see figure 38), others are intraformational (in one place 11 were counted in 10 feet of grit). Coarse ripple marks were observed years ago on the surface of one bed, with winnows of macerated eurypterids and seaweeds in the valleys of the ripple marks.

Figure 36 Top of anticline in Normanskill grit striking across Catskill creek in Austin glen, Catskill. The Manlius rests horizontally on the grit farther back in the woods. (E. J. Stein photo, 1936)

Figure 37 Heavy Normanskill grit beds. Large, downward concave thrust-plane crosses quarry. The shale containing graptolites and eurypterids is exposed in the upper left corner. Normal fault in background. Broome Street quarry, South Catskill. (E. J. Stein photo, 1936)

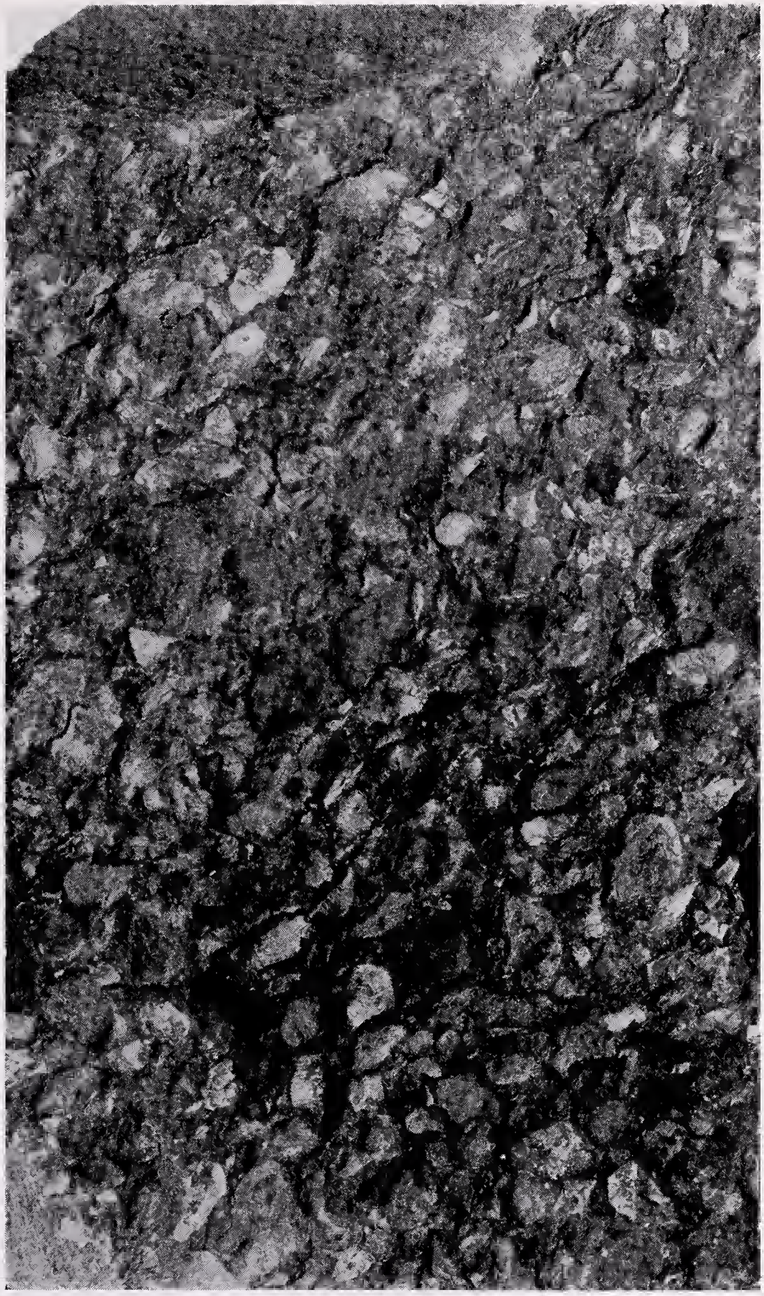

Figure 38 Normanskill grit bedding plane with mud pebbles. Broom Street quarry, South Catskill. (E. J. Stein photo, 1936)

Figure 39 Alternating Normanskill grit and shale. Along New York Central Railroad, one mile south of Linlithgo. See also figure 42. Courtesy of New York Central Railroad. (Sharp photo, 1914)

The crowded clay pebbles on the bedding plane, shown here in figure 38 may well be of the nature of "Ton-Gallen," as the Germans call them: clay balls formed by the breaking up of thin clay-seams on the sandy tideflats, that are broken up by sun and wind and roll up. (Häntschel, '36, p. 341). These ton-gallen occur already in Precambrian formations (v. Bubnoff, '37, p. 37.)

Larger mud pebbles, up to half a foot in diameter are often seen in the grit, as in a road-metal pit along the road north of Catskill. These mud pebbles appear to have been clay balls that rolled along with the current upon the sandy bottom, as one sees them today on the bottom of rivers or bays.

Numerous outcrops, such as the fine sections of vertical beds along the New York Central from Hudson to the south end of the quadrangle and beyond (see figure 39), show the regular, hundredfold repeated alternation of grit and shale.

Owing to their competent character the thick grit beds with intercalated shales that serve as gliding planes, form exquisite material for the orogenic forces. They bend, where pure shale is merely intensely crumpled, into fine upstanding or overturned folds. These are beautifully exhibited along the New York Central railroad (see figures 40 to 43). A fine overturned fold of grit and shale is also seen on the north side of the Catskill creek in Catskill (see figure 44).

A striking exposure of Austin Glen grit and shale is found just north of Tivoli station in an abandoned quarry. Here more than 100 feet of shale and grit are exposed, the grit beds ranging from one foot to 10 feet in thickness. As in other exposures along the railroad on steeply dipping rocks the underside of the grit beds is often marked by mud flow structure, indicating the action of currents and eddies.

At the mouth of the Roeliff Jansen kill at Linlithgo even 100 feet of solid grit are visible.

These and other exposures prove clearly that the Austin Glen member is an exceptional mass of grits and shales that reaches 500+ feet in thickness. The grits, owing to their hardness, massiveness and resistance to erosion, appear in protruding ledges on the surface, while the equally thick masses of shales are buried in valleys and under drift and are shown only in exceptional cases, where river erosion has bared them, as in the Roeliff Jansen kill west of Burden where over 100 feet of black shales are exposed.

Owing to the great thickness of the member it forms a broad belt about five miles wide at the widest part near the southern margin of the quadrangle. As a glance at the southern margin of the Capital District map (1930) will show, however, part of the belt is buried under the Helderberg plateau.

The largest area of exposed Austin Glen grits is on the east side of the river, in Germantown, where many outcrops are seen along the New York road and from Cheviot to Tivoli and Madalin. The grit appears here in a multitude of ridges and ledges, south of Madalin in beds more than 30 feet thick! Black mud pebbles and cross-bedding are here observable in weathered ledges.

The infinitely alternating beds of grit and shale, the lenses of mud pebbles, the cross-bedding, the large mud balls and the mud flow structure altogether give the impression that this formation was deposited in shallow water, probably near shore, where the velocity of the currents was frequently and rapidly changing, the slow currents depositing black and gray mud, the faster ones sandstone and grit.

The *petrographic character* of the Austin Glen grit, as described by Dale ('99, p. 187) agrees with the macroscopic characters given above, all pointing to an abundance of partly fresh material brought to the sea from the weathered surface of near-by land. Dale gives the following description:

It is coarse, grayish, sandy looking. Fresh fracture surfaces are very dark and show glistening glassy quartz grains and very frequently minute, pale, greenish, slaty particles. Under the microscope it consists of angular grains of quartz, orthoclase, plagioclase, and scales of muscovite, probably clastic. The cement contains not a little carbonaceous matter, secondary calcite and pyrite. . . . The marked features are the heterogeneity of the fragments, their irregular size, angular outline, and usually the absence of any arrangement in them.

A further peculiarity of the Hudson grits is that they contain particles of various fragmental rocks, showing that they were derived from the erosion not only of older granites and gneisses, but of sedimentary rocks of Ordovician or pre-Ordovician age; [the particles of clastic rocks were found to consist] of shale, micaeous quartzite, calcareous quartzite, limestone or dolomite, shale and flint. The most abundant were found to be quartzite, slate and shale.

Animals are not likely to flourish on bottoms of moving sand, often overwhelmed by inflows of mud. Fossils are therefore exceedingly rare in the Austin Glen beds. They consist of seaweeds, graptolites and eurypterids. The seaweeds occur as black irregular thick carbonaceous patches. They were originally described as sponges (*Rhombodictyon*) by Whitfield (1886), but later recognized as plant remains (Clarke and Ruedemann 1912, p. 412).

Figure 40 Crest of overturned pitching anticline in Normanskill grit and shale. One surface shows ripple marks. Three-fourths of a mile below Rhinecliff along New York Central Railroad. Courtesy of New York Central Railroad. (Sharp photo, 1914)

Figure 41 Syncline with fault on right cutting off anticline, and anticline on left. In Normanskill shale and grit. Along New York Central Railroad, south of North Germantown. Courtesy of New York Central Railroad. (Sharp photo, 1914)

Figure 42 Large anticline with accessory smaller anticline in Normanskill beds, showing regular alternation of grit and shale. Along New York Central Railroad, south of North Germantown. Courtesy of New York Central Railroad. (Sharp photo, 1914)

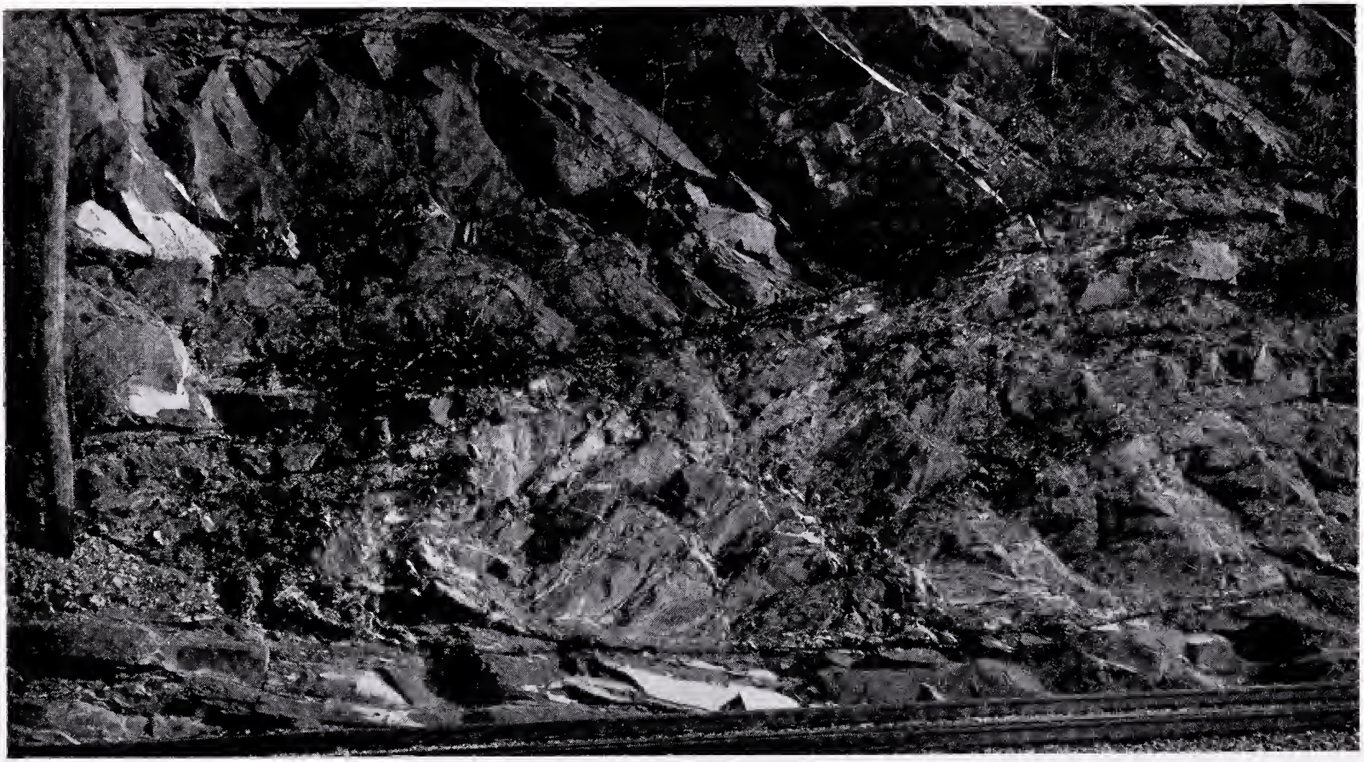

Figure 43 Compressed, recumbent anticline in Normanskill grit. Along New York Central Railroad, south of North Germantown, looking north. Courtesy of New York Central Railroad. (Sharp photo, 1914)

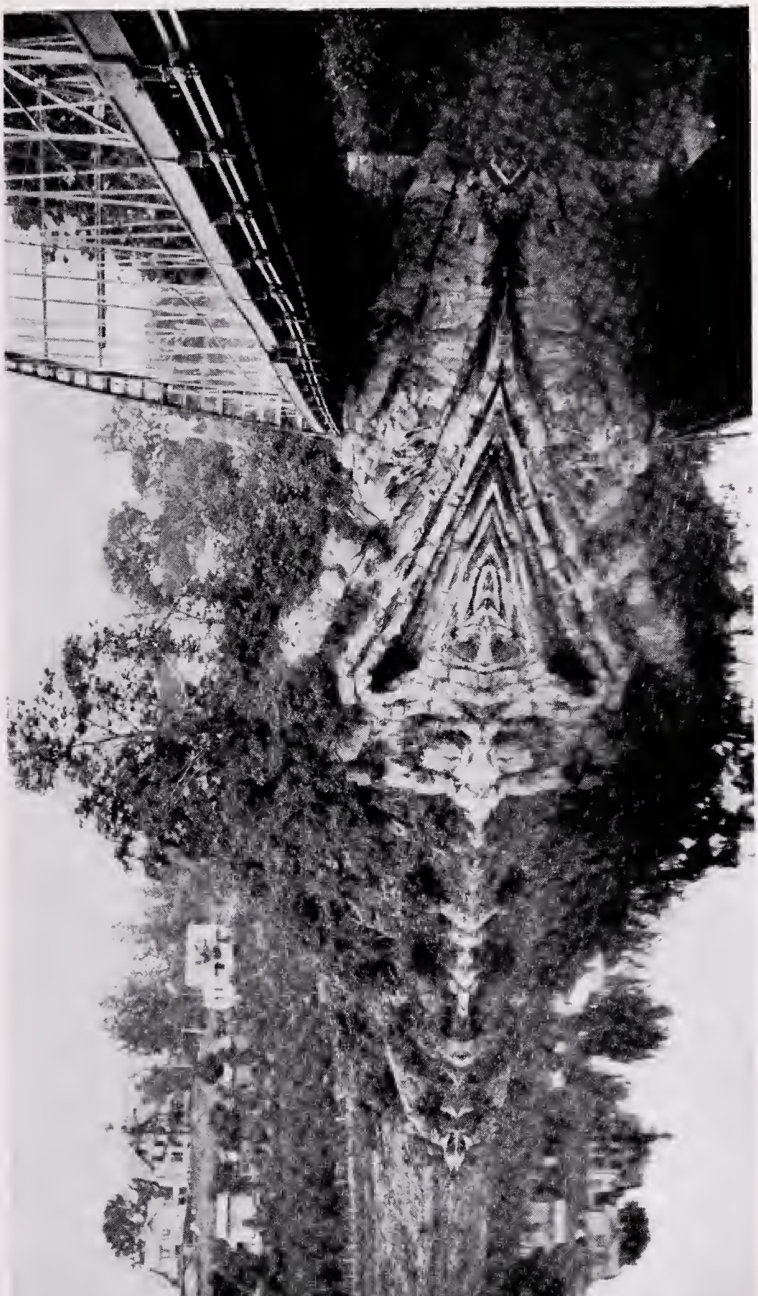

Figure 44 Asymmetric overturned anticline in Normanskill grit. Catskill. (H. Ries photo)

The *graptolites* occur only very rarely and in small faunules in the black shales of the Austin Glen member. Occasionally one sees also a few widely scattered graptolites, mostly broken rhabdosomes of *Climacograptus bicornis,* on the bedding planes of the grit beds. A few such were seen by the writer in the Broomstreet quarry and in outcrops along the New York Central Railroad, and by others in Austin Glen.

Austin Glen has furnished to Chadwick and Robert Jones just below the Helderbergian rocks the following graptolites: *Dicellograptus* sp., *Mastiograptus* sp. nov., *Climacograptus bicornis* Hall, *C. bicornis peltifer* Lapworth. Along the river shore at Catskill Chadwick (letter of October 2, 1936) found *Dicellograptus* cf. *gurleyi* Lapworth and *Glossograptus whitfieldi* (Hall). The largest faunule was found in Broomstreet quarry. It was discovered by Professor Chadwick in black shale and later the associated eurypterids were found by the writer. The graptolite faunule (see Clarke & Ruedemann, 1912, p. 412) consists of:

Dicellograptus gurleyi Lapworth
Climacograptus bicornis Hall
id. var. *peltifer* Lapworth
Cryptograptus tricornis (Carruthers)

A comparison with the Mt Merino fauna shows that this faunule lacks the characteristic elements of the lower Normanskill, especially the prevailing *Nemagraptus, Dicranograptus* and *Dicellograptus* forms.

The eurypterids that were found in the Broomstreet quarry constitute the oldest true Eurypterid fauna known. They were described by Clarke and Ruedemann (1912, p. 413 ff.). The faunule consists of:

Eurypterus chadwicki C. & R.
Eusarcus lingulatus C. & R.
Dolichopterus breviceps C. & R.
Stylonurus modestus C. & R.
Pterygotus? (*Eusarcus*) *nasutus* C. & R.
P. normanskillensis C. & R.

Later (Ruedemann, 1934) *Pterygotus normanskillensis* was also found in Austin Glen grit and shale at Kenwood, a new form *Hughmilleria prisca* Ruedemann was obtained in the Normanskill (Mt Merino) shale at Glenmont, and a still older form (*Pterygotus deepkillensis*) was even obtained in the Deepkill graptolite shale at the Deep kill.

This strange and rare cooccurrence of planktonic graptolites with eurypterids has played a prominent role in discussions on the habitat of eurypterids. The fact that both the very fragmentary eurypterids and the few graptolites occur in the Austin Glen member—the grit of which points to near-shore conditions of deposition—would seem to mark the assemblage as produced by accidental washing of planktonic graptolites on littoral deposits, perhaps of deltaic nature. This would make the whole occurrence a very exceptional one.

Rysedorph Conglomerate

Two outcrops of Rysedorph conglomerate have been found on the Catskill quadrangle, one along the New York road at the east foot of Mt Merino, the other one and one-half miles north of Elizaville, on a ridge east of the road leading to Manorton. As this formation has been fully described before by the writer (1901, 1930), from better outcrops in the Capital District, we will quote here from the 1930 publication (p. 104 ff.):

Rysedorph conglomerate. Two of the most interesting rocks of the capital district are a conglomerate and a fault breccia. The conglomerate was fully described by the writer in 1901 and termed the Rysedorph conglomerate, from its exposure on Rysedorph hill, a prominent eminence two miles southeast of Rensselaer (figure 61). . . .

The Rysedorph conglomerate has a wide distribution within the Normanskill shale belt in the Capital District; but it also extends into the Schuylerville quadrangle, where the writer has described it from the base of Bald mountain ('14, p. 80); and it is found at Schodack Landing. . . .

The typical outcrop on top of Rysedorph hill is a vertical ledge; the main bed is two and one-half feet thick. It is distinctly underlain by black and green shales on the west side. This condition led Emmons ('55, pt. 11, p. 72), in his endeavor to establish the Taconic system, to cite this hill as one of his critical localities. As his section indicates, Emmons believed he had the "Calciferous sandstone" (Beekmantown), resting unconformably on the "green Taconic slates," thereby proving the primordial age of the latter. The writer has fully described the later history and interpretations of this interesting locality, ('01, p. 4 ff.). . . .

A study of the conglomerate by the writer was carried out with a wagonload of pebbles, most of which being composed of intensely hard siliceous limestone which broke through the fossils, had to be baked in the kitchen range and dumped into cold water, to assure breaking along the fossils. The material proved fully worthy of the work spent on it. There were found seven kinds of pebbles which furnished an amazingly rich and strange fauna. The writer ('01) described 84 species from this small locality, a prodigious number for Paleozoic outcrops, and 25 of these were new, among them six new trilobites. . . .

The most interesting facts obtained were that the faunas of the pebbles ranged from the Lower Cambrian to the Trenton, that the Chazy is represented in the pebbles, which is only known on the surface in northern New York and Vermont, and that the Mohawkian fauna contains Atlantic elements hitherto known only from Europe, but which since have been found at Quebec, in Pennsylvania, Virginia and Alabama in the identical forms first described from Rysedorph hill. It may be added that, with the exception of the Lower Cambrian limestone, none of the groups of pebbles with their faunas can be referred to ledges of rock in eastern New York or the neighboring parts of Vermont and Massachusetts, which means, in our view, that they came from rocks in the east and northeast which are now so metamorphosed (as the Stockbridge limestone and marble etc.) that the faunas are unrecognizable, just as the shales of the slate belt are metamorphosed farther eastward into schists (the Berkshire schist). This small ledge thus presents us, like a page from a lost work, with a glance into hidden treasures that may never become more fully revealed to science.

The following are the groups of pebbles from the Rysedorph hill conglomerate and their faunas:

1 Gray limestone of Lower Cambrian age
   Hyolithellus micans *Billings*
2 Gray and reddish sandstone
   No fossils
3 Black crystalline limestone (Chazy limestone)
   Bolboporites americanus *Billings*
   Palaeocystites tenuiradiatus (*Hall*)
4 Lowville limestone
   Phytopsis tubulosa *Hall,* Tetradium cellulosum *Hall*
5 Black compact limestone
6 Reddish gray compact limestone
7 Gray crystalline limestone, which often changes into a veritable shell rock.

The most important and interesting forms of the black limestone pebbles are the brachiopods *Plectambonites pisum* and *Christiania trentonensis,* and the trilobites *Tretaspis reticulata, T. diademata, Ampyx hastatus, Bronteus hastatus* and *Sphaerocoryphe major,* because they all belong to extremely rare genera or species. Representatives of the genus *Tretaspis* were before known only from Great Britain.

The brachiopod *Plectambonites pisum,* a small, almost globular shell, is so common in these beds that it makes an excellent index fossil. It has also been found in other outcrops of the Rysedorph Hill conglomerate (see below), and in association with *Christiania trentonensis* and *Tretaspis reticulata* has been traced into Virginia (Bassler, '09) and Alabama (Butts, '26) and Quebec (Raymond, '13). The formation in which they occur is the Chambersburg limestone, a thick formation that comprises the uppermost division of the Chazy (the Blount), and the Black River group of New York (including the Lowville, Watertown and Amsterdam limestones).

The Rysedorph conglomerate is exposed in a number of other localities in the Capital District. It appears in a five-foot bed at the upper falls in a ravine just east of Papskanee island and thence south in a series of outcrops on top of the Van Denburg ridge. Another interesting outcrop is on Papskanee island on the shore of the Hudson river. Here it forms a hill and cliff on the river bank, on which the clubhouse of the Papskanee Boat Club stands. The writer has picked up there Ordovician brachiopods, as *Plectambonites sericeus,* alongside of recent fresh-water gastropods at the edge of the water. An excellent exposure of the conglomerate is seen in the big cut of the Boston and Albany Railroad on the hillside south of Rensselaer. Here it is involved with Normanskill shale, grit and chert.

A fine series of outcrops of the Rysedorph conglomerate is exposed in the lower Moordener kill near Castleton. Dale ('04, p. 34) describes five different outcrops of conglomerate from the Moordener kill from Prindle's observations, the fifth being 50 feet thick, and the third 12 feet thick.

We consider all these outcrops as belonging to the same bed, repeated by folding and doubled in places upon itself. The matrix and pebbles, as well as the fossils, are the same in all outcrops. The first outcrop is below the lower falls, about 200 feet upstream from an outcrop with Normanskill graptolites.

Another conglomerate bed, five feet thick, forms the top of the lower falls, containing boulders two feet in diameter (composed of the brownish sandy calcareous matrix of the Rysedorph conglomerate and squeezed off the main body). The conglomerate here contains also white and brown quartz pebbles and black chert pebbles. Two hundred paces farther up the conglomerate appears again, 12 feet thick, another is below the upper falls and 500 feet above the upper falls is a fifth outcrop. . . .

Two further outcrops of brecciated conglomerate are found in the Vlockie kill, the next creek south of the Moordenerkill, one of these six and one-half feet thick, and both closely associated with the black white-weathering Normanskill chert and black Normanskill graptolite shale.

The Moordener kill conglomerate (see Ruedemann, '01, p. 544) contains Lowville limestone boulders with "bird's-eyes" (*Phytopsis tubulosa*) and *Tetradium cellulosum,* and still larger boulders (two and one-half feet in diameter) of dark gray Trenton limestone. . . .

Northward of Rysedorph hill the conglomerate is very little exposed. An excellent exposure was, however, found as far north as Bald mountain, northeast of Schuylerville, where it forms the northern point of the wedge of Bald Mountain limestone, and lies between the Snake Hill shale and Lower Cambrian, separated from both by overthrust planes. . . .

The origin of this strange rock has been the subject of animated discussion, whenever it has been studied by geologists. The writer ('01, p. 109) has fully discussed the earlier views and will here but briefly mention them. Walcott, in his well-known paper on intraformational conglomerates ('93, p. 191), suggested that the sea bed was raised in ridges or domes above the sea level, and thus subjected to the action of seashore ice, and the aerial agents of erosion. It was the writer's opinion that the erosion of anticlinal ridges would be best suited to furnish the variety of materials of different ages, such as is found in the Rysedorph conglomerate. Others have suggested flood-plain deposits and others glacial beds or sea-ice transportation. To the writer, the presence of fossils in the calcareous matrix is of decisive importance in proving the submarine origin of the conglomerate either along a shore swept by currents of an advancing sea that deposited the coarse material derived from the promontories and rivers, or on the flanks of an anticline that was being eroded. The extension of the conglomerate in a north-south direction, as well as the crude assortment of the material, shown by strings of pebbles, especially on Rysedorph hill, and the fact that in some places the pebbles are still angular and appear to belong to a continuous bed broken up and at once recemented, all these observations suggest the deposition of the bed in the sea and the derivation of the material from exposures along an anticline. There are certain features in the conglomerate which suggest to us a derivation of much of the material of the pebbles from rocks outcropping farther north. These are especially the rare Chazy and the more common pebbles of typical Lowville limestone. There is no Lowville limestone known in the East at all, and west of the Rysedorph conglomerate not until the upper Mohawk valley is reached.

In the first paper ('01) dealing with this conglomerate, we placed it within the Normanskill shale, seeing in the Trenton fauna of the conglomerate evidence of the Trenton age of the Normanskill shale. With the recognition of the fact that the typical Normanskill shale is older than the Trenton, it became necessary to assume that the Rysedorph conglomerate either is intercalated in the upper division of the Normanskill (Magog shale) of Black River and perhaps earliest Trenton age or rests entirely on the series. The relative position of the conglomerate to the shales gives no indication of its age, except that, as at the Moordener kill, it is undoubtedly interfolded with Normanskill shale, which yet must be considerably older. We are now placing the Rysedorph conglomerate at the top of the whole Normanskill shale and below the Snake Hill shale, correlating it with the lower Trenton.

Since the preceding was written important new views have been advanced on the origin of these polymikt conglomerates and breccias. Cornelius ('27) has pointed out that polymikt breccias rarely, if ever, are of tectonic origin, and that breccias which are bound to definite horizons, which contain components that are not known in the immediate neighborhood and which show no distinct dependence from dislocations and no traces of tectonic effect within themselves, perhaps even contain fossils, can in no case be tectonic breccias. These criterions if correct clearly rule our Normanskill breccias out of the class of tectonic breccias.

On the other hand recent work (Bailey, E. B., Collet, L. W. and Field, R. M., 1928) has produced good evidence that such polymikt conglomerates and breccias are produced by submarine landslips. This is probably true of the well-known Quebec conglomerates which are also associated with graptolite beds and which according to Dresser (1925) mark a distinct horizon in the "Quebec group," as well as of younger similar conglomerates, as that of the Pennsylvanian Caney shale of Oklahoma (see Kramer, 1933). It is a common feature of these strange polymikt conglomerates that they not only contain a great mixture and variety of pebbles and boulders, but also boulders of amazing size. This is best known of the Caney shale, but also apparent in the Quebec conglomerate. Also the outcrop north of Elizaville contains boulders of Trenton limestone 20 feet in diameter and recent erosion has exposed an enormous block (or country rock?) of Bald Mountain limestone directly below the Rysedorph conglomerate cliff on Rysedorph hill.

It is very probable that these conglomerates are produced on an extensive scale on submarine slopes by periods of violent earthquakes (see page 180). This would explain both the size and the variety of the boulders and pebbles. As Dresser (1925) has pointed out, the Quebec-Magog conglomerate is a distinct horizon marker in the "Quebec group." In the slate belt of eastern New York the Rysedorph conglomerate is now known to appear intermittently from Bald mountain in Washington county to Elizaville in Columbia county, a distance of 75 miles, but it is probably distributed much farther north and south.

The Lacolle conglomerate described recently by Clark and McGerrigle ('36) from southern Quebec and containing pebbles (phenoclasts) of Beekmantown, Chazy and Lower Trenton is of the same nature as pointed out by the authors as the New York (Rysedorph) conglomerate. They consider it as caused by a local tilting when but a small amount of the Trenton had been deposited.

Some of the large masses of breccias, as those in western Newfoundland and in the Quebec region are now considered by some authors as due to strong earthquakes. Also in Great Britain seismicity is recognized as an agent producing breccias and in Ireland (Lamont 1936) certain graywackes are "unquestionably attributable to it" (seismicity). These are all found in geosynclines where the steeper submarine grades occur.

Figure 45 Thin veneer of Rysedorph polymikt conglomerate on shale. East foot of Mt Merino. (E. J. Stein photo, 1935)

Figure 46 Enlargement of portion of polymikt conglomerate, showing black chert pebbles and a larger pebble of Lowville limestone at right margin with worm borings ("Birdseye limestone").
(E. J. Stein photo, 1935)

Along the Mt Merino road two conglomerate beds (see figures 45 and 46) are found in apparent association with Deepkill graptolite beds (see page 87). These beds are each about one foot thick and separated by a half foot bed of shale with some pebbles. Above and below are greenish gray sandy shales. The conglomerate beds are lenticular, thickening in some places and pinching out in others. The matrix is calcareous with much sand (also rounded grains). The pebbles are as much as 10 inches across and of a great variety of lithic composition. Most are limestone of various composition. The most striking are of the appearance of typical "Bird's-eye" (Lowville) limestone, some six inches across (see figure 46 at upper right). Other limestone pebbles are 10 inches in diameter. Most pebbles are well rounded, but some are angular. There is much black chert (one pebble 10 inches across), and also ferruginous quartzite is seen. The composition of the pebbles indicates that the conglomerate is younger than the Normanskill chert and about the age of the Rysedorph conglomerate. It is therefore necessary that the conglomerate and the adjoining Deepkill shale be of greatly different age and separated by a fault. The fact is that the two sets of formations abut in the locality at an angle which indicates disturbed relations as does the appearance of strips of Ash Hill quarry beds of Deepkill age and of Normanskill grit on both sides of the road and of the Rysedorph conglomerate.

No fossils have been collected in the outcrop at the foot of Mt Merino, but the character of the pebbles clearly indicates an age of the conglomerate younger than the chert pebbles and younger than the Lowville limestone.

The outcrop north of Elizaville covers an amazing area for it is some 550 feet wide across the top of the hill, with the beds dipping at 60° east at the western edge and about 45° east in the eastern edge. It may therefore be the top of a flat, overturned anticline, and not be indicative of the thickness of the formation. The majority of the pebbles (see figure 47) are limestone of Trenton appearance. The conglomerate is followed on the east by Mt Merino phyllite. Only a few fossils were observed, among them *Rafinesquina alternata* Conrad and *Plectambonites pisum* Rued., a characteristic brachiopod of the Rysedorph conglomerate, but also occurring in the Chambersburg limestone (Christiania bed) of Pennsylvania, Maryland and Virginia (Bassler, 1919, p. 253). The Christiania bed is of late Black River age. As the *Plectambonites pisum* is also found in the matrix of the conglomerate, this may well be the age of the conglomerate.

Gordon (1911, p. 91) has described a limestone conglomerate containing *Solenopora compacta* from the Poughkeepsie quadrangle. This conglomerate is associated with limestone and apparently is not of the polymikt type.

SILURIAN AND DEVONIAN STRATA OF BECRAFT MOUNTAIN

Doctor Chadwick has described the Siluro-Devonian Helderberg belt in the western part of the Catskill quadrangle.

The greater eastward extension of this imposing mass of rocks before the Hudson river broke into it is proved by two outliers, one the Becraft mountain outlier and another a very small relict of Silurian and Devonian limestone, Mt Ida at Mellenville on the Kinderhook quadrangle, northeast of Hudson.

The Becraft Mountain outlier early attracted the attention of geologists. As early as 1828 Silliman described the "marble of Hudson." The first detailed work was done by W. M. Davis ('83) who also published the first map. Later Beecher ('97) and Clarke ('00) became interested in the faunas, notably the Oriskany fauna, Clarke publishing a memoir (N. Y. State Mus. Mem. 3) about it. Finally Grabau ('03) was engaged by Clarke to write an elaborate report on the stratigraphy and tectonics of Becraft mountain. In this report Grabau gives also a full history of the investigation of Becraft Mountain geology. Those specially interested in Becraft mountain are referred to the full, painstaking account of Professor Grabau, which contains a multitude of data for which there is no place in this report.

The following formations can be recognized in the Becraft Mountain section:

Silurian:	Manlius limestone
Devonian:	Coeymans limestone
	New Scotland shales
	Becraft limestone
	Alsen limestone
	Oriskany beds
	Esopus grit and Schoharie grit
	Onondaga limestone

Manlius Limestone

The Manlius limestone rests with a distinct angular unconformity (see figure 4) on the Normanskill shale on the western side of

Figure 47 Thick ledge of Rysedorph conglomerate. Two miles north of Elizaville. (J. W. Graham photo, 1935)

Figure 48 Schodack-Manlius contact at Hudson cemetery. The person is standing on the Schodack shale. (E. J. Stein photo, 1936)

Becraft mountain and on Schodack limestone on the three other sides.

At the southwest end of the Atlas Cement Company quarry, visible from the state road depressions in the Normanskill shale (see figure 4) are filled with an iron-stained limestone, apparently either the product of the advancing Manlius sea or a relict of the earlier Rondout sea. Farther north in the quarry three feet nine inches of sandy basal rock with a calcareous matrix is seen. At the north side of Becraft mountain the contact has recently become well exposed by enlargement of the Hudson cemetery below the Hudson "Old City Quarry." T. E. R. A. work has there brought out two to three feet of sandy basal rock of the Manlius (see figure 48), underlain by conformable Schodack beds, of which about five feet of alternating black shale and sandy weathering thin limestone strata are exposed. At the southwest corner of Becraft mountain the contact of Normanskill and Manlius beds is a sharp line, without intervening sandy beds.

Grabau ('03, p. 1039) measured at the northern margin of the mountain near Greenport a section where he obtained a thickness of 55 feet of Manlius. The rock is a compact finely stratified lime-mud rock. The most common fossils are the ostracod *Leperditia alta* and the *Stromatoporas*. The latter form two reefs: the uppermost, varying between three and four feet in thickness, forms the top of the Manlius; the other is near the base.

Other species are the guide-fossil *Spirifer vanuxemi* Hall, *S. corallinensis* Grabau, a species first described from the Cobleskill limestone, but also occurring in the upper Stromatopora bed, *S. eriensis* Grabau var. The latter species occurring at Williamsville connects *corallinensis* with *vanuxemi* according to Grabau. *Camarotoechia hudsonica* Grabau and *Rhynchospira excavata* Grabau are species first described and only known from Becraft mountain. Also a *Whitefieldella* (cf. *nitida* Hall) occurs in the Becraft Manlius.

Coeymans Limestone

This is a compact, finely crystalline, generally dark-colored limestone. Its most characteristic fossils are *Atrypa reticularis, Sieberella coeymanensis* Schuchert (formerly *Gypidula galeata* Conrad) and crinoid stems. Its thickness in the Becraft section is about 45 feet, the lower 20 to 25 feet of which are generally massive-bedded and with the Manlius commonly form the vertical cliff that bounds the Becraft Mountain area. The upper portion of the Coeymans is thinner bedded, with more or less shaly layers. Grabau cites the following 33 species from Becraft mountain:

Bryozoans:
Monotrypa tabulata (Hall)
Corals:
Favosites helderbergiae Hall
Enterolasma strictum Hall
Fistulipora torta Hall
Brachiopods:
Roemerella grandis (Hall)
Lingula rectilatera Hall
Dalmanella subcarinata Hall
D. perelegans Hall
Leptaena rhomboidalis (Wilckens)
Stropheodonta varistriata Conrad
S. varistriata var.
Strophonella headleyana Hall
S. leavenworthana Hall
S. punctulifera (Conrad)
Cyrtia dalmani Hall
Spirifer perlamellosus Hall
S. cyclopterus Hall
S. macropleura Conrad
Uncinulus nucleolatus (Hall)
Eatonia peculiaris Conrad
E. medialis Conrad
Atrypa reticularis (Linné)
Gypidula galeata (Conrad)
Anastrophia verneuili Hall
Meristella princeps Hall
Mollusks:
Pterina (?) *textilis* (Hall)
Platyceras platystoma Hall
P. subnodosum Hall
P. cf. *retrorsum* Hall
P. unguiforme Hall
Trilobites:
Dalmanella micrurus (Green)
D. cf. *pleuroptyx* (Green)
Phacops logani Hall

The fauna indicates a pronounced brachiopod facies.

Layers of chert observed in some outcrops and the transitional character of the upper layers (with New Scotland species associated with *Sieberella coeymanensis*) indicate the presence of the *Kalkberg member* of the Coeymans.

New Scotland Beds

The New Scotland beds are thin-bedded argillaceous and siliceous rocks with a variable amount of lime. The beds are very calcareous and heavy-bedded when freshly broken, as in the quarry face of the Jonesburg stone crusher. Grabau measured 68 feet. The fauna consists again largely of brachiopods. Grabau gives the following list:

Corals:
Enterolasma strictum Hall
Brachiopods:
Rhipidomella tubulostriata Hall
R. eminens Hall
R. oblata Hall
Dalmanella perelegans? Hall
D. cf. *subcarinata* Hall
Schizophoria cf. *multistriata* Hall
Orthothetes radiatus Fischer
O. woolworthanus Hall
Stropheodonta becki Hall
Strophonella headleyana Hall
Leptaena rhomboidalis (Wilckens)
Spirifer macropleura (Conrad)
S. perlamellosus Hall
Eatonia peculiaris Conrad
E. medialis Vanuxem
Meristella cf. *arcuata* Hall
M. subquadrata Hall
Anastrophia verneuili Hall
Mollusks:
Diaphorostoma ventricosum (Conrad)
Platyceras bisulcatum Hall
P. ventricosum Conrad
P. sp.
Trilobites:
Dalmanites micrurus Green
D. nasutus Conrad
D. pleuroptyx? Green

Becraft Limestone

The Becraft limestone, according to Grabau, is "a light gray, crystalline limestone, becoming in places a shell-marble. Certain beds, especially near the bottom are composed of crinoid joints, and the bases of *Aspidocrinus scutelliformis,* while near the top shells of *Gypidula pseudogaleata* locally make up the rock." Grabau measured a total thickness of 40 to 45 feet.

The most abundant and characteristic fossils are *Spirifer concinnus, Gypidula pseudogaleata, Atrypa reticularis* and *Uncinulus campbellanus.*

Grabau lists the following forms:

Crinoids:
- *Aspidocrinus scutelliformis* Hall

Bryozoans:
- *Fenestella* sp.

Brachiopods:
- *Schizophoria multistriata* Hall
- *Leptaena rhomboidalis* (Wilckens)
- *Spirifer concinnus* Hall
- *S. perlamellosus* Hall
- *S. cyclopterus* Hall
- *Rhynchospira formosa* Hall
- *Uncinulus campbellanus* (Hall)
- *U. nobilis* Hall
- *Atrypa reticularis* (Linné)
- *Meristella princeps* Hall
- *M. arcuata* Hall
- *Eatonia medialis* Vanuxem
- *Trematospira perforata* Hall
- *Gypidula pseudogaleata* Hall
- *Rensselaeria mutabilis* Hall

Mollusks:
- *Platyceras* cf. *gibbosum* Hall

The top layers of the Becraft limestone contain a transition fauna to the Port Ewen fauna, as follows:

Bryozoans:
- *Monotrypa sphaerica* (Hall)

Brachiopods:
- *Leptaena rhomboidalis* (Wilckens)
- *Spirifer concinnus* Hall
- *Rhynchospira formosa* Hall
- *Eatonia medialis* Vanuxem
- *Gypidula pseudogaleata* Hall
- *Spirifer* sp.

Alsen Limestone

The 25 feet on Becraft mountain originally ascribed to the Port Ewen beds by Grabau ('03, p. 1034, 1063), have since been recognized by him ('19, p. 470) as Alsen limestone. The Port Ewen beds, exposed at Port Ewen near Rondout with a recorded thickness of 222 feet, typically are shaly limestones, similar both in lithologic character and fossil content to the New Scotland beds, a fact which has led to confusion. Grabau ('03, p. 1065) found the supposed Port Ewen of Becraft mountain represented by dark crystalline limestones, particularly characterized by *Monotrypa tabulata.* The dark blue-gray color, weathering buff, the finer grain and the occurrences of black chert seams distinguish the Alsen from the Becraft. In field outcrops it might at first glance be confused with the Kalkberg limestone from which the presence of the brachiopod *Spirifer* *concinnus* and the bryozoan *Monotrypa tabulata* help to distinguish it. Grabau, in a preliminary list, cites 18 species from the Becraft Mountain exposure, as follows (*ref. cit.* p. 1066, 1067):

Corals:
- *Cladopora* cf. *styphelia* Clarke

Bryozoans:
- *Monotrypa tabulata* (Hall)

Brachiopods:
- *Leptaena rhomboidalis* (Wilckens)
- *Stropheodonta* sp.
- *S.* (*Leptostrophia*) *magnifica* Hall
- *Spirifer concinnus* Hall
- *S. cyclopterus* Hall
- *S. perlamellosus* Hall
- *S.* sp.
- *Rhynchospira formosa* Hall
- *Eatonia peculiaris* Conrad
- *Meristella typus* Hall
- *M.* cf. *princeps* Hall
- *M.* sp.
- *Rensselaeria* sp.

Mollusks:
- *Platyceras* cf. *trilobatum* Hall

Oriskany Beds

The Oriskany beds are siliceous limestones with an abundance of chert, according to Grabau not more than a few feet thick, probably not much more than one foot. Yet this formation owing to its rich and novel fauna has received more attention than any other of the Becraft Mountain strata. The fossils are only obtainable in the rusty-weathered rock, where the lime has been leached out, as external and internal molds, which, however, give exquisite casts. Clarke ('00, p. 65) lists no less than 113 distinct specific forms, among which are a great number of new species (mostly brachiopods and trilobites), which one may see in his beautifully illustrated memoir.

Esopus and Schoharie Grits

The Esopus and Schoharie grits according to Grabau

are dark, chocolate-colored, gritty shales, with a combined thickness of about 300 feet, of which about one-third is considered as belonging to the Esopus. The dividing line is drawn on lithic characters, which are chiefly expressed in topographic features. The Esopus rapidly crumbles into small cubical fragments under the influence of the weather, and hence presents rolling surfaces, which commonly constitute the best farming ground of the region. The Schoharie, on the other hand, resists the weather more easily, but generally has its clevage planes well developed by the weather. These are commonly at a high angle, and their presence obliterates the original bedding planes. The topography of this rock is rugged, with numerous ledges, and hence is generally left wooded. The best exposure of the Esopus is above the contact line with the Oriskany on the west side of the mountain.

Clarke (*loc. cit.* p. 14) has recorded the following species from the Schoharie:

Dalmanites anchiops, Phacops cf. *bombifrons, Coelospira* cf. *camilla* and *Chonetes* cf. *arcuatus.*

Onondaga Limestone

The Onondaga limestone, the highest formation of Becraft mountain, has only a very limited outcrop on the top of the ridge in the southeastern portion of the mountain. There is altogether exposed about 20 feet of light gray, finely crystalline limestone, the upper part of which is very cherty. Clarke has recorded *Spirifer raricosta* and *Zaphrentis, Orthoceras* and *Euomphalus* from the upper cherty beds, and *Odontocephalus selenurus, Spirifer varicosus, Atrypa reticularis, Leptaena rhomboidalis, Streptorhynchus pandora, Chonophyllum, Zaphrentis, Favosites* and *Stromatopora* or *Fistulipora* from the lower beds.

Tectonic Features of Becraft Mountain

The tectonic features of the western Siluro-Devonian belt are fully described in this report by Doctor Chadwick. We will add only a note on the structure of Becraft mountain, because this lies outside of the area studied by him. The Becraft Mountain geology has already been elaborately worked out by Professor Grabau, both as to its stratigraphy and as to its tectonic character. We have the great advantage of having been conducted by our friend Grabau over the most interesting structural part of Becraft mountain which on close study proved to be quite complex through the development of numerous folds and faults, though not quite so intensely disturbed as the area on the other side of the river.

Grabau ('03, p. 1071) is inclined to consider the Becraft Mountain outlier as a part of a deep synclinorium. He writes:

> Whether Becraft mountain represents a fault block of the Helderbergs dropped down among the "Hudson River" strata and so preserved from erosion, or whether its low lying position with reference to the Hudson River beds surrounding it, is due to the fact that it forms an axis of a particularly deep syncline, which during the peneplanation of the surrounding country was too low to suffer erosion, is not easy to determine. Certainly, if the strata on the west of the mountain were continued upward at the same angle with which they now dip into the mountain, they would pass above the highest point of Mt Moreno, which is the highest mass of Hudson River strata lying between Becraft and the Helderbergs. The fact also that Mt Ida, lying in the direction of strike of the Becraft strata, has a synclinal structure, indicates that they are one and the same part of the low lying synclinorium.

He has distinguished and described as riding on the master syncline three principal folds and several minor folds between the major ones.

The principal folds are strongly asymmetric, their western limbs varying from steeply inclined through perpendicular to strongly overturned. In addition to this, the eastern side of the mountain is strongly diversified by numerous faults.

Grabau adds that the general pitch of the Becraft syncline is toward the southwest, but that there is also a local pitch to the northeast in the strongly folded southwestern area.

Thus a basin-shaped appearance is produced, with a successive rimming around of the outcrops of the lower about the higher strata.

The faulted district begins on the northeastern corner of the mountain and extends along the eastern margin to the southwestern margin (see figure 49). Grabau has distinguished 21 faults; most of them are gravity or normal faults, many with vertical or very steep hade and often small displacement; one is a thrust fault, and most are longitudinal or strike faults, some produced by the collapse of the keystone of a small anticline, and there are also a few cross faults.

It is a difficult task to make out all small faults in a broken-up wooded area such as Becraft mountain and it is easy there to mistake monoclinal flexures or slight shifts in dip and strike for indications of faults of small throw that are not exposed. It is therefore possible that some of the faults with better future outcrops may not prove actual breaks in the rock. The drawing of fault lines on slim or even unwarranted evidence can easily be overdone. There are maps of Adirondack quadrangles, published and unpublished that are regular checkerboards of faults that could not be located by later observers, because they were inferred from topographic features.

STRUCTURAL GEOLOGY

The Catskill quadrangle in its structural geology is a segment of the Hudson Valley-Lake Champlain depression that extends from north to south between the Green Mountain-Taconic Mountain folds in the east and the Adirondacks and the Helderberg plateau in the west. The quadrangle, therefore, shares its principal structural features with the whole physiographic unit.

Cushing and Ruedemann ('14) have fully described the structural geology of the Saratoga and Schuylerville quadrangles and Ruedemann ('30) has described that of the Capital District. As the latter area is separated from the Catskill only by the Coxsackie quadrangle, we can quote from our bulletin to obtain a general survey of the tectonic conditions in the Hudson valley in the area and add the specific irregularities of the Catskill quadrangle.

Figure 49 Thrust in Devonian strata near Smith's Inn, south end of Becraft mountain. Trace of thrust shown by ink in the photograph, is outlined by a calcite band. Coeymans strata above, New Scotland below. (From Schuchert & Longwell, 1932)

In the structural history of the district we have to distinguish between three periods of folding and two of faulting, which formed the last phases of the two last periods of folding.

The first period of folding was Precambrian in age. It produced several long barriers, running in north-northeast to south-southwest direction across the district, and forming two or more troughs. Two of these troughs we have positively recognized and designated as the eastern and western troughs. They are characterized by their entirely different geologic series of formations, as we have fully set forth in the preceding chapter. The eastern trough is the one which contains the Lower Cambrian beds and the long series of graptolite shales, the Schaghticoke, Deepkill and Normanskill shales and the Snake Hill beds. Ulrich and Schuchert ('01) have termed this the Levis trough, from Point Levis in Canada, where the graptolite shales and other rocks of the trough are well exposed. It is bounded on the east by the Green mountain barrier, and on the west by the Quebec barrier. The latter separates it from the Chazy basin and its southern continuation which we have termed the western or Lower Mohawk trough ('14, p. 140).

The western trough [see figure 50] contains the "normal series" of beds, namely: the Potsdam sandstone, Theresa formation, Little Falls limestone, Beekmantown and Chazy beds farther north, the Amsterdam limestone, Glens Falls limestone, Canajoharie shale, Schenectady shale, Indian Ladder beds and the Helderberg series of Silurian and Devonian formations. A minor barrier seems to have separated this trough in the west, at least at certain times, from the series of formations found in the upper Mohawk valley.

The Green Mountain and Quebec barriers, delimiting the Lower Cambrian sedimentation, must have been present at the beginning of Lower Cambrian time and arisen, probably as low folds, in Precambrian time. They are prenuncial in their direction and location of the much greater folding in Ordovician and Carboniferous time. They arose in a geosyncline, or broader trough, (Schuchert's eastern proterozoic geosyncline) that extended in later Precambrian time from the northern Atlantic (or its ancestor Poseidon), beyond Newfoundland, in a southwest direction to the present site of the Gulf of Mexico. To the east of it were still broad "borderlands of the continent" (Nova Scotis in the north, Appalachis in the south), which furnished the material for the great thicknesses of formations in the eastern trough.

These two troughs persisted through Cambrian and Ordovician time according to the record they have left in the sediments and fossils. They were, however, more or less independent from each other, so that one could be drained while the other was inundated. . . .

The second folding that affected the rocks of the Capital District was the Taconic folding, named after the Taconic mountains on the New York-Massachusetts boundary line. This folding took place at the end of the Ordovician period, according to general assumption. It was believed to have extended over such a wide area in eastern

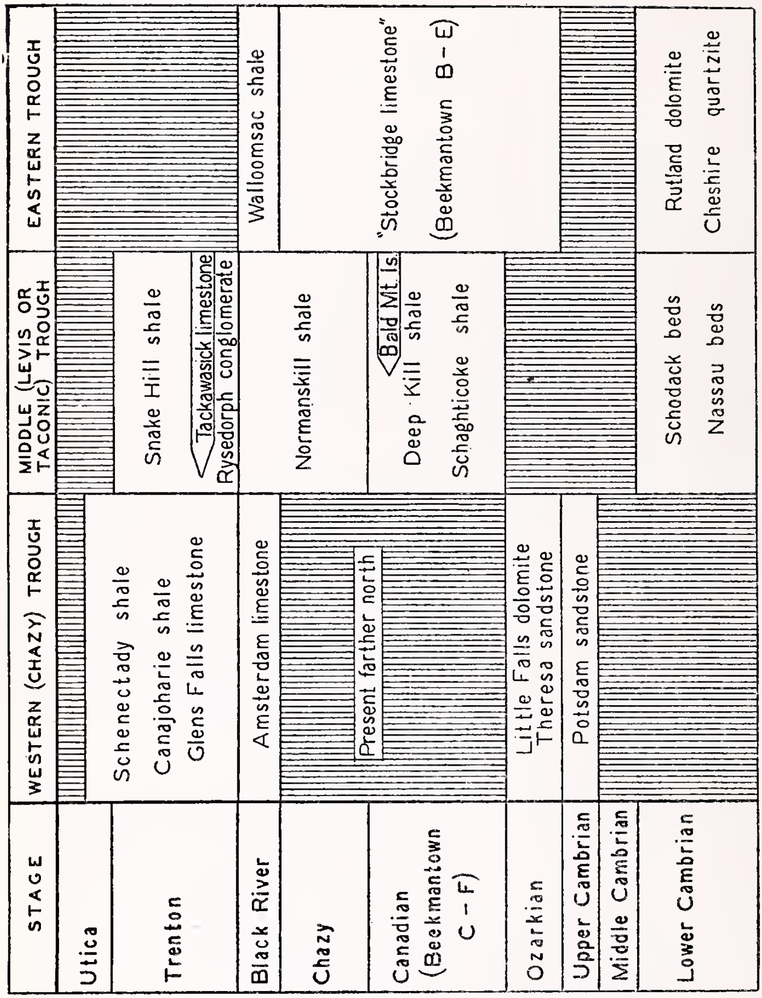

Figure 50 Diagram of the three supposed troughs in the shale belt of the upper and middle Hudson valley

North America that Dana termed it the Taconic Revolution. It has more recently been claimed by Clark ('21) that the Taconic folding, at the close of the Ordovician, was localized in eastern and northeastern New York State. In this region, however, we have evidence of a very extensive folding first, followed by equally profound and widespread overthrust faulting.

The rocks of the eastern trough are everywhere intensely folded; those of the western trough are only faulted, or but slightly folded, as in the Helderbergs by a later post-Devonian revolution.

Being for the most part incompetent shales, the rocks are mostly closely folded, the folds turned over or bent over westward, the packed folds producing the so-called isoclinal folding, where all beds, the anticlines and synclines being deeply worn off, seem to incline in the same direction, in our shale belt toward the east, and all striking in the general north-northeast direction (N. 20° E.). Where, however, harder and thicker beds are present, as the Cambrian quartzites and grits of the Normanskill shale, the anticlines and synclines are less compressed; broad symmetric folds are found and often well shown. . . .

At the end of the Taconic folding, or rather as a special phase of it, extensive overthrusting took place. We have recognized two major thrust planes in the Capital District, both of which were already fully described by the writer from the Saratoga-Schuylerville regions in 1914 (p. 109 ff.).

One of these separates the intensely crumpled sediments of the eastern trough from the undisturbed formations of the western trough, or comes to the surface along the Snake Hill-Schenectady boundary. This fault, which is probably a nearly horizontal thrust fault, is of the character of a "scission" fault or "charriage." The eastern formations have been pushed westward over this plane for an unknown, but probably considerable distance. It is only by this movement that the deposits of the two different troughs could come in direct contact, as they do along the line. A considerable portion of the crumpling of the shales may be due also to this overthrust movement. The barrier which once separated the two troughs has been completely overridden.

This overthrust plane has nowhere been directly observed, not even in the section along the Mohawk river, where it would be most likely to appear. In its place appear a number of small overthrust planes. It is therefore our conviction that the overthrust is dissolved into a multitude of smaller overthrusts. We had already found clear evidence of this structure on the Schuylerville quadrangle (Ruedemann, '14, p. 103). In a good east-west section through the Snake Hill shale along the Batten kill at Clark Mills, a whole series of such faults, about 10 to 20 feet distant from each other, were observed in the northwall and traced across the river bed. They all rise toward the west at angles varying from 20° to 45° and many are made conspicuous by calcite veins. The throw is always small, but the upthrow side is always pushed a little to the west.

While the throw of each of these overthrust faults is small, their accumulative effect, going from west to east, owing to their great number and uniform direction of throw, must be quite large. If we assume a throw of six inches for each fault and that they are 20 feet apart, we obtain for the belt measured from the foot of Willard mountain (on the Schuylerville quadrangle) normal to the strike, with a width of 10 miles, a compound throw of 1320 feet. The effect of this accumulative throw would be to bring progressively older beds to the surface as one goes east. It is therefore possible that the position of the Normanskill belts to the east of the Snake Hill belts is due largely to this effect of the small overthrust faults which might be termed "multiple overthrusts."

Likewise the rather indistinct boundary of the Snake Hill and Schenectady beds is probably caused by the presence of numerous small overthrust planes at the boundary instead of one large one.

We have cited (Ruedemann, '14, p. 103) instances on the Saratoga quadrangle where the slickensides upon the thrust planes, and especially the direction of the slickenside scales, leave no doubt that the upthrow side had moved from east to west upon that plane. Some of these overthrust faults have clearly resulted from overturned folds (fold thrusts). The upper leg is seen in such cases to have been pushed westward beyond the lower. Some instructive examples of these were seen about Saratoga lake, especially on Snake hill. Most of these small faults ran with the general strike (north-northeast direction) of the beds or are *strike faults;* there are observed, however, some which cut the beds obliquely, as one at Victory Mills, striking N. 60° E. These deviations from the general north-northeast direction are probably connected with local irregularities in the general trend of the folds.

The multiple overthrust structure appears to be on a small scale, what the Germans have called "Schuppenstruktur," the separate "Schuppen" being pushed one over the other like scales. It is an imbricated structure, produced by many small overthrust faults that has the total effect of a general overthrust. This structure has recently been termed "shingle block."

We ascribe to this structure the rather indefinite boundary line between the Schenectady and Snake Hill beds on one hand, and the Snake Hill and Normanskill on the other. . . .

While the Schenectady-Snake Hill and the Snake Hill-Normanskill overthrust lines are obscure, the overthrust which brings the Lower Cambrian beds on top of the Ordovician east of the Hudson river is very distinct and sharply defined. This overthrust is supposed to be a segment of a more or less interrupted overthrust line that extends from Canada through Vermont and New York south, perhaps to the southern Appalachians. This line has become known as "Logan's Line" after the former director of the Canadian Survey, Sir William Logan, who first pointed to its long extension and structural importance. . . .

The Cambrian overthrust line, where the overthrust plane now comes to the surface, passes from the northeast corner of the State, from Easton to Schaghticoke, Grant Hollow, Lansingburg, Troy, where it crosses the Rensselaer Polytechnic Institute campus, Defreestville and Schodack Depot and Schodack Center. . . .

There is considerable and quite conclusive evidence that the thrust plane is irregular in its hade, through folding; for while the thrust plane is very slightly inclined at Bald mountain and the Moses kill, it is steep east of Willard mountain and in the neighborhood of Troy. Also the sinuous form of the fault line near the southern margin of the map in Schodack is due to the unevenness of the plane through later folding. That these irregularities of the line are due to folding of a character transversal to the general northeast strike of the beds is indicated by the fact that where the hade is steep, the Cambrian rocks descend deeper than where it is flat, these deeper appearances of the Cambrian corresponding to depressions or synclines.

There is considerable evidence extant of folding of the entire region long after the Green mountain or Taconic revolution, marking the Silurian-Ordovician boundary, and which is considered responsible for the principal folding and overthrusting of this region. Such later folding, probably of Carboniferous age, is shown by the folded condition of the Rensselaer grit (see p. 148) and by the remnants of the folded and overthrust Devonian limestones still found farther down along the Hudson river, as at the Vlightberg at Kingston and Canoehill at Saugerties.

OVERTHRUSTS

The pre-Silurian series of rocks of the Catskill quadrangle belongs entirely to the eastern or Levis trough, the rocks of the western or Chazy basin having dived under the Helderbergs southwest of Albany, not to reappear until the west side of the Hudson valley below Kingston is reached.

Also Logan's Line which marks the western edge of the great thrust of Lower Cambrian over Ordovician rocks has reached the river or rather disappeared in the river on the Coxsackie quadrangle, north of our area, probably to reappear south of the Catskills. The great overthrust mass undoubtedly reached farther west originally and what we see now is merely the edge of the uneroded portion of the overthrust plate. How far west this overthrust mass reached originally, we do not know. It is, however, important to note in this connection that it stops on the Albany and Coxsackie quadrangles before it reaches the Helderberg escarpment and is missing there below their Silurian and Devonian rocks. This can only mean that the overthrust mass was already widely eroded when the late Silurian and Devonian seas invaded the peneplaned Cambro-Ordovician area. This is conclusive in proving the late pre-Silurian age of the large overthrusts in the Cambro-Silurian rocks.

In place of the front of the Logan's line overthrust seen farther north there appear on the Catskill quadrangle smaller overthrusts, that may be independent of the greater Logan overthrust or merely portions of the same overthrust sheet. A glance at the map shows two distinct fault lines, one at the western margin of the Burden iron ore belt, another in the southeast corner (see figure 51).

The *inlier of the Burden iron ore* belt is bounded on the west by the upper Normanskill grit on which, separated by the eastward dipping fault plane, rests the Nassau slate (see figure 20), the lowest formation of the Lower Cambrian. This is followed to east-

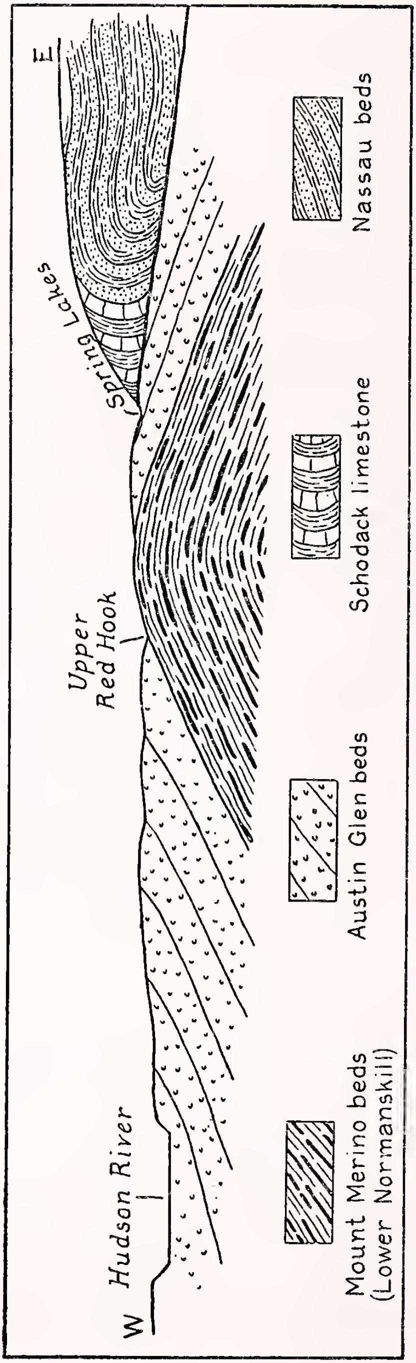

Figure 51 Diagrammatic section through southern part of Catskill quadrangle to show relations of Lower Cambrian to Normanskill beds

ward by a belt of Schodack limestone with the iron ore and by successive belts of Deepkill and Normanskill shale with chert. There is here a normal succession of formations probably much thinned by minor faults, producing dip-slip displacements. This series with its iron ore beds is abruptly discontinuous both in the north, at the south end of Mt Merino and in the south, half a mile from the Burden mines. This is an abnormal condition that probably finds its explanation in the fact that this short belt corresponds in location and length with a sector that is missing in the long iron ore belt at the foot of the Taconic range in the Harlem valley. It may then well be a fragment of one of the eastern overthrust plates that has been carried farther to the west than the rest. The existence of a series of overthrusts in the Taconic region has been demonstrated by Prindle and Knopf ('32).

The other distinct overthrust fault line is in the southeast corner in Galatin, Clermont and Milan townships on both sides of the Roeliff Jansen kill. This line enters the sheet east of Snyderville, swings past the Twin lakes, where it turns south and continues west of Elizaville to the south margin of the sheet. It consists of Nassau phyllite and quartzite and is bounded in the west by a belt of Schodack rocks, resting on Normanskill rocks, grit and phyllite in the south, near Crokertown and on chert and phyllite farther north. This overthrust plate is undoubtedly of considerable size; its delimitation awaits the mapping of the Copake quadrangle to the east and the Rhinebeck quadrangle to the south.

The distinctly less folded character of the overthrust plate, expressed in its wide open folds (see page 145) contrasts with the closely folded underlying Normanskill beds of apparently equal competent character. This difference in folding is somewhat suggestive of nappes, "striking examples of less folded beds thrust over beds more folded so that the displacement becomes more and more in the direction of movement" (see Robin Willis, '33).

At present, on the State geologic map (Merrill, 1901), as well as on all recent charts (see Longwell, 1933) it is still buried in the Ordovician "Hudson River beds" (Merrill) or the Ordovician "Taconic sequence" (Prindle and Knopf's name for the writer's "eastern" sequence).

There is also good reason to infer that the contact between the Normanskill chert and shale on the west and the Schodack beds on the east in the small inlier southeast of Blue hill, as well as that of the large inlier in the northeast corner of the quadrangle, upon which the Becraft Mountain outlier rests, are overthrust lines. In each case the Lower Cambrian rocks are seen at a higher level than the Ordovician rocks and the intermediate strata, notably the Deepkill beds are not observable. Although neither the actual thrust plane nor an unconformable contact can be seen, the different altitudes and dips of the rocks leave little doubt of overthrusting. In fact, practically all larger overturned folds in this whole much compressed belt develop flat-lying slip planes between the harder and less competent shale beds which become fault planes and overthrusts wherever the movement assumes somewhat larger proportions. The whole region may therefore be considered as partaking to a large extent of the shingle block structure, as we have already stated in the Capital District bulletin. Much of this is hidden in the rocks of the same formation, as especially those of the Normanskill.

NORMAL FAULTS

Likewise there are numerous *normal faults* running in the direction of the strike, as the one that brings out the belt of Deepkill chert and shale on the east foot of Mt Merino. Another one runs lengthwise on top of Mt Merino and is exposed in the quarry at the north brow (see figure 52). It would be impossible to map all these faults, many of them of small throw and only observed by accident, where they traverse but one formation.

CROSS FAULTS

Finally there are also numerous cross faults, also as a rule escaping notice. Their rather close arrangement was strikingly brought out in the mapping of the underground workings in the Burden iron mines (see figure 14). All four of the iron basins show in the groundplan distinct offsets by crossfaults, the small southernmost basin one, the Burden basin three, the others one to two. Also the section AC shows between *B* and *C*, that is in southern direction the four crossfaults of the two southern basins.

The result of the presence of these numerous, mostly hidden thrust faults, normal strike faults and cross faults, all of various sizes of length and throw, is that the country rock is really broken up into a checkerboard of blocks. Probably most of the faults are shallow and the blocks of not very great thickness. One of these shallow overthrust planes that is exposed in a quarry at Catskill is well shown in figure 37. This is in the Ordovician Normanskill grit. Others of like local character become visible in quarries and road cuts in the

Figure 52 Normal strike fault in Mt Merino quarry. Normanskill (Mt Merino) graptolite shale. (E. J. Stein photo, 1929)

Devonian rocks, as at Alsen and the south end of Becraft mountain (see figure 49).

The most peculiar inlier of Cambrian rocks is that extending through Germantown and into the township of Clermont. This is somewhat bird-shaped with a protruding head and neck, a long body with tail and two wings, stretched out obliquely. This oddly shaped inlier which appeared unexpectedly in the supposed Normanskill area is entirely composed of Schodack beds, and except along the western edge is most probably brought up by folding. This is most clearly shown along the western margins of the right (eastern) wing and the tail, where Deepkill beds appear in their normal position between the Schodack and Normanskill beds.

FOLDING

It is not necessary here to enter into an elaborate discussion of the folding, inviting as the field may be. We have already quoted some general notes from the Capital District. More recent work, however, especially the brilliant investigations of Dr Robert Balk (1932, 1936) in the metamorphosed rocks of southeastern New York have revealed incredibly complex and intricate movements of the rocks, with folding, shearing, faulting and fracture cleavage, leading finally to plastic flowage of marble beds (of Ordovician age), so that they have floating in them disrupted fragments of folded schists (see Balk 1936, p. 722) and even to the vertical thrusting of blocks of Precambrian granite and gneiss through the Cambro-Ordovician strata, as at Stissing mountain near Poughkeepsie.

While, owing to the prevailing shales in the rocks, the great mass of folded rocks appears to be composed of small overturned, isoclinal folds, which pitch northward and do not extend very far and frequently, where greater thicknesses of soft shales are met, the whole body has become crumpled into miniature zigzag folds (some are very well shown in figures 53 and 54 from the Mt Merino quarry in Normanskill shale), which are still more complicated by shear zones and fracture cleavage, as Balk has so well shown in the metamorphosed rocks where these fractures become more distinct. On the other hand, where competent beds are alternating with the shales as in the Normanskill grits and the Nassau beds, the folds become open. This is especially well seen in the section along the road on the north side of Roeliff Jansen kill, in the southeast corner of the sheet. Here the writer measured all the dips across the strike and found but three broad open folds developed (see diagram) with an overturned fold in the Schodack beds at the western edge.

While the phyllite of the Nassau beds has taken up most of the orogenic pressure into cleavage fracture, the quartzite beds of the Nassau formation have developed a peculiar structure of their own, which will be described separately at the end of this chapter (see Boudinage, page 150).

The most outstanding hills, Mt Merino and Blue hill, are fragments of overturned anticlines and synclines (see figure 55) much disturbed by gravity folds, as well as by shearing.

There is one feature connected with the folding that requires special notice because it indicates a large scale folding of the type of anticlinoria and synclinoria. The bird-shaped inlier of Schodack beds in Germantown is already suggestive of folding on a larger scale. Likewise the broad belt of Normanskill chert in the Normanskill grit belt south of Glasco in the southwest corner of the quadrangle and that of Normanskill chert and shale in the south-central marginal area are both indicative of broader complex folds, supposedly anticlines bringing up the chert beds (Mt Merino beds), through the younger grit and shale (Austin Glen beds).

It is a moot question whether the two broad principal belts of Austin Glen beds in the west and Mt Merino beds in the east are caused by broader folds or by overthrusting.

On one hand it appears very significant that the Burden iron ore overthrust belt lies between the grit and chert belts and likewise the Germantown inlier to the south of it, which is also bounded by a thrust plane on the west. The section across the Burden-Pless Hill ridge leaves no doubt of the overthrust and indicates strongly that the whole eastern belt of Mt Merino beds is part of an overthrust plate, that is still further overridden by another thrust plate (Lower Cambrian), appearing in the southeast corner. Besides these larger thrust plates there appear to be smaller overthrusts, giving the whole area the character of an imbricated thrust mass of shingle block structure. On the other hand the area south of the left (western) wing of the birdlike Germantown inlier shows alternation of chert and grit beds, indicative of transitional or stratigraphically adjoining beds and of folding rather than overthrusting. Likewise the fading out of the chert belt south of the Germantown inlier and its reduction to the narrower belt at Upper Red Hook are more suggestive of folding on a broad scale than of overthrusting. We consider it therefore possible that broad folding, becoming exaggerated into overthrust faulting along the western margins, is responsible for

Figure 53 Sharp zigzag folding in Normanskill (Mt Merino) graptolite shale. Mt Merino quarry. (E. J. Stein photo, 1929)

Figure 54 Normanskill chert, forming steeply overturned and broken anticline on Hudson-Germantown road at approach to Rip Van Winkle bridge. (E. J. Stein photo, 1935)

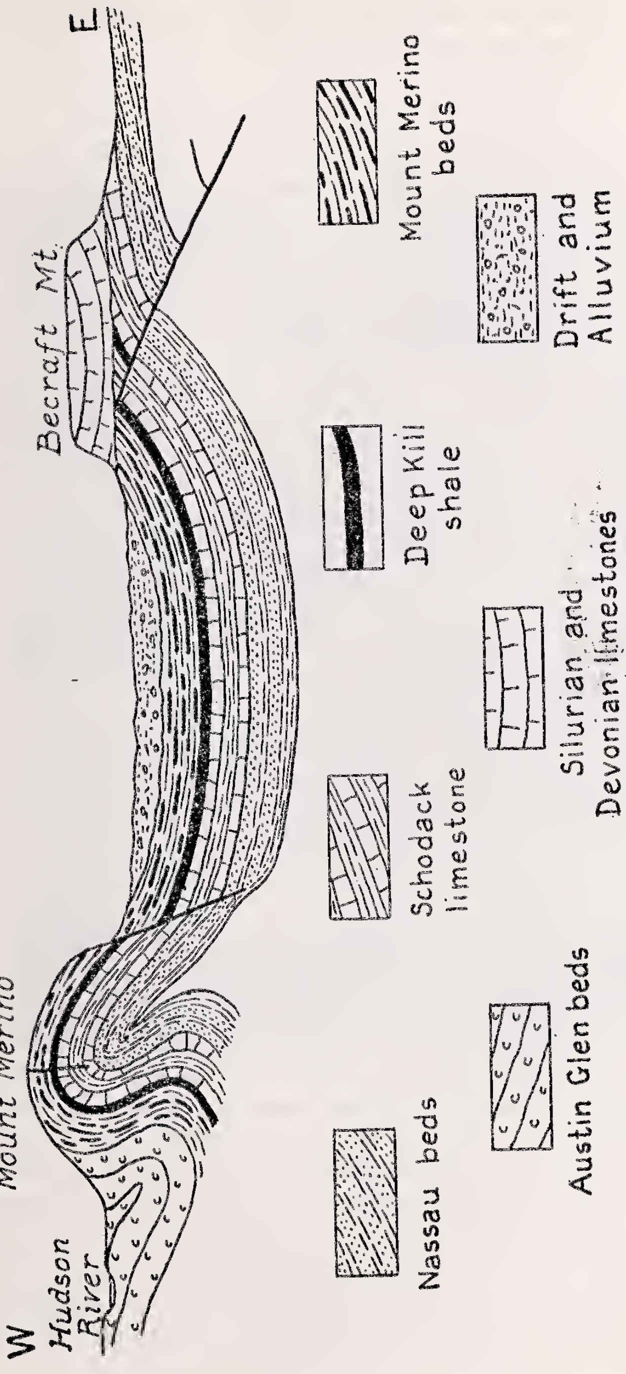

Figure 55 Diagrammatic west-east section through Mt Merino and Becraft mountain

most of the features observable, especially the long narrow overthrust belt in the northern portion.

BOUDINAGE AND CLEAVAGE

A small feature which appears worthy of special notice here, because it shows so well on the quadrangle, is the action of the heavy quartzite beds, incorporated in the Nassau phyllite in the Roeliff Jansen kill section under the influence of the orogenic westward pressure. The best locality to observe the features here described is along the Roeliff Jansen Kill road, one and three-fourths miles southeast of Elizaville.

Figure 56 shows the strong fracture cleavage that has developed in the phyllite, taking up the compressive pressure at an oblique angle to the bedding which is shown on the upper weathered front, while the cleavage shows in the fresh rock at the right. Figure 12 shows the intersecting cleavage and bedding (brought out by the thin quartzite bands) in fresh rock near Jacksons Corners. In the road cut near Elizaville a quartz bed about a foot thick was not able to take up the entire pressure in cleavage fractures. It broke into bricklike wedges, as figure 57 shows in a picture that was taken before the widening of the road exposed fresh rock in that locality. Finally it buckled into open folds of the character of drag-folds. Later it was seen that in a number of places the quartzite bed broke so that where an anticline-syncline couple had formed the eastern anticline slipped over the western syncline (see diagrams figures 60, 61) thus doubling and producing minute overthrusts (see figure 59 where the writer points to one still further enlarged).

Holmquist ('31) has described similarly disjointed quartzite beds from the Swedish Precambrian, using the term boudinage ("twisting") that was before applied to the peculiar structures observed by Lohest ('22) in quartzitic layers in Belgium. The boudinage structure is there described as having two characteristic traits: one is the separation of the quartzite beds into equal blocks (with secondary quartz veins filling the breaks, see figure 62), the other is the bulging of the quartzite blocks in the middle (see figure 63); the latter trait is but faintly observable, if at all, in our material, probably because the overthrusting relieved part of the pressure. There is disagreement among Lohest ('22), Stainier ('07), Quirke ('23) and Holmquist as to the *modus operandi* of the compressing and stretching forces that produce the breaks and barrel-shaped blocks. Quirke's explanation is set forth under the supposition

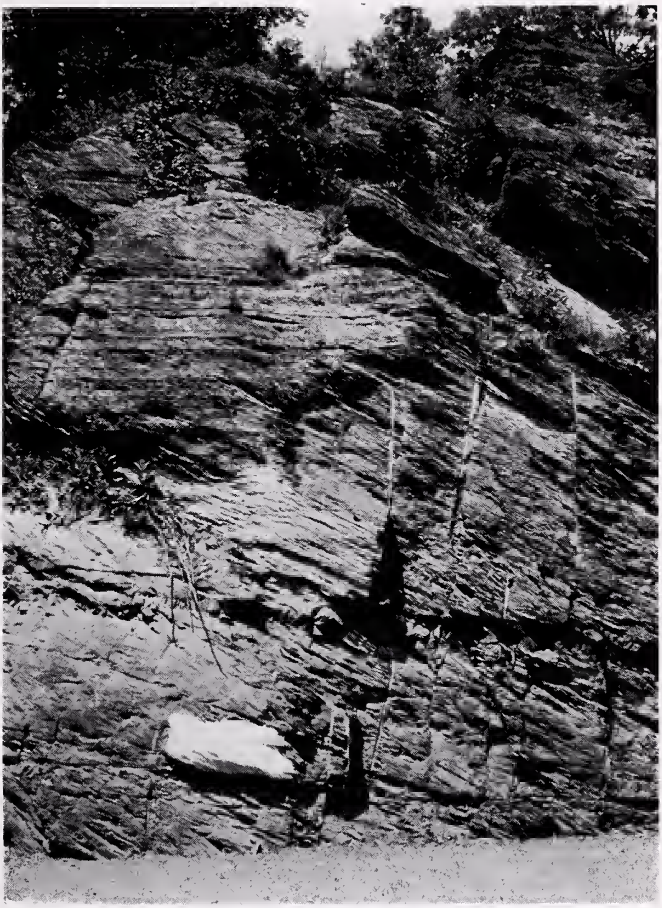

Figure 56 Nassau phyllite and quartzite, showing bedding in upper weathered surface, cleavage on lower fresh surface. Jacksons Corners. (E. J. Stein photo, 1936)

Figure 57 Quartzite bed in Nassau phyllite, showing boudinage fracture; former outcrop in woods along Roeliff Jansen Kill road, two miles southeast of Elizaville. (A. Knopf photo)

Figure 58 New outcrop of boudinage structure in Roeliff Jansen Kill road through road improvement. View shows series of small broken and overthrust folds, one pointed out by figure. Phyllite yielded by cleavage. (E. J. Stein photo, 1936)

Figure 59 Enlargement of buckled and broken quartzite, one fold at figure. (E. J. Stein photo, 1936)

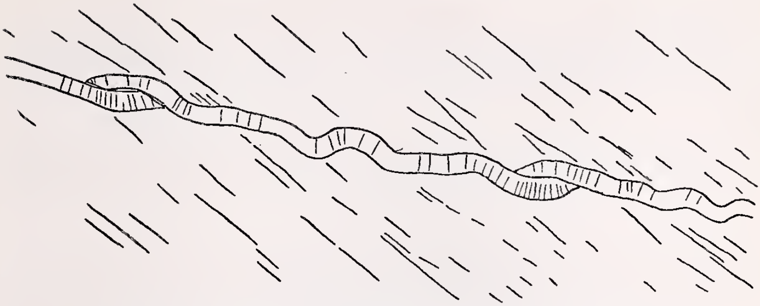

Figure 60 Diagram of structure shown in figure 59

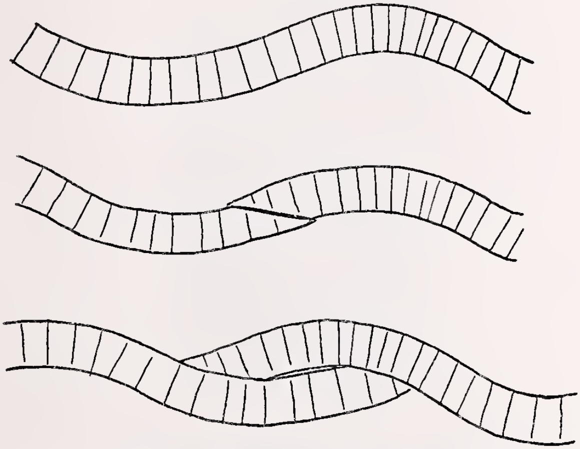

Figure 61 Diagrams showing successive stages in buckling

that compression was previous to stretching; the others incline to the other view.

Aside from the most striking features of the Roeliff Jansen locality, *viz.*, the boundinagelike breaking and the buckling and overthrusting of the quartzite bed, there is still another tectonic feature of peculiar character to be observed in the outcrop of Nassau phyllite. That is the remarkable difference in the direction of the fracture cleavage in the phyllite and the quartzite (see figures 12, 13 and 56). In the phyllite it forms an angle of about 20° with the horizon, while in the quartz bed the fracture which is merely diverted cleavage stands vertical.

A similar case had been observed before by Dale (1895, see also Nevin 1931, p. 161) in alternating shale and limestone at Jackson, Washington county, and described under Geikie's (1893) term of "differential cleavage." It appears in these cases that the angle of fracture cleavage is determined by the physical character of the formation.

Finally there is not only a difference in the direction of the cleavage in the phyllite and the quartzite, but also one in character for while

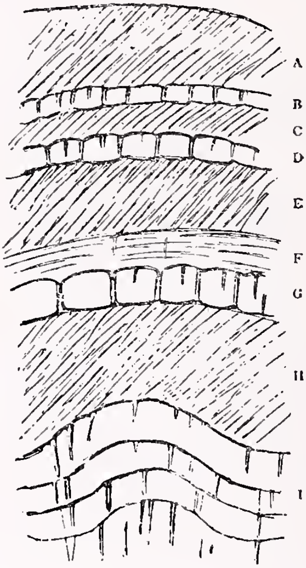

Figure 62 Vertical section through the layers with "boudinage" in the carrière de la Citadelle at Bastogne. The total height of the section is about 7.5 m. (After Lohest)

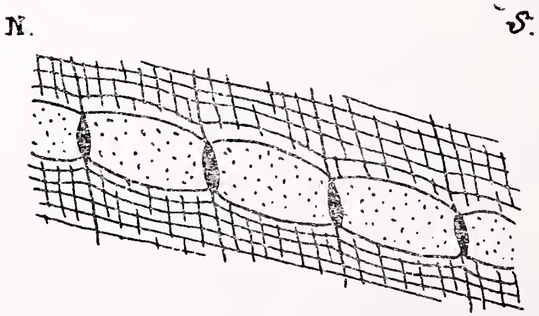

Figure 63 Schist containing disjointed quartzite bed cemented with quartz, as seen in a quarry at Acul. Boudinage structure. (After Stainier)

that in the quartzite is still distinctly a pure *fracture cleavage* that in the phyllite has undergone in the metamorphism of the shale to phyllite the first stage of *flowage cleavage* which a little farther east leads to the formation of schist.

METAMORPHISM

It is a well-known fact that a progressive gradual metamorphism of the rocks takes place from west to east in the eastern New York shale belt, so that near the river unmetamorphosed rocks are met, which eastward change into phyllite, schist and finally gneissic rocks. These metamorphosed rocks have been the subject of investigations by several authors, notably Dale, Prindle, Knopf ('27) and Balk ('32, '36) who have worked out in more or less detail the recrystallization and formation of new minerals in the process of metamorphism. As we have in our territory only to deal with epizonal or low-grade metamorphism that produced phyllite, although schists appear just east of the margin of the sheet, we need not enter into the details of this metamorphism, fascinating and intricate as they are. It may suffice to state that in the area, marked off by a special overprint on the map, the shales of the Normanskill and Nassau beds have assumed a glossy, silky appearance which appears at first hardly noticeable, but rapidly increases southeastward, some shale beds, however, being more affected than others. The quartzite, limestone and dolomite beds do not show yet any macroscopically visible effects. Doctor Newland found that the prevailing new mineral in the phyllite of the Nassau beds is chlorite; in a smaller degree also sericite (a mica mineral) appears. The latter is especially responsible for the silky sheen of the bedding planes; the former, for the greenish color of the phyllite.

Farther east the rocks become so thoroughly metamorphosed that the different authors felt it necessary to apply separate names, *viz.*, Berkshire schist for the mica schists of the metamorphosed Hudson River beds (see Merrill 1901 *et al.*) and Stockbridge limestone for the "Cambro-Ordovician crystalline limestones" *ibid.* Later work (Prindle and Knopf '32) has broken up these terranes into several sequences supposedly formed in different eastern troughs, and applied new names to the different quartzites, limestones, dolomites and schists of the sequences. The distinctions between these similar formations are small and require refined examination entirely petrographic and tectonic as fossils are lacking. This work has been carried out with great care by Prindle and Knopf. It leaves, however, in those cases where the formation could not be connected with the western unmetamorphosed belt the age and correlation of the formation undetermined. Dr E. B. Knopf ('27) has already made a partly successful effort to distinguish and correlate the crystalline limestones of the eastern (Stockbridge) belt with those of the rest of the State. The fact that the writer, however, when jointly with Doctor Newland studying the old iron mines in the Harlem valley, was able to recognize the Nassau formation in the schists and the Schodack formation in the limestone, indicates that a procedure by which the recognized unmetamorphosed formations of the Hudson valley are being traced east into the schist and gneisses would be more successful in correlating the metamorphic rocks than the petrologic methods hitherto pursued.

The cause of this regional metamorphism is still a moot question. Doctor Knopf, whom we quote, has given a synopsis of the previous views ('07, p. 449):

Former workers in the region have recognized the decreasing intensity of the metamorphism from east to west and from south to north. This so-called gradation has been ascribed to the westward dying out of the folding accompanied by a resultant decrease in metamorphism. As far back as the days of Mather the schists and slates of the Taconic range were considered to be the equivalent of the shale of the Champlain-Hudson-Mohawk lowlands only "modified by metamorphic agency and the intrusion of plutonic rocks." Dana in his final conclusion on the Taconic region called attention to the increasing grade in metamorphism from west to east and also from north to south, but he does not commit himself as to the causes of the metamorphism. Pumpelly in 1893 states that the "high degree of metamorphism of Paleozoic rocks is intimately connected with the folding." Dale ascribed the metamorphism of the so-called "Hudson beds" of the Taconic range to a post-Ordovician Taconic movement, which was more intense toward the east. Barrell also speaks of the rapid dying out of the metamorphism in the axes of the Taconic synclinorium, but he points out the fact that there is a lack of exact accord between the local degree of deformation and the local degree of crystallization.

The lack of accord between degree of deformation and intensity of metamorphism pointed out by Barrell is not merely local, for, in the first place, the regional change from biotite schist to slate is not accompanied by a notable dying out of the folding. The Normanskill as far west as the Hudson river is intensely folded and overturned, nevertheless the regional metamorphism is slight; and where the folding does abruptly die out, three miles southwest of Albany, according to Ruedemann, there is practically no change in regional metamorphism.

Moreover, in the second place the axis of the folding in the schists and slates of the Taconic and Chestnut Ridge-Winchell Mountain ranges is N. 5° to 15° E., whereas the axis of maximum metamorphic intensity strikes about N. 35° E. Thus the intensity of the metamorphism does not decrease along a line that is perpendicular to the strike but along a line that makes an angle of approximately 30° with the strike. The same relation holds as far north as the writer has followed the section into southern Vermont. The metamorphism therefore cannot be considered to be genetically related to the axes of folding in the rocks that make up the mountains and cannot be explained merely as a result of waning intensity of dynamic action across the strike of the folding. However, although the regional metamorphism is not obviously connected with the regional axes of folding, Barrell's alternative explanation of the metamorphism as a result of the thermal action of widespread subjacent batholithic intrusion rather than of dynamic origin is still far from proved by field evidence.

White has shown that the regional metamorphism of coal beds in the Appalachian trough, as represented by the isocarbs of fixed carbon content, does not coincide with the axes of folding. There is even a drop in carbonization in strongly folded regions that were nearest to the presumable source of pressure. He explains the maximum carbonization as dependent upon the maximum horizontal compression of the beds. Where folding and faulting have taken place the horizontal stress has found relief in mass movement and is, so to speak, compensated and therefore less effective in producing metamorphism, with the result that the fixed carbon content of the coal shows an appreciable drop in areas of buckling and overthrusting.

The Taconic region is folded and faulted throughout its extent, so that horizontal stress has been largely compensated throughout the whole area. But the increased strength that was imparted to the argillaceous rocks by having become folded would furnish the conditions of resistance to yielding to continued or repeated horizontal compression. Thus, if dynamic metamorphism takes place under conditions of resistance to stress rather than as a result of yielding to stress by folding, under such conditions of increased resistance the intensity of metamorphism would naturally increase and the formation of encarsioblastic biotite with helicitic preservation of the earlier folded structure might ensue.

Origin of Metamorphism

So far the results of this reconnaissance do not justify positive statements about the origin of the regional metamorphism. The lack of correspondence between structural axes and axes of metamorphic intensity disproves the casual relation between folding and metamorphism, although it does not disprove the agency of horizontal compressive stress in the regional metamorphism of the area. The discovery of granite gneiss intrusive into rocks that have been hitherto called Paleozoic casts a serious doubt upon the Paleozoic age of those rocks, owing to the fact that the granite has not yet been proved to cut fossiliferous rocks of demonstrated Paleozoic age. The occurrence of granite in these rocks hitherto called Paleozoic furnishes an explanation of the widespread occurrence of tourmaline pegmatites and of contact silicate minerals in the marble and schist of Stockbridge valley and of the Dover-Pawling valley, but it does not yet prove that the regional metamorphism is caused by the thermal effects of the underlying batholiths. Positive evidence of the relation between the highly metamorphic schist that is intruded by granite and the less metamorphosed Paleozoic sequence to the west is hard to find in such an area where intense metamorphism would have obliterated evidence of overthrusting.

We shall have occasion to recur in the next chapter (on the age of the folding) to Doctor Knopf's important suggestion that the intensity of dynamic metamorphism may be due to conditions of resistance to stress produced by preceding folding. It is expected that Doctor Balk will take up the great problem of the metamorphism of the rocks of the eastern shale belt of New York and in particular of the Taconic region in the second part of his studies. Meanwhile we should like to point to a further important view on the origin of regional metamorphism, that has been expressed by F. E. Suess ('34) after a study of the Appalachian metamorphics in connection with the International Geologic Congress. Suess, in applying the results of his well-known studies of the problems of orogenesis as seen in the Variscian structures of middle Europe to the Appalachian system concludes that the metamorphic facies remain within the same boundaries as in the corresponding zones of the Alps and Variscids as is especially well shown by the work of Dr Eleonora Bliss Knopf and Dr Anna Jonas. He finds there all the gradations from fossiliferous quartzites and pelites to phyllites and green schist and to biotite carrying rocks. Albitization is as common as across the ocean in the same stages and he concludes that also here as in Europe, especially as in the Silesian mountains, the fading of the metamorphism outward indicates the marginal lines of the eroded parts of the higher overthrust sheets or nappes. It is the extent of the pushed-over thrust sheets that determines the distribution of metamorphism.

AGE OF FOLDING AND THRUSTING

In the Capital District bulletin ('30, p. 157) the writer has distinguished three stories of folding as follows:

In summarizing the orogenic revolutions of the past in the Capital District, it can be stated that we have here distinctly three stories of folded rocks one above the other and each separated from the preceding by a distinct plane of unconformity and erosion. The oldest is that of the Precambrian rocks now deeply buried here but exposed in the Adirondacks to the north and the Highlands to the south. Its folding runs in NE-SW direction. Upon this first story rests the second, that of the Taconic folding, seen in the Cambrian-Ordovician rocks. It strikes N. 20° E. As the Precambrian rocks were stiffened by their folded conditions, they were little affected by the later folding. This second story is again cut off by a great plane of unconformity and erosion that is now seen at the base of the Helderberg cliff. Upon this rests the third story of folding, that of the Appalachian revolution, shown in the Helderberg and the Rensselaer plateaus. This folding probably also had but little effect upon the already closely folded underlying rocks. It strikes nearly north and south.

In other words, we have here the remains of three worn-down mountain systems, each erected upon the deeply eroded roots of the preceding, and each running in a somewhat different direction.

This view, which was in accordance with current opinions that—neglecting the Precambrian folding which furnished the grain of the continent—only the Taconian and Appalachian orogenies had affected the northeastern portion of the continent, may have to be modified as a result of recent investigations which have made known a spasm of orogenic activity in the Devonian period, known as the Acadian orogeny of Middle Devonian age which may be recognizable in the folded rocks of the Hudson valley. As Charles Schuchert has been the most active exponent of the geosynclinal structures and orogenic phases of the entire Appalachian belt, we will present his views ('30) first. He distinguishes in the northern Appalachian structure the St Lawrence geosyncline (our Chazy basin and Levis or eastern trough), which is bounded on the east by the New Brunswick geanticline (see figure 64), which passed through southern Newfoundland and New Brunswick and skirted the New England coast. Still outside of this is the Acadian geosyncline, which reached the continent only in Nova Scotia, before compression. Now in their present position (see figure 65) the Acadian geosyncline has moved westward, so that it passes through western Nova Scotia, eastern New Brunswick and enters the coast region of New England, while the New Brunswick geanticline has moved into western New Brunswick and passes through central New England and southeastern New York. Schuchert distinguishes four orogenic times in greater Acadia (see his text figure 4, our figure 64) namely (1)

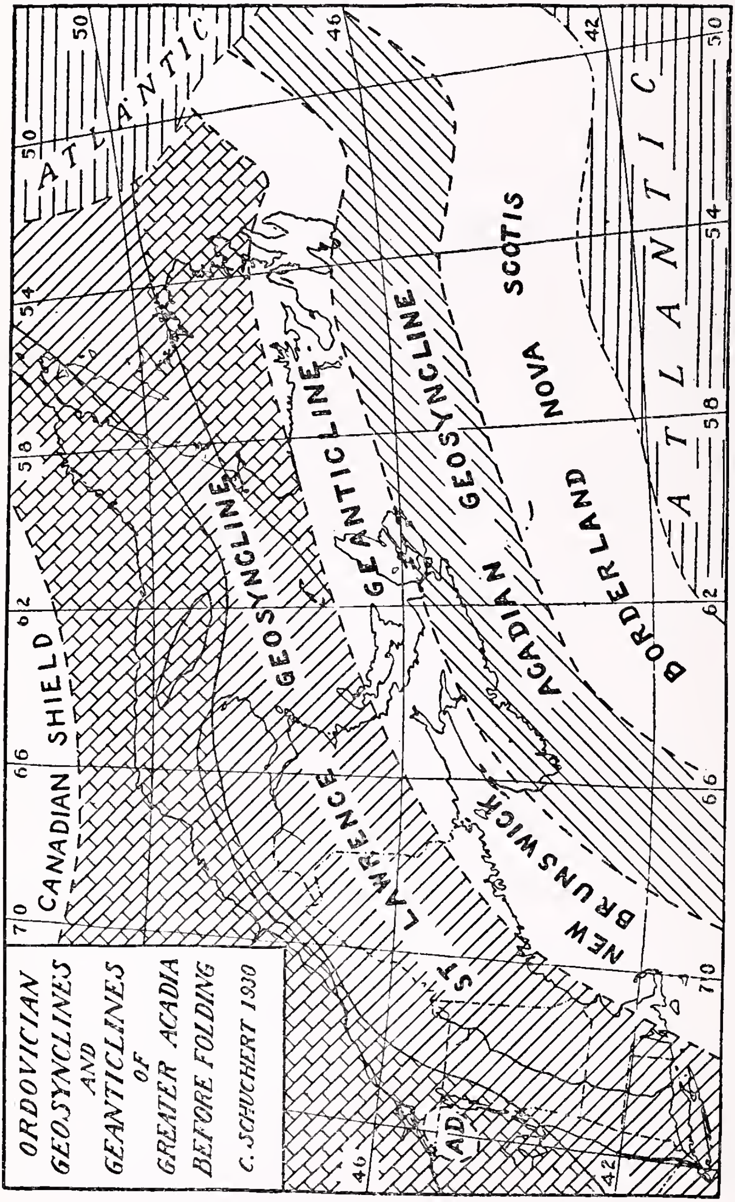

Figure 64 The St Lawrence and Acadian geosynclines in their original position, with the folding straightened out.
(From Schuchert, 1930)

latest Cambrian folding, only known in northwestern Vermont* (2) Taconian orogeny (3) Acadian disturbance and (4) the Appalachian folding.

As figure 65 (Schuchert's text figure 5) clearly indicates the middle Hudson River region was only folded by the Taconian and Appalachian orogenies, which intersect in this region. The Acadian folding remained outside of the area, running along the present New England coast. It is stated by Schuchert ('30, p. 710 ff.) that while many (meaning notably Keith) maintain that the intense folding and overthrusting east of Lake Champlain in Vermont and south is of the Appalachian type and not made during the close of the Ordovician but coincident with the Appalachian revolution during Permian time, he holds that "all of this deformation took place during the late Ordovician." Schuchert continues:

Furthermore, the area of the Taconian folding in the western and northern parts of the Saint Lawrence geosyncline, from about Albany, New York, through Vermont and southern Quebec, has not again been refolded, but in all probability was epeirogenically elevated and more or less normally faulted by the Devonian crustal disturbances. On the other hand, the southeastern part of the Saint Lawrence geosyncline, and more especially the Acadian trough, were refolded and greatly intruded by granites during the Acadian disturbance of Devonian time. Finally, the Appalachian revolution did decidedly refold the Acadian geosyncline from the Gut of Canso in Nova Scotia to eastern Massachusetts and Rhode Island; and the eastern part of the Saint Lawrence geosyncline was more or less warped or strike faulted as far south as the Catskills of New York; while Newfoundland was decidedly cross faulted (about north-south across the northeast-southwest fold strike).

There is no doubt about the Taconian orogeny in the middle Hudson River region, for this is the classic area for it and according to some, as Clark ('21) the orogeny is not even traceable very far beyond this region. Schuchert, however, recognizes its influence in both the St Lawrence and Acadian geosynclines (and the New Brunswick geanticline) as far as Newfoundland.

More recently the opinion has become more prevalent that the Acadian revolution may also have affected the Hudson Valley region.

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* Professor Schuchert in his friendly review ('31, p. 87) of the writer's Geology of the Capital District considers the mentioning of a crustal movement that folded the Lower Cambrian strata as "seemingly a slip of the pen." It is that in so far as the statement remained unsupported in the bulletin. It was taken from notes in the field notebook which slight evidence was intended to be worked up but was finally forgotten. Whatever evidence there may have been for such late Cambrian movement is greatly obscured by the Taconian folding and overthrusting.

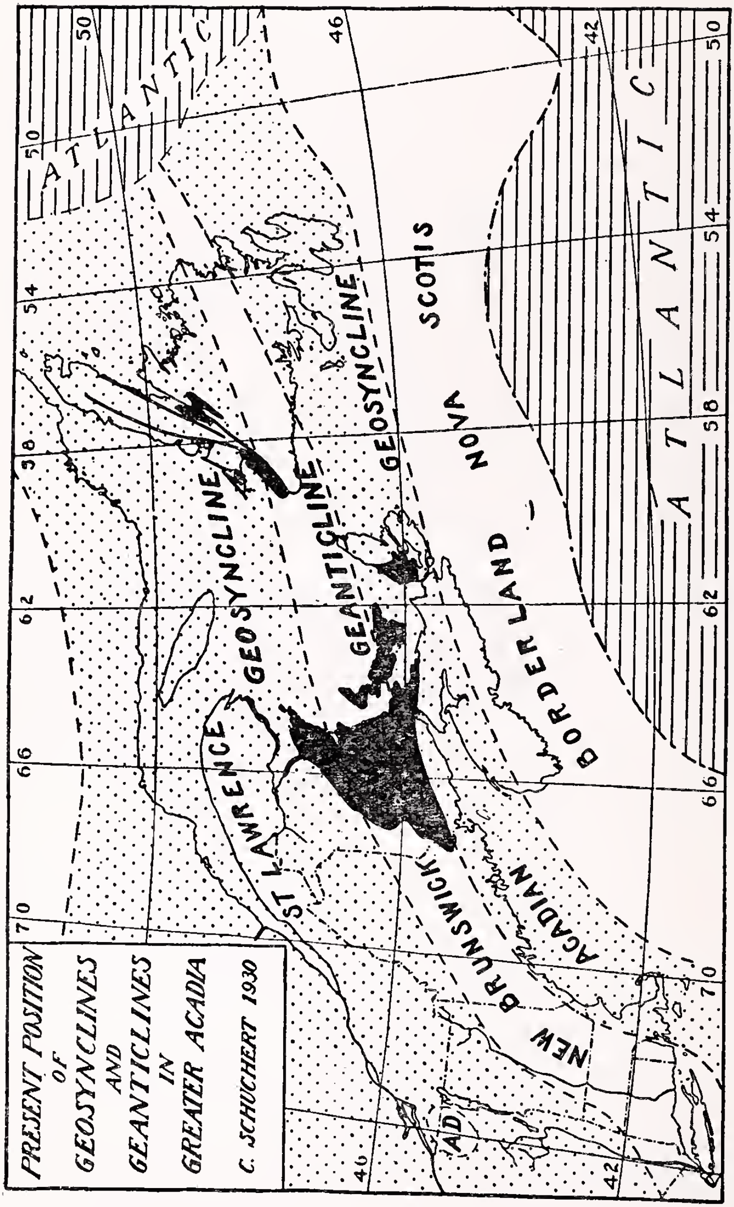

Figure 65 The four structural units of the preceding figure in their present position. (From Schuchert, 1930)

Thus Billings and Williams ('32, p. 25) write: "With the advent of the Middle Devonian the Acadian revolution began. The great land mass of Acadia began to migrate toward the northwest and for the second time during the Paleozoic the sedimentary rocks of New England were caught in the jaws of the great vise." After stating that it is difficult in many localities to decide definitely whether the folds are products of the Acadian or the Appalachian revolution they continue: "We can say with assurance that New Brunswick, Maine, Vermont, western New Hampshire and eastern New York were caught in the Acadian Revolution."

Schuchert and Longwell ('32, p. 324 ff.) after asserting the influence of the Taconian movement in western Vermont against Keith's view that the Appalachian folding and particularly overthrusting is responsible for the structures found there, continue: "However, the possibility cannot be denied that both the Acadian and the Appalachian movements made some contribution to the folding and metamorphism in western New England and eastern New York." They add that at present it is uncertain what were the effects of the Acadian and Appalachian movements in the important Hudson River belt of complex geology.

The great mass of Catskill sediments testify to important uplift along or near the Taconian axis in the later Devonian. Was this a simple warping, unaccompanied by folding and thrusting such as occurred in the maritime provinces during the same period? How severe was the Appalachian movement along the Taconian axis, and how far north did it extend? From the indirect evidence we incline to the view that the Silurian and Devonian of the Hudson Valley was folded in the late Paleozoic, as Davis and Ruedemann suggest; but even if this date were established, other important problems would remain.

Finally, in reference to E. B. Bailey's suggestion ('28) that the deformation in western New England is of "Caledonian" date, and that the front of the "Hercynian" folded belt, swinging southwest from Massachusetts, crosses the older belt in southeastern New York, the authors assert that they can not see the slightest evidence in trend lines or other structural features that the later Appalachian folding cuts across the earlier (Acadian) in southeastern New York. The most concise statement of the history of the northern Appalachian geosynclinal trough is probably given by Longwell ('33, p. 5) and Chadwick and Kay. Longwell writes as follows:

Sedimentation in the trough was not continuous. Near the end of the Ordovician period the strata from the St Lawrence Valley to

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

The Appalachian movement near the end of the Paleozoic era deformed the Devonian strata in the southern part of the Hudson valley; but farther north the results of this movement, if they exist, have not yet been differentiated from those of the older deformations.

Chadwick and Kay ('33, p. 7) have summarized the tectonic history of the region as follows:

There is evidence in the region of at least two periods of deformation. In several exposures Ordovician beds lie in close contact with angular unconformity beneath the basal Silurian sediments. Formations as young as Middle Devonian have been folded and affected by faults of low angle showing relative overthrust from the east.

The first of these deformations is definitely assigned to the Taconian disturbance, for which this is the classical area of study. The later deformation may have been produced either in the Acadian disturbance at the end of the Devonian or in the Appalachian revolution, or in both. Inasmuch as the late Paleozoic rocks are not present in the disturbed areas, it is not possible to date the movements precisely. The tectonic movements that produced the coarse clastic Upper Devonian sediments to the west may have been accompanied by this folding and faulting; if so the structures are Acadian. On the other hand, the structures are similar to those formed farther to the southwest and northeast in the Appalachian revolution, and it is probable that some of the effects were produced at that time.

The preceding quotations clearly demonstrate what an interesting region of critical importance the Hudson valley actually is for the elucidation of the relations of the different orogenies. Unfortunately the evidence is mostly nonconclusive and often contradictory.

The writer, in the Capital District bulletin ('30, p. 151) had inferred that the Taconian folding, affecting the Cambrian and Ordovician rocks had a N. 20° E. strike in the Albany region, while the Appalachian folding in the eastern Helderbergs, south of Albany, had a decided N.-S. trend. I suggested to Dr James F. Pepper that it would be important to get more definite data on the trend of these two orogenies in the middle Hudson valley. So far only a preliminary note of his results (Pepper, '34, p. 186) has been published and the full report awaits printing. He reached by measuring the cleavage the rather unsuspected result that much of the deformation of the Ordovician beds has been caused by the Appalachian rather than by the Taconian orogeny. We quote here in full his brief statement:

Northward from Kingston, New York, folding caused by the Appalachian orogeny trends about N-10°-E, and unfortunately this direction is also parallel to the axis of Taconic (Ordovician) folding. Therefore, in this part of the Hudson River region, although the Ordovician formations were affected by at least two orogenies, geologists have heretofore been unable to find evidence, in trend lines or other structural features, that the Appalachian folding cuts across the earlier Taconic deformation.

Since cleavage gives an excellent clue to the type and direction of regional stresses, it was thought that a careful study and comparison of cleavage in the Ordovician with that in the Devonian formations might help to distinguish the Taconic and Appalachian orogenies.

Near the axis of Taconic folding, just west of Mt Washington, cleavage in the schists has a strike of N-10°-E over a wide area. Along the Hudson river, wherever cleavage is well developed in the Normanskill (Ordovician) grits, it also has a strike of N-10°-E.

The Esopus and Schoharie grits (Devonian) are usually within a mile of these Ordovician beds. Cleavage readings were taken at most of the good Esopus and Schoharie outcrops along the strike for some 40 miles. It was found that, wherever well developed, the cleavage almost invariably had a trend of N 25° to 30° E. This cleavage must have been developed by stresses later than the Taconic; and it is noteworthy that the trend corresponds exactly to that of the Appalachian folding, farther south.

It, therefore, seems logical to assume that much of the deformation in the Ordovician beds along the Hudson river has been caused by the Appalachian rather than the Taconic orogeny. Moreover, a careful study of cleavage appears to offer the best means of unraveling the complicated structure of this region.

We believe that besides the new evidence obtained by Pepper from the fracture cleavage, further information can be obtained through the following lines of attack:

(1) The character of some of the rocks, (2) the folding of the strata, (3) the possible folding of the Ordovician-Silurian unconformity, (4) the folding of the overthrust planes, (5) the faulting and (6) the metamorphism.

It is here not the place to enter into a discussion of all these possible criterions; it may suffice to suggest their usefulness in future work and add a few observations of the writer along these lines, none of them as yet conclusive.

1 The character of the rocks, when fully recognized, can not fail to give useful clues. While for instance the presence of the Normanskill cherts with their deep-sea radiolarians suggest a great depression of the middle portion of the northern Appalachian geosyncline (Levis or St Lawrence trough) in early Normanskill time, the superjacent grits and arkoses demonstrate just the opposite, *viz.*, the deposition of considerable quantities of coarse materials in the basin, indicating the orogenic or epeirogenic elevation and rapid erosion of near-by land, most probably in the east, a fact that may point to the rising of the New Brunswick geanticline. Likewise the coarse clastic materials of Upper Devonian sediments in the Catskills may indicate the rising Acadian mountains in the east, as already remarked by Chadwick and Kay.

2 The folding of the strata needs no further comment. As the Siluro-Devonian folded beds end south of Albany, through erosion, data are lacking to connect it with any of the Northern orogenies. On the other hand, the folding dies out rapidly west of the Hudson river and can be seen affecting only the rocks as far up as the Onondaga and Marcellus, the overlying Hamilton having been eroded. While the heavy Onondaga limestones are distinctly folded, the incompetent Marcellus shales are merely strongly crumpled. The overlying sandy Hamilton beds do not show any folding and in places there is a suggestion of a disconformity (fide Goldring). Does this mean a pre-Hamilton folding of Acadian age or merely a failure of the softer higher beds to react to the stresses near the outer boundary of the orogenic field? Becraft mountain (Grabau, '03) owing to the competent character of its thick limestone beds, shows on the whole only broad, open folding, much less intense in character than that of the underlying Ordovician.

3 The folding of the Ordovician-late Silurian unconformity could not be observed in our area because the contacts on the west side and at Becraft mountain run from south to north with the trend of the possible folds. F. Holzwasser ('26, figure 2, sections A and B) shows an undulating contact between the Ordovician and the Shawangunk conglomerate in her sections, but does not state whether these are based on observation.

4 The folding of the overthrust planes is likewise thus far noncommittal. Knopf and Jonas ('29, p. 74) have recognized the latest Appalachian folding by the corrugation of a low angle thrust plane, that separates the crystallines and limestones of the Chester Valley region in Pennsylvania. If there can be found folded overthrusts

younger than Taconian age in the Hudson Valley region, the overthrust planes will prove of critical value for the determination of later folding. We have observed shallow folds or broad undulations that are indicated by the sinuous outcrops of the fault line, as in the southern Troy quadrangle, at approximately the same level. Chadwick ('10) has observed a downward undulating overthrust fault in the folded Lower Devonian rocks, which is suggestive of a later folding. Where this overthrust faulting, that accompanied the last stage of Taconian revolution, is clearly folded, it indicates a post-Ordovician orogeny. Where the Lower Devonian overthrust is folded, it may mark the last stage of the Devonian folding and suggest Acadian age, rather than the much later Appalachian age.

5 The faulting will undoubtedly in time afford good criterions, when the strike faults, as well as the cross faults, can be shown to be of greatly younger age than the folding and can be correlated with the normal faults in the Mohawk valley and the Champlain valley. If as Quinn ('33) thinks, the Champlain faults resulted from the sagging of the Appalachian geosyncline under the weight of accumulating sediments (late Ordovician time) or by the initial tensional forces which caused the geosyncline, it is possible that the numerous marginal faults of the folds of the Devonian rocks will produce valuable clues.

In connection with the faults the fact should be mentioned that slip cleavage, minor faults, shear zones and diagonal joints also will be able to furnish important data. Thus Dale ('99) was able to recognize two periods of compression and folding by these structures in the eastern Vermont-New York slate belt. Newland ('36, p. 78) has summarized Dale's results as follows:

> The field relations of the slates are complicated by intricate folding and deep erosion which has removed much of the overlying strata. Dale found evidences of two periods of compression and folding. The first and most apparent in its results came at the close of the Ordovician and effected the cleavage foliation and development of grain in the clays as well as the formation of new minerals, particularly muscovite and chlorite. In the coarser sediments like sandstone, quartz was deposited as cement and in veins. In the later period of compression slip cleavage, minor faults, shear zones and diagonal joints were produced. New infiltrations of silica and carbonates took place in the openings made at this time and along some of the fractures came intrusions of igneous material which consolidated as dikes.

This important observation is the best evidence that the later revolutions (Acadian or Appalachian, most probably Appalachian) clearly also affected the already intensely folded slate belt, produced by the Taconian revolution. The multitude of quartz veins, mostly of north-south direction which we had occasion to observe in the eastern folded belt, notably the Nassau phyllite, undoubtedly belongs in the same class of evidence. It also supports Pepper's conclusion of the Appalachian age of the cleavage.

6 Finally also the metamorphism will yield some clues if properly understood. We have already mentioned Doctor Knopf's ('07, p. 449) suggestion that metamorphism may be due to conditions of resistance to stress produced by preceding folding. This avenue of approach may allow us to recognize the metamorphism in the Taconic region as a function of an orogenic stress of younger than Taconian age, unless Suess's contention that the metamorphism is connected with the overthrust sheets should prove correct. The observations of Pepper, Dale and Knopf suggesting that the folded Taconic region reacted to renewed orogenic compression rather by cleavage, jointing, shearing and by metamorphism than new folding are important for our problem when weighed with the claims of European authors, as notably Stille that folded blocks become stiffened and resist further folding. It is then proper to infer that the folding of the Cambrian and Ordovician belt which is of Taconian age, has not been diverted to any appreciable amount by later orogenic stresses.

In summarizing it can be said that there are several lines of evidence that unmistakably indicate secondary effects, other than folding, of orogenic stresses after the Taconian revolution, in the Cambro-Ordovician shale belt of the Hudson valley and apparently also suggestions of the effects of more than one orogeny in the Silurian and Devonian rocks.

It may be added in this connection that these effects in the Cambro-Ordovician shale belt are distinctly of a minor order of magnitude, consisting in no case of distinct folding. This is in line with the well-known fact that the Appalachian type of folding is essentially superficial, involving only an outer fraction of the crust (Chamberlin, R. F. '10, see also Bucher, '33, p. 151). It is probably for this reason that the Taconian folding remained uncontaminated by Appalachian folding, and that the latter, as seen in Becraft mountain and west of the Hudson river is not characterized by series of overturned, closed folds and larger anticlinoria, as the Taconian folding is, but expresses itself merely in smaller open folds and small overthrusts and gravity faults.

HISTORICAL GEOLOGY

The geological history of the Catskill quadrangle, as in fact of the whole Hudson Valley region is a very complex one as the region has been part of a very unstable area, that existed from Precambrian time. This unstable area was the Appalachian geosyncline. Dana ('73, p. 430) used the term "geosyncline" for a depression of the earth's crust which has received sediments of excessive thickness. The Appalachian geosyncline extending from Newfoundland to Alabama was his prototype.

Geosynclines have been recognized as fundamental structures of the earth's crust. They are the mobile belts out of which the mountain ranges rise. We can not enter here into the much mooted question of the origin of geosynclines but may state with Bucher ('33, p. 66) who summarizes the views of preceding authors, notably T. C. and R. T. Chamberlain and Schuchert, that in a general way they "arise in a broad border zone of indefinite width through the action of crustal stresses controlled by the contrast of ocean floors and continental platforms." These crustal stresses arise "through the subcrustal processes which lie back of the sinking of the ocean floor."

The great Appalachian geosyncline, starting as a great "furrow" of the crust in a weak belt inside the "borderland" Appalachia, formed a great "welt" by the stresses arising in the continent from the sinking floor of the Atlantic ocean. It was this rising borderland Appalachia (Nova Scotis of Schuchert in north) that furnished the great masses of clastic material to the Appalachian geosyncline, as in the later Normanskill time (Normanskill grit, or Austin Glen member) as well as the New Brunswick geanticline at times. On the other hand Bucher ('33, p. 61) shows that the thickness of the sediments forming in the geosyncline is not the controlling factor in the sinking of the bottom of the geosyncline which does not keep filled *pari passu* with its dropping bottom as had been believed originally and until recently. It is, therefore, under the influence of deeper-seated factors, possible for the bottom of the geosyncline to sink to great depths, as it did in earlier Normanskill time, when the Mt Merino cherts were deposited, and to rise again rapidly as when the Austin Glen grit was deposited.

The Appalachian geosyncline already in later Precambrian (Proterozoic) time began to be subdivided in its northern portion into two secondary geosynclines, that were separated by a geanticline (New Brunswick geanticline). These secondary geosynclines were the

St Lawrence geosyncline in the west and north and the Acadian geosyncline, which passed east of the New Brunswick geanticline (Schuchert, '23, p. 172, '30, p. 703, also figures 64 and 65).

We are here interested only in the western or St Lawrence geosyncline since rocks of our district were deposited in that depression.

According to Schuchert (see figures 64 and 65) the folding moved the whole Appalachian geosyncline northwestward. The St Lawrence geosyncline in its original position passed through Massachusetts, Connecticut, eastern New York, including the whole Hudson valley outside the Adirondacks, down to Long Island, while after the contraction had taken place, it passed through western New Hampshire and eastern New York, above the Highlands, touching Massachusetts only in the northwest corner.

Ulrich and Schuchert ('02) had early distinguished two troughs or basins in the greater northern part of the Appalachian geosyncline (St Lawrence geosyncline of Schuchert) which they distinguished as the Levis trough and the Chazy trough. The Levis trough (named after the Point Levis graptolite beds at Quebec) is the eastern basin in which the great deposition of the Lower Cambrian and the Ordovician graptolite beds took place; the Chazy trough is the western basin in which the normal succession of the Potsdam sandstone, Theresa formation, Little Falls dolomite, Beekmantown, Chazy and Trenton beds is found. The writer has fully described the relation of these two basins in the Capital District bulletin ('30, p. 132) where it is stated that "the two troughs persisted through Cambrian and Ordovician time according to the record they have left in the sediments and fossils. They were, however, more or less independent from each other, so that one could be drained while the other was inundated, and a study of the diagram (text figure 37) shows that they were drained in fairly regular alternation." A permanent landbarrier was assumed by Ulrich and Schuchert and the writer to have separated the two basins, because of their mutual independence. Doctor Ulrich (personal information) became early convinced that still a third trough existed farther east in the same geosyncline. It agrees with this view that subsequently Prindle and Knopf ('32) have distinguished two sequences in the Taconian area, *viz.*, their "Taconic sequence" (our Eastern series) and an "eastern sequence" in the Mt Greylock range, consisting in the metamorphosed area of schists (Rowe and Hoosac schists, of supposed Cambrian age) in the less metamorphosed area of basal quartzite (Cheshire quartzite), dolomite (Rutland dolomite, also Cambrian), limestones (formerly Stockbridge limestone), of Beekmantown to Black River age and shale (Walloomsac shale, probably of upper Normanskill age).

If the three sequences (Chazy, Levis and Prindle and Knopf's eastern) are plotted in a diagram (see figure 50), it is readily seen that the two marginal troughs correspond roughly in their sequences, while the middle one differs fundamentally. The two marginal troughs begin with quartzites, which are followed by thick dolomites, limestones and finally by shale. The sandstone (Potsdam) in the western basin is of late Cambrian age, that in the eastern basin (Cheshire quartzite) of Lower Cambrian age; in the western sequence follow the Theresa and Little Falls dolomites, the Beekmantown dolomite and limestone series, the Chazy limestones, Lowville and Black River (Amsterdam) limestones, Trenton limestone (Glens Falls limestone) and Trenton shale (Canajoharie and Schenectady beds). In the eastern sequence the Cheshire quartzite represents the basal quartzite (Lower Cambrian). This is followed by the Rutland dolomite, of Cambrian age, and the Stockbridge limestone, corresponding according to fossils found by Prindle ('32, p. 271) to the western Beekmantown (B and E), Chazy, Black River, lower Trenton series and the Walloomsac shale, a correlative in the east if not in age, so in position of the Canajoharie shale.

In the middle sequence are the Nassau shale and quartzite and the Schodack shale and limestone, both of Lower Cambrian age, followed by the graptolite series of Beekmantown age (Schaghticoke and Deepkill shale), Chazy age (uppermost Deepkill and Normanskill), Black River age (Upper Normanskill) and Trenton (Snake Hill shale).

It is even possible judging from evidence in the Rysedorph conglomerate, that typical Lowville and Chazy limestones occur in the eastern sequence now obscured by metamorphism.

The view generally favored is that of the presence of barriers that separated the several troughs and thus produced the different sequences of rocks and the differences in the faunas. This view is well supported by the fact that such barriers have been established as unmistakable facts in Europe, as in the Variscian geosyncline, by numerous borings in the coal basins. There is no trace of the former barriers left in our geosyncline, nor could this be expected as all three troughs have been shoved together and even partly pushed over each other by the general northwest compression of the geosyncline in the Taconian revolution. Also, the varying presence and absence of formations in the different troughs, as that of the Upper Cambrian Potsdam sandstone in the two eastern troughs, while the Lower Cambrian is absent in the western trough, strongly indicates a considerable degree of independence of the troughs, hardly possible in a single basin.

There are certain facts, however, which can not be overlooked as indicating a certain unity of the whole geosyncline at certain periods. These are the presence of the great graptolite shale series in the middle basin, flanked on both sides (in the western trough farther north in the Chazy basin) by corresponding thick limestone and dolomite series. The graptolite series is to be considered as representing the deposits of the deeper middle regions of the geosyncline, the sandstones and limestones of the two marginal basins, the littoral or at least nearer shore deposits. At times, as in earlier Normanskill time where the radiolarian cherts were formed this middle portion of the great "furrow" may have even reached abyssal depths, while on both sides in the marginal troughs the limestones formed. It must be inferred that at such times the whole geosyncline formed one wide sea with a current sufficiently strong to carry the oceanic plankton through the middle of the wide basin and to deposit the Sargasso-sea derived graptolite faunas and at extreme stages even abyssal radiolarian cherts. It is suggestive of such temporary conditions and of the occasional submergence or entire disappearance of the barriers that at times typical beds of one trough encroach on the neighboring trough, as the Canajoharie shale appearing as thin intercalations in the Snake Hill beds (see Ruedemann, '30, p. 32) and the upper Normanskill shale as Walloomsac shale in the eastern trough.*

There are those who would obliterate all barriers in the St Lawrence geosyncline and consider the three sequences merely as expressions of different facies in the same basin, a central oceanic planktonic facies and two littoral benthonic facies. It would seem that the varying conditions in the geosyncline allow the conclusion that both working hypotheses may be applied at certain times, that of the barriers where one trough remained entirely unaffected or emerged, as in Lower Cambrian time when the western trough apparently remained dry and in Trenton time when the eastern trough received

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* Since this was written, an important paper by G. M. Kay on the stratigraphy of the Trenton group (1937) has advanced the view that a great barrier, his Vermontia, that began with a chain of islands in Rockland time, developed into a broad folded barrier that lasted through middle and late Trenton time and separated the Champlain trough from his Magog trough, thus occupying essentially the place of the earlier "Quebec barrier."

little or no sediments and that of a single basin at such times when the Schaghticoke, Deepkill and Lower Normanskill graptolite shales and especially when the Lower Normanskill (Mt Merino) radiolarian cherts were deposited.

After we have obtained the preceding rather cursory survey of the history of the Appalachian geosyncline in the region in which we are at present particularly interested, we can trace the geological history of our area through the different geological periods.

PRECAMBRIAN HISTORY

There are at present no Precambrian rocks exposed in the Catskill quadrangle, but we have not far to go to find the gneisses and granites in the southern Green Mountain range along the New York-Massachusetts boundary, or the great Precambrian massif of the Adirondacks and the Precambrian mountains of the Highlands.

There is no doubt that the Precambrian granites and gneisses underlie the Catskill area at a depth of 4000 to 5000 feet as the fundamental complex. As a matter of fact these crystalline rocks underlie the whole continent as a foundation that is a portion of a once greater continental block known as Laurentia.

These Precambrian rocks are intensely folded. It was generally held that these folds are irregular in direction and hence of no structural significance. The writer ('22) has shown that the folds are all arranged in orderly fashion, and that this order is connected with the original form of the continent, the folds having arranged themselves parallel to the outline of the continent, and the compressing force having acted from the heavier bottom of the nearest ocean. Thus in the Adirondacks the Precambrian folds strike in northeast direction and the same is true of the Precambrian folds in the Highlands and the Appalachian system generally. The same is undoubtedly true of the folds deep under the Catskill district. This uniform northeast folding in the eastern half of the continent, to which corresponds a northwestern folding in the Cordilleran region is the fundamental structure of the continent. It has been termed the "grain" of the continent by the writer. This original folding was induced by the pressure of the bottom of the primeval oceans east and west of the continent and it runs in a rough way parallel to the primeval coast lines of the continent. It has influenced the general physiography of the continent throughout its history in the location of the coast lines, geosynclines, mountain ranges, periodic marine inundations and to some extent the location of the river systems (as that of the St Lawrence).

As Schuchert ('23) has shown already in Proterozoic time a prenuncial geosyncline of the Appalachian geosyncline can be made out in eastern North America. The first indication of mountain ranges that appeared in this geosyncline were the bars or ridges that separated the troughs which we find in early Cambrian time.

CAMBRIAN HISTORY

A glance at the diagram (figure 50) shows that the western trough remained emerged while the middle and eastern troughs received great thicknesses of sediments in Lower Cambrian time, *viz.,* the Nassau shales and quartzites and the Schodack limestones and shales in the middle trough, and the Cheshire quartzite and Rutland dolomite in the eastern trough. The Nassau and Schodack beds are both formed by clastic sediments that indicate by the frequent and often regular alternation of quartzite and shale in the one, and of limestone and shale in the other, that currents of varying velocity were active at the bottom of the depositing sea. These currents are also the cause of oblique sedimentation and plunge structure in the quartzites. The character of the prevailingly fine-grained rock suggests greater depths or farther distance from the shore line. A notable feature is the edgewise conglomerate lenses in the Schodack limestone which on one hand prove a fairly steep grade of the bottom that received the deposition and on the other suggest the occurrence of recurrent strong earthquake shocks that produced the submarine slumping, the same as they have done recently on the Newfoundland banks. The Nassau beds have proved so far entirely barren of fossils save the *Oldhamia* which indicates the primeval life of soft animals (worms?) unprotected by shells. It is therefore possible that the Nassau beds even represent the last stage of the Precambrian.

The Schodack limestone besides the lenses and beds of edgewise conglomerate (or rather breccia) is also distinguishable from other limestone by the frequent occurrence of well-rounded, frosted sand grains that are evenly distributed in the limestone. These floating sand grains have all the appearance of having been blown into the sea from land. As one rarely observes them in later limestones, they give a fair indication of the desert conditions that prevailed on land and the power of the storms that raged over it. Such gray quartz grains are also common in the Burden iron ore. As, according to Newland, such gray quartz is not found in the Adirondacks, but is prevalent to

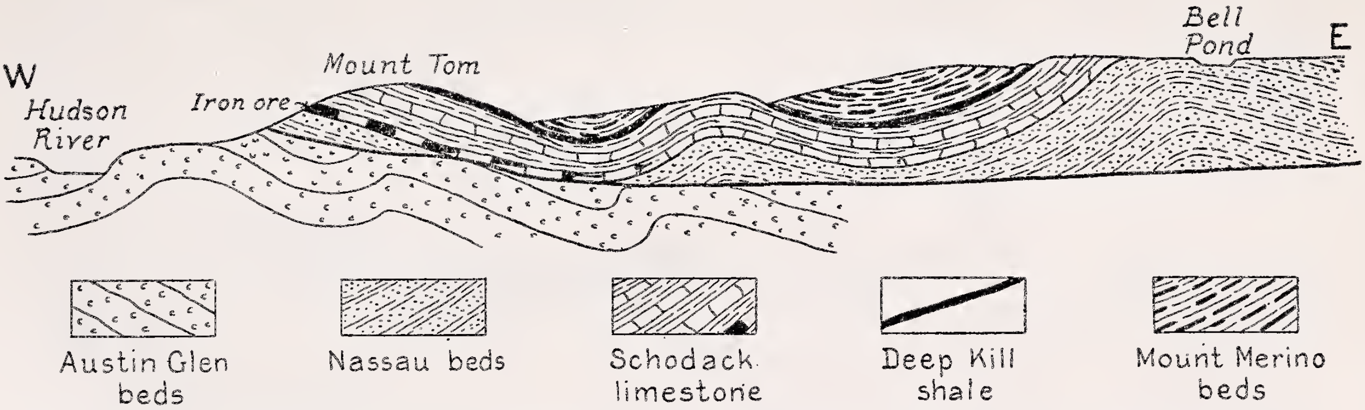

Figure 66 West-east section through Mt Tom to Bell pond to show relation of Burden iron ore bed to adjoining formations

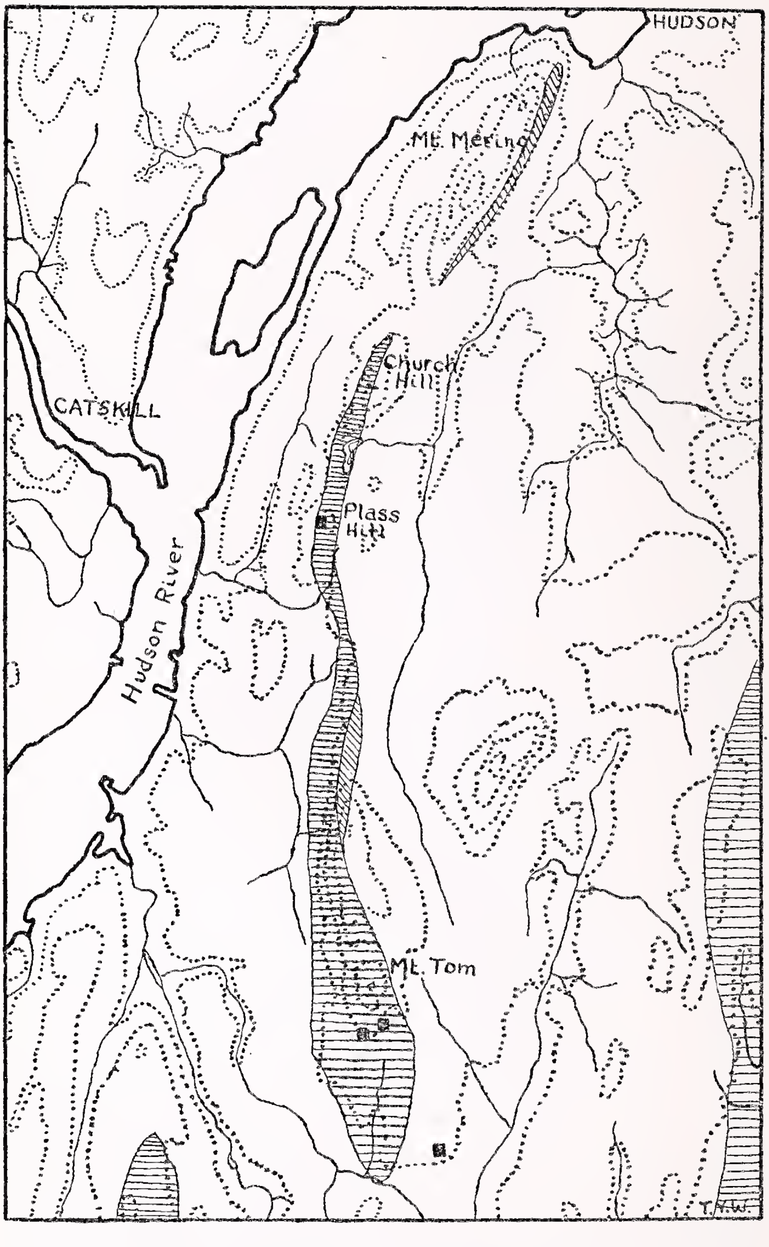

Figure 67 Sketch of Burden iron ore belt. Black squares adits. Horizontal lines Schodack beds, oblique lines Deepkill.

the east in the Green mountains and New England, it may be properly concluded that these storms came from the north and east, that is, most probably across the New Brunswick geanticline. The Burden iron ore, found on the boundary of the Nassau and Schodack beds, or formed in earliest Schodack time, was according to Newland ('36) most probably formed in shore lagoons. It thus would indicate rather shallow water for that particular time in our area, provided the whole iron ore body is not thrust over from the east as we have suggested in another place.

The bulk of the Nassau and Schodack beds are shales, mostly greenish gray, but there are also abundant red and purple beds which may indicate subtropical conditions on land or exposure and thorough oxidation of the mud on flats.

Meanwhile the western trough remained dry, unless there were deposits there that have since been eroded. Upper Cambrian Potsdam sandstone, however, with its sands and basal conglomerates gives the distinct impression of having been laid down in an advancing sea. This invasion came clearly from the north, as the thickest beds are in the north and the formation disappears southward.

All three troughs seem to have become emerged in Middle Cambrian time, unless the rocks were later again eroded in Upper Cambrian time. It is now established that the Middle Cambrian invaded the geosyncline both in the north (Vermont) and in the south possibly as far as Stissing mountain.

Upper Cambrian (Ozarkian of authors) time is well represented in the western trough by the Theresa sandstone, Hoyt limestone and Little Falls dolomite. The sandy beds of the Potsdam are there replaced gradually by limestones that indicate genial conditions by their flourishing Cryptozoön reefs. From fossils found in the lower Stockbridge limestone indicating Beekmantown B, it would appear that a contemporaneous sea also invaded the eastern trough.

In the middle trough the next rocks above the Schodack beds are the Schaghticoke graptolite shales. These the writer ('03) had originally described as marking the top of the Cambrian, a view still held by many in Europe, especially in Great Britain, while here it is now commonly placed at the base of the Ordovician (Canadian of Ulrich). Whether the interval from Lower Cambrian to Canadian time was occupied by land or deep sea that did not produce any sediments is not known at present. It is also possible that Middle and Upper Cambrian deposits that existed there were entirely eroded away in Upper Cambrian (Ozarkian) time before the Schaghticoke shales were formed. There is a very marked break between the Schodack and Schaghticoke beds and it seems rather improbable that the thick Upper Cambrian (Ozarkian) dolomite and limestone beds in the western and eastern troughs should have been deposited, while the middle trough remained entirely exposed.

CANADIAN AND ORDOVICIAN HISTORY

The Canadian period is represented in our middle trough by the Schaghticoke and Deepkill graptolite shales of Beekmantown age and possibly Lower Chazy age; the Lower Ordovician by the Normanskill of Chazy and Black River age. These form, with the superjacent Snake Hill shale, one of the greatest continuous series of graptolite shales in North America, thousands of feet thick, the Snake Hill shale alone amounting to about 3000 feet (Ruedemann, '30, p. 168), the Normanskill shale to about 1000 feet (*op. cit.* p. 99) and the Deepkill shale 200 to 300 feet (*op. cit.* p. 87). As the many successive graptolite zones, observed in these shales prove, they must represent an immense interval of time, in fact the greater portion of Ordovician time to which are assigned 75 million years. It may well have taken 50 million years to deposit this series of shales and during this long period the geosyncline was swept in the middle by the graptolite-bearing currents while on the eastern and western flanks the limestones were deposited probably in one general basin. The planktonic graptolites of the shales, as well as the planktonic radiolarians of the cherts, prove that the open ocean had free ingress and egress in this great basin so that ocean currents could freely sweep through it (Ruedemann, '11). At times, as at the Lower Normanskill (Mt Merino) time the bottom sank to abyssal depths, to rise again in Upper Normanskill (Austin Glen) time near enough to the surface to receive thick deposits of sand, alternating with shales.

At the end of this period the Rysedorph conglomerate was formed, the matrix and some of the pebbles of which already contain Trenton fossils, besides Lower Cambrian, Chazy, Lowville and numerous Black River and Trenton pebbles. Many of the latter (Ruedemann, '01) point to a North Atlantic invasion into the geosyncline, contrasting with the western and southern invasions of the continent outside of the geosyncline. The origin of this strange conglomerate is probably to be sought in wide submarine slumping on the flanks of the rising mountain ranges of the beginning Taconian revolution. There seem to be thicker and thinner beds of this conglomerate, so that the process was repeated, probably at times of severe earthquakes.

The top of the Ordovician series of shales in the middle of the geosyncline is formed by the Snake Hill shale. This is not any more a pure graptolite shale as are the preceding ones, but contains a much reduced graptolite fauna and a large neritic fauna of brachiopods, pelecypods, gastropods, trilobites etc. There are 85 species of these cited in the Capital District (Bul. 285, p. 121 ff.), leaving no doubt that the more or less foul bottom conditions that prevailed much of the time in the depths of the middle of the great geosyncline, while in the higher levels the ocean currents flowed, had been supplanted by conditions fairly favorable to bottom life.

No Snake Hill beds were found on the Catskill quadrangle, but as they are present in the Capital District overlying the Normanskill shale and reappear in great force again in the Newburgh area (Holzwasser, '26) they undoubtedly were also deposited in the intervening area, but had been eroded already at the end of the Ordovician period, for the folding and overthrust plates creeping westward at the end of the Taconian revolution did not find any more Snake Hill shales in this area, as they did in the Capital District and in the Newburgh area, where they are involved together with the Normanskill shales in the Taconian orogeny.

The Taconian orgeny closed the Ordovician period in the belt of rocks formed in the middle or Taconian trough or the middle of the Appalachian geosyncline. We have discussed its effect fully in a preceding chapter. It thoroughly folded and overthrust the Cambrian, Canadian and Ordovician rocks of the entire district.

SILURIAN HISTORY

The Silurian period is represented on the quadrangle only by a few feet of Rondout waterlime of Upper Silurian age and the Manlius limestone, the latest formation of the Silurian. It is probable that more Rondout waterlime was originally present, as it is found in greater force south and north, but that it had been eroded before the deposition of the Manlius. The Rondout waterlime is clearly a marine sediment, formed by chemical deposition in a shallow epicontinental sea that extended from the Atlantic to Michigan and in a narrower embayment southward into Virginia. The following Salina sea which spread in western New York with a very incomplete connection with the ocean apparently did not reach this region which must have been emergent at the time.

The Manlius sea invaded from the east and spread some distance south in the old Appalachian basin to Tennessee and across it westward through western New York and Ohio to Michigan. A fauna of corals, pteropods, brachiopods, pelecypods and trilobites flourished in this sea. In the Helderbergs and the Hudson valley these beds give distinct evidence of deposition in extremely shallow water and on tide flats. Here the thin-bedded limestones with their tentaculites, ostracods, small spirifers and lamellibranchs, mud cracks and mud pebbles, and their association with the Stromatopora beds, suggest that these limestones are principally lagoon deposits on tide flats, formed between and behind the Stromatopora reefs.

DEVONIAN HISTORY

The Manlius sea in the Hudson Valley area seems to have changed gradually into the Coeymans sea, as is indicated by the transition beds. It is thus seen that the boundary between the Silurian and Devonian systems is not so distinctly marked as we would expect to find it.

The Coeymans sea was not greatly different in general outline from the Manlius. In New York it extended westward from the Helderbergs not quite so far as did the Manlius sea, and eastward it had about the same extent. The sea in the Helderberg portion of the Capital District was deeper than before and produced a fairly pure limestone, containing principally brachiopods. Farther west, in Herkimer county, plantations of crinoids and cystids are found, suggesting quiet waters.

The Coeymans beds are again connected by transition beds with the overlying New Scotland beds, proving a gradual change of conditions. The New Scotland sea lacked the westward extension of the Coeymans and Manlius seas, but it extended southward in the Appalachian region and it found a passage eastward across the Taconic region into a narrow area that extended to the St Lawrence country and beyond the Newfoundland region to the Atlantic. The condition had changed in the Hudson district in that there was a much greater influx of mud, so that the New Scotland beds are impure shaly limestones and calcareous shales.

The Becraft limestone is so well set off from the subjacent New Scotland beds that there may have taken place a brief elevation of the region above sea level, or at least a shifting of barriers and currents, that produced a mud-free clear sea in which a limestone, largely composed of crinoid stems and plates and brachiopods, could form. This sea formed but a narrow arm in New York, but it extended far down to Virginia and across the southern Taconic region into an eastern trough that led, as in New Scotland time, to the lower St Lawrence (Gaspé) country and Newfoundland.

The Oriskany sandstone is characterized by its thick-shelled fossils and sandy limestone, changing to pure quartz-rock at Oriskany; there is no doubt that the turbulent sea near the northern shore line deposited these beds. The Oriskany sea, like all the preceding seas had an oceanic connection in New Jersey, spread westward in a narrow embayment into Ontario and like the preceding seas over the Taconic region into Massachusetts and thence northward into the Gaspé country, where thick calcareous beds (Grand Grève beds) were deposited. The broad access of the northern Atlantic in the Gaspé region and in Nova Scotia brought in the North Atlantic fauna with European relations (Clarke's Coblenzian invasion), that furnishes the typical Oriskany brachiopods, in contrast to the preceding faunas that had southern Atlantic characters. The thick mass of the blackish, gritty or sandy Esopus shale is but a different facies of the upper Oriskany beds or later Oriskany sea. These barren beds, containing only the spiral worm trails, known as *Taonurus cauda galli*, indicate such an influx of mud, that organic life was almost impossible. These conditions did not extend far west (to Otsego county), but southward to Pennsylvania.

The Schoharie grit is but a local development or sandy facies of the lower Onondaga limestone, indicating a great influx of sandy material in the region from Albany county to Otsego county. In spite of this sandy admixture to the calcareous mud, the formation has furnished a large fauna (of 123 species), indicating congenial conditions, especially for brachiopods (33 species), cephalopods (44 species) and trilobites (16 species). It is a distinct cephalopod facies, many of which, as the Trochoceras and Gyroceras forms were undoubtedly bottom-crawlers. It was altogether the rich benthonic life of the zone below the tides. This cephalopod facies of the Schoharie grit marked only a restricted area in the great Onondaga sea, that spread far to the west to the Great Lakes region, sending a broad arm north to Hudson bay, and another south to the Gulf of Mexico, as well as a narrow blind arm through the old eastern trough to the St Lawrence region. The short Schoharie grit episode was followed by the open Onondaga sea, depositing pure lime and harboring widely spread coral reefs, that give evidence of very clear warm water and generally congenial conditions, reflected in brachiopods, large cephalopods and trilobites.

The Onondaga limestone is abruptly followed in the Hudson valley by nearly 200 feet of black fissile shales, the Marcellus beds with a characteristic diminutive fauna. This fauna came from the southeast, having wandered into this region from the southern Atlantic by way of the Appalachian interior sea. Going west from here one finds that the beds become more and more calcareous and that at least the lower 50 feet correspond to the upper Onondaga of western New York. The Marcellus is therefore, in part at least, a muddy facies of the Onondaga sea. Also the upper Marcellus contains in the west a calcareous intercalation known as the Spafford limestone. This, as well as an earlier smaller calcareous intercalation, beginning just west of the Capital District and known as the Cherry Valley limestone, contains a Hamilton fauna. The sea, when these muds were being deposited along the eastern and northeastern shore lines, was already beginning to spread far to the west, even beyond the Onondaga sea. The source of the black muds must be sought in the higher lands, bordering the sea in the east and north.

The Marcellus sea became by transitional stages, as shown in the limestone intercalations with Hamilton faunas, enlarged into the Hamilton sea, which spread from its entrance at the St Lawrence and New Jersey regions across the continent with arms extending to the Gulf of Mexico and north through the Mackenzie region to the Arctic ocean. In New York this sea deposited several thousand feet of shales and sandstones teeming with life, especially brachiopods and lamellibranchs, adapted to the muddy sediments. In the east the faunas entered from the Atlantic, carrying the characteristic Atlantic brachiopod *Tropidoleptus carinatus,* that is found as far south as South Africa and the Falkland islands. In the western portions of the great inland sea, Arctic and Pacific faunas are found. Even if deposition of the beds took place much faster than that of the limestones, the great thickness of the formation and the wide extent of the sea indicate that it must have persisted over a long period of time.

The Devonian beds that overlie the Hamilton beds in the eastern belt of New York are the Sherburne sandstone, the Ithaca beds, the Oneonta sandstone and the great mass of the Catskill beds. These several thousands of feet of shales and sandstones indicate at least two floods and emergences of the country. First it appears that there was a withdrawal of the sea in the northeast, for in western New York there are a number of formations, the Tully limestone, the Genesee beds (with Geneseo black shale, Genundewa limestone and West River shale) that do not reach eastern New York and in southeastern New York are the Bellvale flags in part of corresponding age. Then the Portage sea advanced from the west, depositing in western and central New York the Cashaqua shale and in eastern central and eastern New York the Sherburne sandstone. In Otsego and Schoharie counties the fossils of this formation are a modified Hamilton fauna, that still lingered from earlier times, but in Greene and Ulster counties, we find only barren flagstones bearing occasionally a few species of plants. It is quite obvious from this observation that a broad bay, the Albany bay, existed where a river, most probably coming down from the north, emptied and brought into the bay the sands and the plant fragments now found in the eastern Sherburne rocks. These conditions continued while in western New York the peculiar foreign Naples fauna flourished, and farther east lived the Ithaca fauna, still a derivative of the Hamilton fauna. This Naples-Ithaca sea deposited in the northeast corner of the Albany bay Ithaca beds, that are reddish and greenish shales and sandstones, instead of the bluish and grayish marine shales of the west. These reddish shales are again barren and both by this fact as by their color denote their derivation from a near-by land and their deposition in a brackish bay. The Ithaca beds are followed by more than 500 feet of Oneonta beds between the Helderbergs and the Catskills. These are "red and green shales, reddish sandstones and coarse-grained grayish to greenish gray sandstones" (Prosser, '99, p. 313). They are unfossiliferous, except for an occasional specimen of the fern *Archaeopteris* and the fresh-water clam *Archanodon* (*Amnigenia*) *catskillensis*. These beds are also correlated with marine beds holding the Naples fauna of Portage age. It was in this time that on land to the east and north of the bay the most ancient forests grew. This we see reproduced in the Gilboa group in the State Museum. Such forests may have grown above the shore lines.

The northeastern Albany bay was now more sharply separated from the sea than before, probably by a bar projecting southward from the coast line in the north such as Clarke ('04, plate B) has described. And upon the Oneonta beds are piled the thousands of feet of Catskill rocks, shales and sandstones, that are mostly of the same age as the Upper Devonian Chemung rocks of western and central New York, with a profuse organic life that strongly contrasts with the barrenness of the Catskill beds. At this time heavy land drainage had changed the Albany bay into a large fresh-water or brackish lagoon or estuary. As we have already described in another chapter, a great river coming from the north into this bay deposited the Rensselaer grit along the edge of the Capital District in a sinking trough at the same time that farther down in the bay the Catskill beds were formed.

This was the end of the marine Paleozoic deposition of which we have a direct record in this part of New York.

CARBONIFEROUS HISTORY

The Devonian was the end of the marine Paleozoic history of which we have a direct record in this part of New York. In southwestern New York and in Pennsylvania a great series of formations of Carbonic age, both of the Mississippian group and the Pennsylvanian group are still found. The rich coal beds of Pennsylvania were formed in this time. There is no doubt that a large portion of these formations, also, once extended into our district and that for all we know luxuriant swamp forests of the coal period may have flourished here as well as in Pennsylvania, for, if we consider that the Capital District was exposed to the gradational work of wind and weather ever since the Carboniferous period, that is, for 300 millions of years as geologic time is figured now, it is readily seen that an enormous amount of material above the Catskill beds must have been removed in this long time.

Toward the end of the Carbonic era the Appalachian revolution began, which again folded eastern New York, throwing the Rensselaer grit into the series of anticlines and synclines that we find now composing the plateau. This folding died out rapidly toward the west. Its last vestiges are the small folds in the Helderbergs, south of Clarksville, described in a former chapter.

And then began the great process of removal of the pile of rocks which from the top of the Catskills to the base of the Cambrian amounted to over a mile, and at the beginning probably to a mile and a half. Considering that this mass was folded in the eastern portion of the Capital District and raised into mountain ranges, it is not too much to say that there were possibly as much as two miles of rock above the site of Albany that have been carried off to the sea since Paleozoic time. The process began in the north on the slope of the rising Adirondack plateau and worked backward and southward in a series of terraces and escarpments, until now everything of Silurian and Devonian age is eroded away north of the Helderberg escarpment, and the older Ordovician and the very oldest Cambrian rocks have come to the surface. Above the receding Helderberg cliff the enormous pile of rock that we see rising farther south in terraces to the top of the Catskills has already been worn away. It is due to this far-reaching erosion that the Capital District furnishes a section from the Lower Cambrian to the Upper Devonian rocks.

MESOZOIC HISTORY

For the Mesozoic history of the Hudson Valley region we have only negative data. There is no trace of deposits of this long era here. It would therefore seem to follow that the region must have been a land area. During the early part of Mesozoic time, in the Triassic period, however, certain troughs along the east margin of the Appalachian region subsided and received a large thickness of continental deposits. No traces of such troughs have been found in the Hudson Valley region. Nor can any of the faults be assigned to the Mesozoic period.

Cessation of the continental deposits of early Mesozoic (Triassic) age in the troughs to the east of the Appalachian folds was probably brought about by renewed uplift. Then followed a long period of erosion, the final result of which was a rather thorough wearing down of the region to a comparatively low plain, a so-called peneplain. A peneplain of late Mesozoic (Cretaceous) age was produced quite generally throughout the Appalachian region and eastern Canada and it is quite reasonable to assume that it was also produced here.

In reconstructing in the mind the events of this Mesozoic era, we can not help being aroused by the thought of the strange world that during this long era (that began some 200 million years and ended some 50 million years before our time) existed at the beginning perhaps two miles above the present site and level of our area; of the strange and gigantic reptiles, the tracks of which are still found in continental deposits of the Connecticut valley, that once wandered about in equally weird forests and swamps high above the Hudson Valley region; and of the 40 million years of time, of which we have no record here and during which the country gradually sank to near sea level.

CENOZOIC HISTORY

The Cenozoic history of the Hudson valley is the same as that of the Saratoga region, which has been described by Cushing and Ruedemann ('14, p. 145) as follows:

At the close of the Mesozoic the region was again uplifted. The low altitude peneplain which had been produced over the Adirondack region was elevated some 1500 feet or more and rapid erosion of its surface began. Stream valleys were cut down and broadened. It is the depth of the valley cutting below the old peneplain level which enables us to estimate the amount of the uplift. The divides between the valleys, however, have been but little worn down during the time that has passed since the uplift. These divides rise now to uniform levels, the level of the old peneplain. An observer, standing upon one of these divide summits and looking abroad to the others, receives the impression of standing upon the surface of a plain and has merely to imagine the valleys refilled with material in order to picture the plain as it was at the time of the uplift.

This old peneplain surface is readily made out over most of the Adirondack region. But in the extreme east it seems to fail and the divide summits rise to very discordant levels instead of being uniform. This we take to mean that here renewed slipping along the old faults occurred as a phase of the uplift; that the Champlain trough displayed anew its tendency to sag relative to the district to the west; that it was uplifted much less than the Adirondacks, and that the difference in amount was made possible by additional faulting, the easterly slices being thrown down relative to those west of them. The old fault scarps had been peneplained along with the rest of the region. These further movements renewed them, and their prominence today is in part due to this late movement. The McGregor and Hoffman fronts of the Saratoga quadrangle would be much less imposing than they are had it not been for this.

It is by no means unlikely that further westward movement of the eastern basin rocks along the thrust fault planes also took place at this time.

During the first part of the Cenozoic, the Tertiary, minor oscillations of level took place in the region, but we lack the precise knowledge of just when and what they were. Later in Tertiary time an additional uplift took place, considerably increasing the altitude of the region, not improbably with renewed faulting. The peneplain that had formed during the preceding Tertiary time and that was now uplifted, is recognized in the Tertiary peneplain of the Helderberg mountains and the Rensselaer plateau. A still lower peneplain began then to form in the inner lowland of the Helderberg and Rensselaer plateaus; this is the Albany peneplain. It is still growing into the surrounding plateaus.

Finally the region was invaded by the ice sheets of the glacial period. The Pleistocene history, or the fate of our district during the glacial period, will be fully described by my colleague, Professor John Cook.

THE GLACIAL GEOLOGY OF THE CATSKILL QUADRANGLE

By John H. Cook

INTRODUCTION

The Pleistocene period of geology was marked by low air temperatures and the accumulation of vast fields of persistent snow which became compacted into sheets of land ice. As these thickened, their margins advanced until all the regions known to have been glaciated were covered. New York State was undoubtedly buried under ice more than once; and each period of glacierization was followed by a warm interval during which the ice was largely (perhaps wholly) melted away.

In spite, however, of repeated invasions and of the scraping and plucking to which the rocks of the Hudson valley have been subjected, the changes wrought on the topography are not of major importance. The creep of the ice appears to have been so slow that the building up of pressures under which deep erosive work is accomplished was of local occurrence only. For the most part the combined action of the several ice sheets did little more than plane off minor irregularities and give to the hills that type of profile popularly called "streamlined." The smooth contours of the various summits on the ridge of phyllite along the eastern edge of the map are due to glacial action of this character; partly by trimming away salient projections and partly by plastering the rock with débris, the overriding ice produced curved surfaces on which it could ride with a minimum of opposition and friction.

The freedom with which the constituent crystals of glacial ice move when under pressure enables the bottom ice to accommodate itself to the topographic relief of the basement in a manner somewhat analogous to that of a liquid moving past an obstruction. For this reason its progress is not inaptly described as a *flowing.* And just as sediment carried by a stream of water lessens the freedom with which the molecules of water move with respect to each other, the presence of dirt and stones incorporated with the basal layers of an ice sheet lessens the freedom with which the ice crystals slide upon one another. Different velocities may thus be attained along different paths throughout the mass of moving ice both vertically and horizontally: ice which is comparatively clean may stream past a lens which is heavily charged with débris and, in so doing, it will glide on the same kind of curved surfaces it uses in passing a fixed obstruction. It may be readily believed that a unit of heavily charged ice creeps slowly along with the more general movement until and unless it is arrested by becoming involved with a boss of rock. At any rate, now that the glacier has disappeared, we find onisciform hills both with and without cores of bedrock, singly and in clusters and sometimes constituting the only land forms of glacial origin over many square miles of territory. When composed wholly of "till" such hills are called *drumlins*. The adjective *drumloidal* refers to the form only and is applicable to all elevations of similar shape irrespective of the amount of bedrock in them.

Many of these ice-molded hills appearing on the quadrangle can be identified by the elliptical contour lines; a few have received names: Beckwith hill, The Whaleback, Cross hill, Round top and Little Round top. Perhaps the most striking as viewed from a paved highway is that near Nevis on which the beacon is located. Beckwith hill is one of a cluster and there are unnamed members of the Round Top group. Drumlins form the east bank of the river opposite Catskill village. The drainage from behind them has made a little valley up which the road climbs from Greenport Landing to the top of the rock terrace, following the easiest natural grade to and from the river and the crossing by ferry: an interesting historical contrast with the cut-and-filled highway location at the east end of the Rip Van Winkle bridge. In this cut, when it was first made, the typical arched bedding of drumlin structure (when there is any) was exhibited by two courses of stones subparallel with the curved profile of the cross section. Two drumlins south of the bridge are heavily coated with a drift sand to which they owe their suitability as agricultural land. The hill known as Mt Ray (around which the eastern outskirts of the city of Hudson are built) is probably a drumloidal ridge if not a true drumlin but its outline is obscured and the materials of which it is composed are concealed in large measure by a blanket of this same drift sand.

There is no known method by which to judge how much of the gross sculpturing of the rock floor was accomplished by earlier glaciations; but the drumlins proper and many of the similarly molded hills in which the presence of bedrock is not obtrusive were undoubtedly formed during the final spreading of the last (Wisconsin) ice sheet. Their longer axes show the direction which the glacial movement was taking; in this part of the Hudson valley it was to the south.

Upon the basement (the surface on which the glacier rested) lie the accumulations left when the ice melted off. Their distribution and the forms which association with contemporary ice has impressed upon many of them make it evident that the glacier had stagnated at some time previous to the uncovering of any of the hilltops east of the river. The deposits made as the ice was being dissipated are not such as could have been dumped along a boundary between land recently evacuated by the ice sheet and land still covered by it; that is to say, they are not end moraines built by moving ice at its line of liquefaction, nor are they recession moraines built over the glacier's marginal zone by floods of meltwater. They consist almost wholly of terraces lying against (or at least tied in with) the slopes of the valley sides. For appreciable distances north and south those which have their flat tops at the same level probably were made at approximately the same time and under the control of one and the same waterplane. This peculiarity of arrangement misled the geologists who first studied the glacial "drift" of the region. So far did it depart from the pattern which they expected of deposits left by a dwindling ice sheet that they *denied their glacial origin* and attributed them to an incursion of the sea during the *postglacial* period. The character of the waterlaid materials composing the more accessible terraces near the river was indisputable proof that deep and quiet waters had once occupied the valley: how could such waters be accounted for except by supposing the land to have been depressed in an amount sufficient to admit the sea? Those who maintained that the extinct waterbody had been a glacial lake were challenged to show how a trench sloping away from the area still under ice and wide open to the Atlantic could have been converted into a lake basin. The challenge was met by the hypothesis that the edge of the continent was then elevated until some point in the riverbed stood high enough to form a dam.

Recognition of the fact that the Wisconsin ice covering New England and eastern New York (part of the glacier's periphery) had melted off in large measure from a stagnated condition made it unnecessary to resort to either of these theories in order to explain the phenomena of embarrassed drainage and the flooding of south-sloping valleys: it was seen that the last unmelted remnants of the ice sheet remaining in and plugging the valley bottoms had prevented free outflow. Can ice constitute a substantial dam? Merely covered by water at a temperature slightly above the freezing point its rate of melting is exceedingly slow; but it is easily worn away by the action of running water such as the outlet of a lake would exercise upon it. It is, therefore, difficult to believe that an ice-filling in the gorge of the Hudson below Kingston, for example, would have been competent *of itself* to retain lake waters for the length of time required by the great thickness of fine sediment above Kingston, if the outlet of those waters was at the southern end; and this, even though the residual ice tongue may have extended to New York bay and been deeply buried under superglacial river deposits. *If* the drainage was southward, a possible explanation of the complex of lakes collectively known as "Lake Albany" is brought out in figure 68.

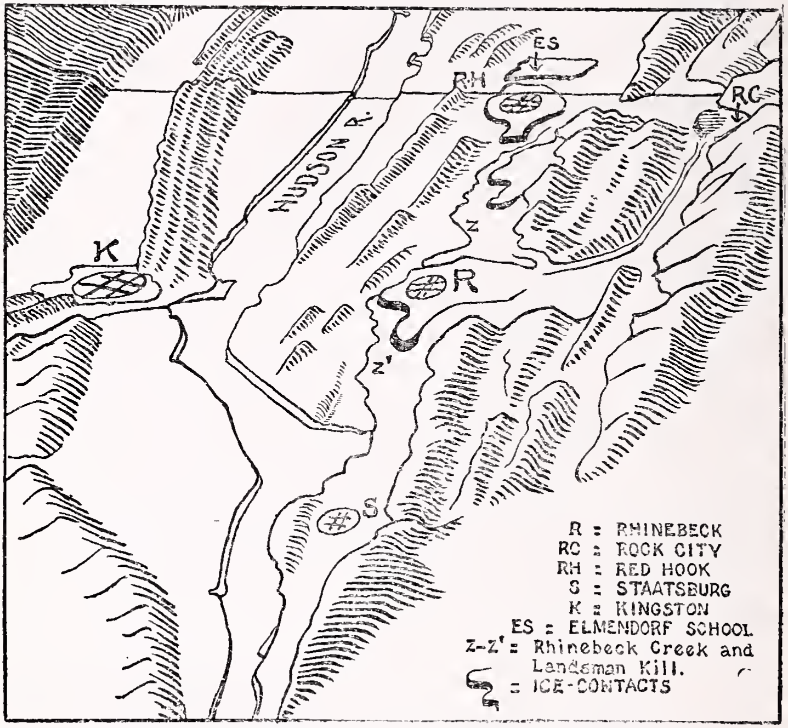

Figure 68 Topographic relations at the southern end of the "Albany clay" district

The figure depicts the more important topographic features of a section of the valley from just below Saugerties to just above Hyde Park (neither of which appears in the diagram) and takes in portions of the Catskill and Rhinebeck quadrangles. The parallel of latitude marking the division between the quadrangles (and which passes through the rim of the circle representing Red Hook) has been introduced into the sketch.

It will be noted that a short distance below Kingston, the river bends sharply, and, for about three miles, its gorge cuts athwart the dominant trend of the rock structure (exhibited by the ridges on the east side). It is a fair assumption that south-flowing glacial drainage, deflected from the east side, would have here crossed the ice-filled gorge to the rock terrace on the west side where hard bottom would have been encountered. This or some other rock terrace might have constituted the long-lived dam demanded by sediments at the north. Clays of a lower series (deposited during a later stage, after the lake had fallen) are found along the lower course of Landsman kill and it is evident that other durable dams existed farther south.

In any case the character of the solution to the problem of glacial lakes discharging southward through the Hudson valley is probably indicated by the relations found at this point. We shall see later on, however, that there is evidence favoring the hypothesis that Hudson Valley meltwaters eventually found escape northward into the Champlain basin; and there may have been no southern outlet for the clay depositing lakes.

Reference was made above to the fact that the forms given to many of the Pleistocene deposits by the presence of what remained of the ice sheet indicate that the abutting ice was stagnant at the time the deposits were made. This implies that in some situations the ice left indubitable records of its contemporaneous existence. Frequently it formed a part (occasionally all) of the shore of a glacial waterbody, and sediments banked against such a shore were apt to retain a moulded edge reflecting the shape of the ice after the latter had melted away. These slopes (sometimes belts or zones) of contact with residual ice are called ice-contacts. Although the several types differ in appearance and there is no single criterion by which they may be identified (except that the slopes are not such as could have been produced either by original deposition in icefree waters or by subsequent erosion), certain of them are so steep and drop so abruptly from a leveled top that it is at once evident that the water-borne materials were laid down against a nearly vertical face of ice. Ice-contacts are sometimes so obscure that unless they have been dug into for gravel their true nature is not apparent. On the other hand, contacts on the grand scale are not unknown. (Probably the most remarkable one in New York State is found between Trenton Falls and Newport in Herkimer county. In a veneer of fine sand covering the hillside is preserved a mold of several square miles of the under surface of stagnant ice which lay in the valley of West Canada creek.)

However much they differ among themselves the phenomena of contact are but variable expressions of a single important relationship: they occur along the boundaries of *areas from which sediments were excluded by the presence of ice.* If the record left by final melting of the ice which occupied such an area has not been complicated by the subsequent action of other agencies (wind or running or standing water), it will consist of the *absence of erosional features* and of all deposits other than the moderate amount of till resulting directly from that melting. Preglacial valleys frequently furnished the sites for basins of this character because they were apt to retain some ice after terrace-building meltwaters had ceased to flow through them. Parts of the valley bottoms used by postglacial streams are not uncommonly found to be inherited basins preserved by ice masses. They differ in physiographic detail from sections excavated in a later glacial filling by existing streams and must be recognized for what they are if their significance is to be employed in regional interpretation.

Contacts fixing the eastern boundary of the ice which plugged the rock gorge below Kingston are found at Rhinebeck and Red Hook (see sketch, figure 68) and the waterplane (indicated by the leveled stretches running back from their tops) lies between the 200-foot and the 220-foot contours. Concerning the present condition of the contiguous ice-occupied area on the west Professor Woodworth (1905) has this to say: "The glacial deposits bordering the river below the 200-foot contour are mainly ill-defined deposits of gravelly till or rude kames such as are laid down where large masses of ice have melted out" (p. 115). The depressions which now carry drainage close under the western bases of the Rhinebeck and Red Hook sandplains were not excavated by the streams now using them. Very little in the way of excavation has been accomplished by Landsman kill (or the branch known as Rhinebeck kill) below the level of the plains, and almost the whole of the apparent valley of the Saw kill (including the broad trench followed by a contributary stream west of Red Hook) gives evidence of having been ice-filled at the time the plains were forming.

It might seem from what has been set forth in the preceding paragraphs that we might hope to work out details of the lacustrine clays and sands north of an ice-dam, and to make them fit into a consistent scheme from which an outline of the late glacial history would begin to emerge. But other factors entering into the problem dispel the idea that we are dealing with a single body of water held to a given level by a dam the elevation of which can be fixed with a reasonable degree of precision.

During the existence of the glacial lakes, there appears to have been too little rainfall to yield runoff and, in consequence, there were no streams excepting those maintained by melting ice. In an attempt to trace the limits of a given body of water we are, therefore, hampered by the absence of a full series of deltas to mark its waterplane. Those built by meltwaters are useful when found, but they do not appear in association with all the side valleys and often they have a feeble development. The three hypothetical deltas shown in figures 78 and 79 indicate a shore line at about 215 feet above sea level, an elevation which permits of their being correlated with the deposits at Red Hook and Rhinebeck. Unlike the latter they were made in open water and slope gently to the sedimentary plain on the west. Evidence of the near-by presence of contemporary ice is, however, not wanting (see page 209); and it is certain that, in this latitude, there never was an ice-free lake at **this elevation.**

On the other side of the river deltalike terraces having flattish tops between the 200 and 220-foot contours occur along the Plattekill and the Beaver kill; both were built against ice (see page 233).

Plains bordered by ice-contacts are not always satisfactory indexes of a general water level. The limited size of the basins in which they accumulated is shown by the frequency with which those basins were *quite filled* with sediments. The inference that deposits representing filled basins and having accordant elevations are evidence of pools in hydrostatic connection is beyond cavil only when the pools were at no great distance from each other. Where the plains are scattered and few, the necessarily local character of ice-confined waters renders the inference that they are contemporaneous deposits of considerably less value. The close spacing of glacial plains from Rhinebeck northward to Elemendorf schoolhouse favors the hypothesis that they were made in the same body of water and the proximity of the lake shore north of Blue Stores at about the same elevation suggests that the water plane may have been continuous from one locality to the other (and this in spite of an intervening higher plain). But, in view of the absence of fossil deltas at the required elevation (215 feet A. T.) in either the Catskill or Esopus valleys, there does not seem to be any good reason for supposing that this water plane necessarily extended to the western side of the river. The conclusion that the

200 to 220-foot pond (or lake) was developed only along the eastern rock terrace receives a certain amount of confirmation from gravel terraces some 35 feet higher. From them it is evident that before establishment of the lake stages the principal line of drainage across the quadrangle was situated on the eastern rock terrace.

Woodworth's concept of a proglacial lake (1905) requires that the waterbody be conceived of as having begun "on the south in the waters standing in front of the retreating ice sheet prior to the opening of the Mohawk outlet of the great glacial lakes on the west" (Woodworth 1905, p. 176). The southern end of the lake was, thus, obviously held to be its oldest part and the persistence of so much residual ice below Kingston is not accounted for. If the sedimentary beds are thought of as the remains of a more or less continuously spread sheet of bottom deposits (later dissected by streams) no explanation is found for those areas without any sedimentary cover in situations where supposition of the subsequent removal of such cover can not be entertained. The concept also demands that we picture deep static waters in the Mohawk valley *irrupting violently into the basin near Schenectady* at some critical moment in the withdrawal of the ice sheet, and that we torture evidence from the upper Hudson valley to conform with theory when we see it as the path of another great stream, the outlet of an ice-dammed lake in the Champlain basin. The union of these two lines of drainage (carrying meltwaters from a thousand miles of icefront and, in seasons of thaw, attaining a volume of supertorrential proportions) is then invoked to explain the present unfilled condition of the broad gorge of the Hudson from which it supposedly swept away several cubic miles of "clay and coarser sediment."

Understood as the product of slowly dissipated stagnant ice the glacial topography tells a story which, though less dramatic, makes no large demands on credulity and permits the interested observer to discover meaning in details and to work out local glacial histories with a considerable degree of satisfaction.

Long before the stages represented by the Albany clays and associated sands a heavy concentration of meltwaters came down the Mohawk valley.

It is recognized by all that a westward or Chicago outlet of glacial waters was followed by such lowering of the ice-barriers in the Mohawk region as to reverse the flow from western and central New York and send it eastward. The critical altitudes for this change were a little below 900 feet...We...recall the rock channels, fossil waterfalls and plunge pools near Syracuse, the scourways on the northern slopes of the plateau in central New York, the high level terraces between Rome and Little Falls and the downcutting of the ancient col at Little Falls. The waters that were active in these works of erosion and deposition found their escape through the Mohawk valley from Lake Warren time to the Lake Iroquois stage (Brigham, 1929, p. 78).

This earlier drainage can not be traced into and through the Hudson valley because it was traversing stagnant ice, and only as a stream cuts through to the basement can it leave a record less transient than the ice itself. It appears to have crossed the Hudson valley at Albany and to have been let down eventually onto the eastern rock terrace from East Greenbush to Niverville. Its bed, quite unlike that of a river confined by walls of bedrock, now forms a continuous gravel terrace between those points. Sixteen miles below Niverville it reappears on the Catskill quadrangle only 35 feet above the highest (215-foot) lake plane. (The theoretic relations are brought out in figure 69.)

The distribution of land and ice at the time when this great watercourse was abandoned, constituted the topography from which the Lake Albany basin was developed. There is no logical necessity determining that the beginnings of that basin must appear at the southern end. Indeed it is not at all improbable that they appeared north of the control (350 feet) at East Greenbush, and that the 215-foot water plane between Rhinebeck and Hudson *was a late addition* to the series of lakes which formed as the ice went out. Sections of the gorge still contained ice *at the end* of the period during which the Albany clays were deposited. Presumably, there was more ice during their deposition. Where a sedimentary terrace slopes away from the river bluffs it is a fair inference that the sediments were carried by currents or streams which had crossed ice occupying the gorge. Such sloping terraces occur here and there throughout the valley and in some instances justify the interpretation that the water on one side of the ice stood somewhat lower than on the other side. Sufficiently clear evidence that portions of the ice tongue outlasted the lake stages is furnished by the postlacustrine marginal "kames" within the gorge and by the well-known "deeps" in the bed of the estuary (*cf.* Peet, 1904). The grading action of running water must have obliterated these now submerged iceblock pits by filling them had it not found the unmelted blocks still in place. This kind of evidence (deeps) does not occur north of Kingston; but there is a patch of mounded gravels at the river's edge half a mile north of Greendale Station which is not different in point of origin from the low level kames found farther south.

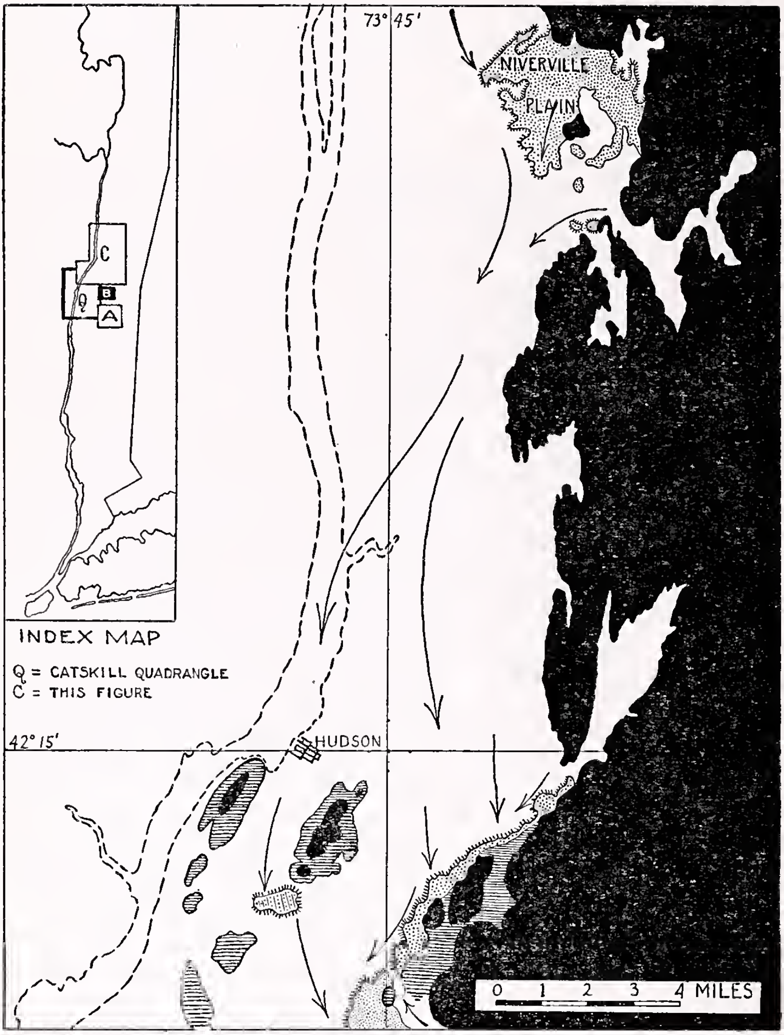

Figure 69 Parts of the Coxsackie, Kinderhook, Catskill and Copake quadrangles (C of the Index Map at upper left of the figure). Designed to show the course of superglacial drainage from the Niverville plain west of Kinderhook lake to the pools in which the deposits forming the 250-foot terrace (on the Catskill and Copake quadrangles) were made. Elevations above that of the Niverville plain are shown in black. At the south, elevations between 250 feet and the level of the Niverville plain are cross-lined. Arrows fly with the drainage. Stippled areas represent deposits referred to in the text; ice contacts are hachured.
(A of the Index Map locates figure 77).

Such considerations free us from any compulsion to believe that the 300-foot water plane which continues across the divide into the Champlain basin marks the latest (because most northerly) extension of the waterbodies in which Albany clays were deposited: the lake which stood across the divide at this (present) elevation *may* have been one of those which drained southward through an ice-cluttered Hudson valley; but it does not follow that the Hudson gorge below Albany was cleared of ice dams *before* the disintegrating glacier ceased to be an effective barrier to northward escape of meltwaters. The Champlain basin was, at the time, relatively lower than now (at least 200-feet in the latitude of Port Henry near its southern end) and no detailed study of the Champlain region has been undertaken which did not presuppose a slow northward withdrawal of active ice. Yet the evidence on which the conception of a proglacial lake spilling into the Hudson valley was based is so unconvincing that northward movement of glacial waters through the Wood Creek pass can not be dismissed as improbable.

This excursus is pertinent to a discussion of the glacial geology of the Catskill quadrangle for the reason that: once it has rejected the reopened Hudson gorge as a product of stream erosion, imagination balks in any attempt to reconcile the direct evidence of deposits made by running water in the Hudson valley with the idea of a swollen river carrying the combined outflows from Lake Iroquois and Lake Vermont. However the gravels may have been handled by earlier, superglacial streams, the currents which moved the materials making up the beds below 400 feet (A. T.) into the situations where they are now found were comparatively feeble. Whatever the volume of the waters going down the valley, their transporting ability was not great and their eroding power was negligible; the grades appear to have been so nearly flat that they may be described appropriately by Brigham's term "flowing lake waters" (1929, p. 82). The currents which must be presumed to have traversed the gravel terraces from East Greenbush to the Roeliff Jansen kill scoured out no hollows and threw up no river bars; they were able to rinse off the near-by ice and to fill in depressions and cavities developing in the ice, but unable to scarify the northern faces of hills projecting above the water or to heap transported materials in the lee thereof. (In this latter connection the base of the conical hill of loose glacial materials one mile a little north of east from Blue Stores is a case in point.) Subsequent stages of down-draining are recorded on the Kinderhook and Coxsackie quadrangles. Those over the eastern rock terrace carry the history of falling water levels down to about 170 feet above the estuary, the approximate elevation of the Jefferson Heights delta (*see* page 234); and the suggestion that here we are confronted with the work of a meltwater discharge concentrated from a thousand miles of ice front leaves the enthusiasm of assent at a low temperature.

"Not before detailed mapping is done will it be possible to correlate all the lower terraces which record the changes which took place as the river sank toward its present bed" (Woodworth, 1905, p. 198). "Some of these changes, it can be shown, took place . . . very late in the history of the removal of the glacial filling of the gorge" (*ibid.*). None of the benches or terraces suggestive of water levels below that of the Jefferson Heights delta (and there are a number between Staatsburg and Albany) gives any indication of having been swept by *rushing* waters. The deposits are mostly those which would have been made normally in quiet pools between an ice tongue and banks from which it had recently shrunk away.

GRAVEL TERRACES AND CONTEMPORARY ICE

The manner in which the ice disappeared from the eastern rock terrace, as described on preceding pages, resulted in the formation of a descending series of ice surfaces details of which must be largely conjectural. But the water levels associated with those surfaces are indicated more or less plainly by deposits made either in still bodies of water (lakes, ponds or pools) or along the beds of streams. Only where the ice had already melted off could deposits come to rest on the basement and be preserved. When the ice surface controlling any given water level was lowered, the water level fell to a new control, leaving the deposits made at the former level as flat-topped shelves ending abruptly where they had been supported by ice. The result is a series of terraces, in which, *for the same line of drainage* the highest is the oldest, and the lowest is the youngest. Terraces along a *contributary* drainage-line may have been contemporary with terraces of the main stream which are lower than themselves.

It is thus evident that in attempting to make restorations of the Pleistocene geography of small areas for any particular stage it is necessary that one should be able to recognize the approximate water plane which governed the upper limit of construction, the areas which must have been occupied by ice during the time when the sediments were deposited and the character of the slopes which proclaim contact with the ice. The plains forming the tops of terraces are often broad and pitted with "kettles" (figures 74 and 82); it is easy to recognize them. But occasionally there are platforms outliers, of no great size (comparatively) which were built into cavities in the ice at a distance from the principal deposits and which are to be regarded as part of the terrace if controlled by the same water plane. Some terraces are wholly made up of scattered platforms.

On our map the terraces from 214 feet (A.T.) down are largely of clay; those above that level are of gravel and (mostly coarse) sand. We shall call the former *lake plains* and the latter *gravel terraces.* Ice-contacts bounding clay terraces appear to have no characteristics whereby they may be distinguished from steep banks due to erosion and, because of the tendency of unsupported clay to yield readily to gravity, it is to be expected that landslides would, on the withdrawal of the ice, soon destroy such slopes. The contact of residual ice with precipitous faces of clay must, therefore, often be inferential. We will find it much easier to make reconstructions among the gravel terraces.

A word must be said about the conditions under which many of the gravel deposits east of the Hudson were made. The water which laid the gravels of a given terrace appears to have been an ice-bottomed stream beneath the bed of which thin ice kept breaking up. As cavities appeared they were filled in by materials rinsed off from the near-by ice (there is no sorting over a wide area such as would occur in an ice-free body of water). As the ice continued to decay, a basin was formed and enlarged until it held a long, lakelike expansion in the water course which may be termed *a pool.* The basins were cleared of ice to varying degrees, the remnants remaining unmelted, if any, when the several pools were drained explaining the kettles.

The gravel plains and terraces which are the fillings of those basins form an instructive subject for study. The more technical aspects of their origin and structure interest only the glacialist, but there are other aspects which ought to appeal to the general reader.

Every boy who has gone fishing in a lake must remember the lily-pads and shallow water at the inlet. He may perhaps realize that the lilies are due to the mud bottom and the shallowness and that these in turn are due to the inlet stream. If geography has been presented to him as the drama of mountains slowly making their way to the floor of the sea and he has learned of some of the great delta deposits of the world, he may be able to recognize the muddy bottom as the underwater fringe of a small-scale delta, especially if there is also an out-of-water flat along the creek, marshy or sandy, where it enters the lake. But to comprehend a large delta, where the whole is not visible at the same moment, he must have learned to read a topographic map. Workmen in the gravel pits usually understand that the sloping streaks and layers of washed sand have been subject to the action of flowing water, and occasionally one is encountered who has "often wondered how a river could have run through here." But to answer his implied query one would have to do more than point out that where a stream enters a quiet body of water it loses all grade and therefore power to carry forward the particles which sink readily. And this is because, in the case of terraces on a slope, no quiet body of water or even the possibility of there having been a basin to contain one seems reasonable—a basin being a depression with a complete rim, and all along one side a terrace falls away to lower ground where there is no confinement. It was not until the fact of the former presence of vast bodies of land ice during Pleistocene time had been established that a satisfying explanation of this puzzle was found. Then those who were studying the "drift" left by the vanished ice sheets recognized that the missing portions of the rims had been of ice; indeed the contact zone, where sand and gravel washed into the lake had accumulated against the ice, was seen to reflect with some faithfulness the form of the latter.

There are variations in the character of the molded surfaces found along such a zone and the beginner will do well to make his first distinction between those which his imagination can readily accept and those which it can not—and there will be many in the second group.

U. S. Highway 9 follows closely the contact zone of a long terrace from just north of Blue Stores to a point opposite Bell pond yet there is nothing particularly arresting in the character of the slopes as seen from the road. If, however, one turns at the Potts Memorial Hospital (see map) onto the county road leading to Manorton, he will be almost immediately on the top of the terrace at an elevation of 250 feet above sea level. The plain stretches southward and on the left for a distance of nearly a quarter of a mile, it is terminated abruptly by the ice-contact shown in figure 81, the slope of which is about as precipitous as the materials will permit. (When opened for gravel, slopes of this type show either that they have remained unaltered or that originally they have been even steeper, the crest having slumped when at last it was deprived of its ice support.) At the southern end of the quarter-of-a-mile stretch, the contact turns to the east at a sharp right angle and becomes a comparatively gentle slope. (Sections through this second type of contact often exhibit undisturbed bedding indicating that the margin of the ice had been melted back near the bottom, and that it overhung at the top. Instances are known where a projecting cornice of ice has evidently separated and fallen, but such overhanging edges, especially when they were partly supported by water and sediments, seem as a rule to have remained attached even when deeply undercut.)

West of the road is an irregular basin marking the site of an unmelted mass which persisted at a little distance from the main body of ice. (When such masses have been numerous, the grades along a former ice-margin are apt to be so broken that the contact is not a single definite slope but a broad zone.) To the east and northeast one looks across an area of ice occupation, that is to say, an area over which deposition was prevented by the presence of ice. On a small scale and in the special case of having been completely surrounded by deposits, such an area is called a "kettle hole" (made recognizable on the map by depression contours). But just as depression contours do not necessarily signify kettle holes, so all ice-occupation areas are not closed basins. This particular hiatus in the terrace extends to a point about a mile beyond Livingston; it was bridged by a salient from the main ice-body.

Proceeding along the road one continues on the plain. Above it project knobs of bedrock and below its level are "kettle holes" of various sizes and shapes. Just north of the first small rivulet shown on the map there is a deep kettle from the side of which sand and gravel have been dug. The excavation gives opportunity for observing the terrace's internal structure. The beds are here dipping *tc the south.*

Within the next mile one crosses an imperceptible divide between the streams which flow northwestward and a creek which, running to the southwest, enters the Roeliff Jansen kill. This creek is come upon at the first road turning westward. North and west of it the plain surrounds a subconical hill of unusual profile and about a mile further to the southwest it terminates along a contact line where the glacial pool, if continued as such, was on the ice extending toward Clermont.

The 250-foot water plane must have extended more than a mile to the south of Manorton for parts of it are to be found as far as the mouth of Doove kill where there is a platform of considerable size (figure 70). (Map studies made in advance of the field work appeared to justify the expectation that the pool evidenced by this long terrace would prove to have had its outlet through the narrow defile followed by the Lakes kill. The hypothesis was, however, abandoned at once when the ground was examined. Ice, insulated by a gravel plain above the 280-foot contour, occupied the basins of both Spring lakes and, if this had been melted away before the lower gap over Clermont was available, the frail barrier which now forms the divide at the head of the upper lake would have been swept away or at least trenched by a stream crossing it. The only deep pit opened under this 280-foot plain shows the gravel beds dipping *to the north.*)

As previously stated, the western margin of the terrace for two miles northward from Blue Stores does not furnish any impressive evidence that it was banked against ice, although the inference that this was the case is inevitable. Where the bedrock is close to the surface the gravel deposit is shallow and contact phenomena are necessarily obscure. Southwest of Bell pond the bedrock lies deeper and the contacts are bolder. From either of the hill tops illustrated in figures 71 and 73 one may obtain broad views of the glacial topography in which the relation of the ice to the terrace is unmistakable. A short distance north of the Maplewood camps, a dirt road leads westward from U. S. Highway 9, passing between the elevations pictured and skirting the base of the more southerly one. This is a ridge trending east and west, evidently a filling at the mouth of a gully in the ice, and a gravel pit above the road exposes gravels dipping to the southeast, *i.e.* away from the ice (figure 72). From the summit one looks south across the large area occupied by ice, wherein is the boulder mentioned (page 18) by Doctor Ruedemann, to the northern contact face of the section traversed by the county road to Manorton. The visible contact ends on the right (west) in a sharp angle near the Potts memorial where the slope descends to a flat lake plain, the higher lake or 215-foot level to be discussed later on.

Eastward are formerly ice-filled spaces separating projections from the terrace, while to the north one observes the details shown in figure 73.

For a considerable distance south from Manor hill (rising from the east bank of Bell pond) the deposit has received contributions of fine yellowish sand washed in from the northeast and, in part,

Figure 70 A glacial "platform." View from the ice-contact of a 270-foot terrace, northwest across the Roeliff Jansen valley near the mouth of Doove kill. Beyond a lower terrace (230 feet) the flat-topped accumulation of gravel and sand encircled by ice-contact (platform) is the filling in a cavity in the ice. The upper limit of construction was determined by a water plane, only slightly below the surface of the surrounding ice. In this example the contact slopes have been cut back after exposure (extreme right) by the action of flowing water. (Photograph by Edwin J. Stein)

Figure 71 Gravel ridge west of Maplewood Camps looking a little west of south. The smooth, gentle slopes illustrate a type of ice-contact which is not always easy to identify (compare note on figure 74). In the distance is the Potts Memorial end of the southern section of the 250-foot terrace. Sedimentary floor of the 215-foot lake in the middle distance.

Figure 72 The gravel pit shown in the upper figure (71). Shows the beds dipping southeastward, away from the ice which occupied the low ground surrounding the ridge and westward (to the right) for an undeterminable distance.

Figure 73 Looking north from the ridge shown in figure 71. Skyline at the right is the top of the northern 250-foot terrace from which ice-contacts slope down to the depression running back to the barns. One small kettle hole in this trough lies below the level of contemporary lake sediments north and south. Ridge on the left is a crevasse filling or a short esker.

from the Taghkanic valley. At the curve opposite this pond, where Highway 9 turns to bear northwest, this sand is exposed in the road cut. It is waterlaid sand.

The 250-foot terrace continues beyond the limits of our sheet (as shown in figure 69) and along the south bank of Claverack creek, which stream is there underfit in an area occupied by ice during the terrace building and *all through the life of the upper (215-foot) lake.*

But there is a further and important addition to the contemporary geography at the southern end of the Becraft hills. Coming northwest from Bell pond, the highway rises to cross a ridge named Cherry hill. Cherry hill is an esker which extends southward in two sections for something over a mile. At the north end its eastern base is very smooth and blends imperceptibly into the clays of the 215-foot lake; its western side is steeper and descends to Cherry Hill pond *which lies below the 160-foot contour.* The pond lies at the bottom of a nearly inclosed "kettle" the northeast side of which is the steepest ice-contact found on the quadrangle. From the top of this steep slope the photographs reproduced as figure 74 were taken. The locality is critically important and the panorama will repay study.

A remnant block of ice must have occupied the basin after the level of standing water in the Hudson valley had fallen below 160 feet (A.T.). The side of the esker (shown at the left) is unmodified, but the contact across the pond has been undercut by meltwater which appears to have been produced within this basin and that of a second ice-block kettle concealed by the trees growing on the beveled slope.

In connection with the study of terraces, however, the chief interest in the picture is the striking ice-contact rising above and back of the kettles and constituting the east face of an amassment of sands and gravels where the glacial river (which according to the interpretation expressed by figure 69 had run out onto ice some 16 miles to the north) again came to a point where the ice under its bed was breaking up. The approximate position of the river is the top of the deposit here shown by the crest of the contact forming the straight southwestern skyline, beyond which may be discerned the summit of Blue hill. That its further course over the ice was to the southeast is shown by the dip of the gravels, and it is a fair inference that it ran into the 250-foot pool at or near the point shown in figures 71 and 72. As a whole, the deposit is of the nature of a platform similar in origin to the one pictured in figure 70. It is roughly triangular in plan, the southern and northeastern edges meeting in a sharp point about a mile beyond the eastern contact which was the only edge to be laid against a steep ice-face. The observer is in line with part of the northwestern contact, the gentle slope of which is brought out in the photograph. The surface features are everywhere more or less covered with drift sand similar in all respects to the fine sand which covers the 310-foot plain west of Kinderhook lake. Confining ice would seem to have held the flattish top for a time at 265 feet (A. T.) but to have been worn down until the stream bed lay practically level with the pool to the southeast thus having its final control south of Blue Stores like the rest of the terrace system.

The several sections making up this system afford the best opportunity for studying the pitted plains and related phenomena on the quadrangle. Not only are the terraces and platforms compactly assembled, but each part is easily accessible from an excellent highway. It is the logical level at which to begin the study of the glacial geology. If the amateur glacialist can stand on the brink of one of the more obvious contacts from which he can look across lower land to another contact and realize that everything covering the basement (here almost equivalent to saying the bedrock) could have been de-

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Figures 74 and 75

Cherry Hill pond and environs: Looking southwest to Blue hill from the steep ice-contact mentioned in the text (page 209), with explanatory diagram (figure 75).

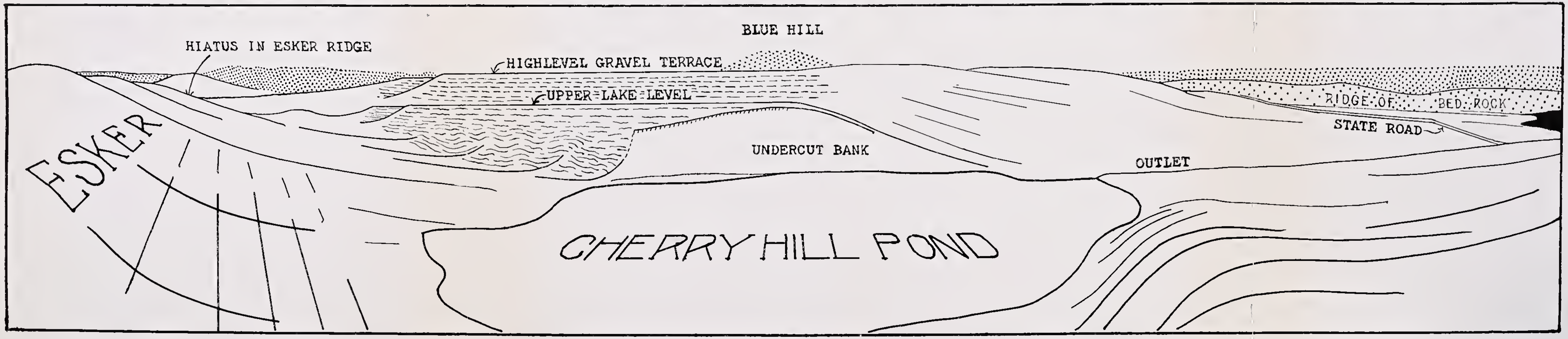
Discussion in the text and the explanatory diagram should enable the reader to identify the elements of glacial topography shown in the photograph. Attention is called to the contrast between the steep eastern ice-contact of the great gravel platform and the gentle slope above the state road which is the northwestern ice-contact. The latter is an example of one of the more obscure types. (Compare note under figure 71.) This critical locality presents a compact assemblage of features bearing on the interpretation of the late glacial history of the Hudson valley, the significance of which can be appreciated easily from a consideration of the following facts:

At the time when the skyline under Blue hill was the bed of a stream the drainage was moving southward as is shown by the dip of the beds exposed in an excavation in the northwestern contact.

From the summit down to the 215-foot level there are no horizontal scars or other evidences of flowing or standing water. Where these last are found elsewhere on the quadrangle they can be shown to be local in character. Either the slopes continued to be protected by ice or the southward movement of the drainage had ceased suddenly.

The water level at 215 feet appears to be represented by the narrow plain above the cut bank. Clays of this series accumulated on the other side of the esker, but their deposition in the kettle basin was prevented by the still unmelted ice.

That this block of ice outlasted the secondary (lower) water plane for which the Jefferson Heights delta is the index (about 170 feet) is shown by the cut bank and the channel now followed by the pond's outlet.


BLUE HILL
HIATUS IN ESKER RIDGE
HIGHLEVEL GRAVEL TERRACE
UPPER LAKE LEVEL
RIDGE OF BED ROCK
STATE ROAD
ESKER
UNDERCUT BANK
OUTLET
CHERRY HILL POND

posited there *only after the ice between the contacts had melted away,* he will be able to work out the meaning of all similar relations.

There are several other less important water levels indicated by discontinuous terraces with good contacts. The associated areas of contemporary ice occupation can generally be distinguished easily from the effects of stream erosion, and there are occasional depression contours which generally will be found to mark ice-block kettles. With patience and the necessary time these plains could be mapped in detail. There is one at 270 feet A. T. which is first encountered along the county highway south of Manorton; it forms the north bank of Dogan's kill at the road. This stream flows in an ice-occupied depression bounded on the south by an unpitted terrace of the 250-foot series (see page 203). The 270-foot water level has been traced northward as far as the kettle holes southeast of the Schuderkook school, and southward to the outlet of the northern Twin lake where the aggrading or degrading meltwaters were derived from comparatively small masses of residual ice.

Other terraces of various areal magnitude are found at intervals up the slopes along the eastern edge of the quadrangle between the Doove kill and Taghkanic creeks; but, since it did not seem likely that a detailed knowledge of these water planes would add appreciably to an understanding of the larger meanings of the glacial deposits, they were deliberately slighted.

THE BED OF A GLACIAL RIVER

We have interpreted the series of terraces and platforms having a common elevation above sea level of 250 feet as deposits made along a main line of glacial drainage. We shall picture this line as occupying a valley excavated in the ice. Its course lay above the eastern rock terrace so that here and there the stream bed was over thin ice which broke up under it permitting the cavities to become filled with sediments appropriate to running water. Considerable areas of this thin ice were melted out north of the Roeliff Jansen kill and the downstream control by the ice from Blue Stores southward for an unknown distance was sufficiently prolonged to permit the formation of a series of pools with hydrostatic connection at the common level. In this view the areas still occupied by ice, including the kettles completely rimmed by gravels, represent masses of ice *in situ* which for one or another reason had not disintegrated when the pools were drained.

Before seeking to test the value of this idea as a working hypothesis we invite attention to figure 76. Nowhere on the earth is there to be found an example of the effects of meltwater in eroding a stagnant glacier which is strictly comparable to the effects produced during Pleistocene time in the Hudson valley as we have imagined them. The picture of the Koettlitz glacier, however, is introduced tc aid the reader in visualizing in some degree the conditions on the Catskill and neighboring quadrangles which obtained while the melt-water river was depositing sand and gravel on the basement as fast as that basement was exposed in its bed.

The Koettlitz glacier of South Victoria Land, Antarctica, is one of the numerous outlets by which ice from the central dome which covers that continent is discharged. The ice is too clean ever to have supplied much sediment to the now frozen river in the foreground. This river, moreover, has not here eroded a valley *in* the ice but, lies between the glacier and the land. Also, in a region where air temperatures seldom rise above the freezing point, it is not probable that the great exaggeration of Peary's "almost impassible roughness" (1898, p. 217) is due in any large measure to a temporary change in climatic conditions. Although Griffith Taylor who headed the party which explored and mapped this glacier does not appear to have considered the possibility of volcanic gases and a locally overheated basement as having been the agents which produced the water, the locality is volcanic and some such explanation seems to be called for.

Making allowance for these differences, it is possible to see in the illustration enough resemblance to the Pleistocene geography which we are endeavoring to reconstruct to make it useful. We may imagine that we are looking from a point on the eastern edge of the valley in the ice, upriver over the site of the southern pool where the thin, water-soaked ice-floor is breaking up. At the right the stream is coming off from solid ice beyond the Potts memorial, and, at the left, it again flows onto solid ice south of Blue Stores. The Hudson gorge is deeply buried under the ice in the middle distance beyond the glacial river. Other valleys may be presumed to be developing; and eventually the pool opposite our point of observation will be drained leaving the gravels which have been caught as in a great strainer above the level of a newly established grade or water plane.

If the volume of pre-Iroquois drainage through the Mohawk valley may be gaged by the effects which were produced west of Little Falls (see Introduction), we will expect to find contemporary effects produced in the Hudson valley by the same discharge of meltwater commensurate with those farther inland. We may, however assume that, in a general way, that outflow is recorded east of (say) Utica by sedimentation only. The ice along the water courses

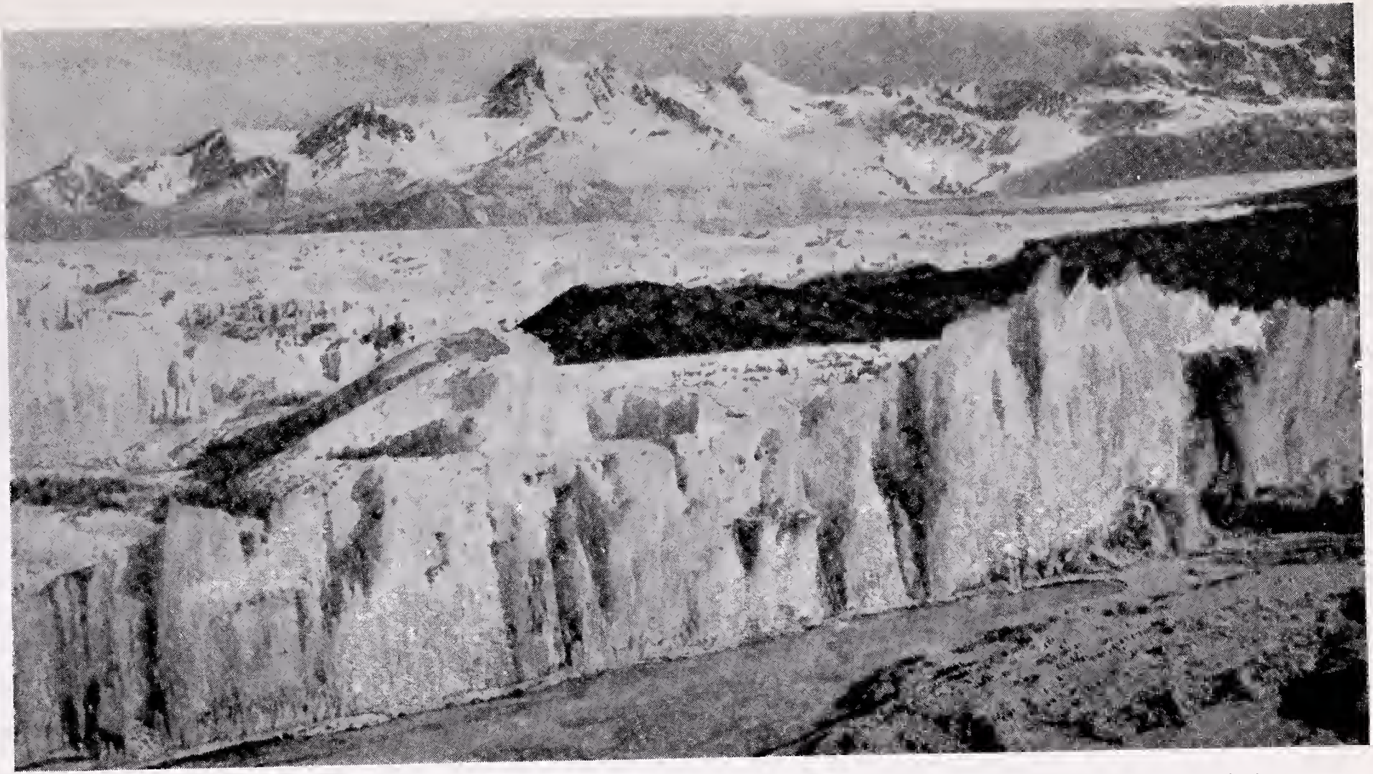


Figure 76 A part of the Koettlitz glacier, South Victoria Land, Antarctica, "an unrivaled study of the effects of thaw-waters and surface weathering on a broad surface of relatively stagnant glacier" (Griffith Taylor: 1930, p. 141). Photograph by F. Debenham. From "Scott's Last Expedition," permission of Dodd, Mead & Co., New York.

was apt to have become heavily suffused with flood plains of gravel, and, with Professor Brigham "we may, perhaps, safely visualize the copious, but changing and braided streams of glacial water that marked its surface" (1929, p 79).

Imagination may thus visualize conditions wherever the facts permit, but the terrace system on the eastern rock terrace southward from Albany does not lend support to the idea that, at this time, the shape of the Hudson Valley ice was comparable to that of a valley glacier. West of the estuary one looks in vain for traces of a corresponding flow marginal to a tongue of ice. The drainage was asymmetrical with relation to the axis of the Hudson valley and was concentrated along the line of gravel terraces from East Greenbush to Blue Stores in a manner which requires us to recognize that, so far from being diffuse, it was here confined between walls of ice.

That the existing surface of this ancient river bed does not bear the marks of strongly moving currents can not be held to invalidate the conclusion that it was *at one time* the main path by which meltwater left the region above Albany. It was not abandoned all at once nor so abruptly that the surface details wrought during its earlier phases are necessarily preserved. For it appears to have been abandoned by the presumably large south-flowing river and then to have become the site of a chain of pools in which were trapped considerable quantities of eolian sand and such sediments as were brought in by tributaries. Meltwater streams continued to make their way down the sides of the valley in the ice to these pools and to make deposits in them. These deposits which are the latest of the series show no signs of having been swept by a current moving down the valley, nor, although mostly of fine sand and practically at the water level, do they bear any indication of having been reworked by wave action.

Because of the necessity for evolving some general picture more consistent with observed facts than Woodworth's conception of an "ice tongue filling the Hudson gorge and overlapping onto the rock terraces (1905)," reconnaissance trips were made into the Copake, Rhinebeck and Millbrook quadrangles in the hope of attaining a better understanding of the topography of the ice contemporaneous with the development of the great 250-foot terrace on the Catskill sheet. Extended description of the anomalous glacial drainage coming in from the east would be not only too lengthy for this publication but too confusing for the reader to follow easily. It is thought best, therefore, to outline the picture which finally emerged in the mind of the writer out of the mass of collected details.

A pre-Iroquois river, having sunk its bed below the general level of the remains of the ice, was eventually brought to a grade as the river bed approached the basement, here and there, along the outer edge of the eastern rock terrace, and contributary ice gullies opened into it. The eastern slope of this valley, lying as it did, above the spur of phyllite and other high-level rock areas, was soon melted down onto them producing a topography partly of the uncovered basement and partly of ice, the latter persisting in the preglacial rock valleys. The courses taken by meltwater streams as they sought the main river over this surface were surprisingly erratic.

Thick ice on the south forced drainage westward at Hillsdale near the eastern margin of the Copake quadrangle into the (as at present constituted) Taghkanic basin. Thence the drainage was forced southward into the ice-filled valley of the Roeliff Jansen kill; at Pine Plains (Millbrook quadrangle) it escaped to a broad outwash on which Wappinger creek has its headwaters (see figure 77). At the northern ice contact of this outwash the elevation is given on the map as 476 feet A. T., and, though a connection was not established between this plain and the next point to be noticed (at 395 feet), it is regarded as probable that such connection existed. At the northern end of the basin of that branch known as the Little Wappinger a considerable and long-continued flow of glacial water spilled over the divide and *dropped 70 feet* to Rock City (Rhinebeck quadrangle). The locality is shown in the sketch (figure 68) and in the map of terraces (figure 78). But before melting had opened the path to Rock City, the stream coming over the col was constrained into a *northward course;* it reappears coming off from ice at the southern edge of the Catskill sheet.

During the building of the 390-foot and 370-foot terraces (figure 78), it must have been prevented from taking a more direct descent westward by higher ice in the Lakes Kill defile and over the other headwater valleys of the Saw kill. There is a glacial channel between the rock hills marked (1) and (2) in the figure, made by water flowing northward after the draining of the pond in which the gravels of the 370-foot (Warackamac lake) terrace accumulated. The ice-barrier over Rock City finally yielded, and the cascading stream made and filled a basin (at 325 feet) at the foot of the drop. An early outlet from the water body in which this (Shook's Pond terrace) deposit was made may have been northward over the ice in the Lakes Kill defile, for the gravels of the 285-foot terrace (where the Roeliff Jansen kill bends sharply at the county line) dip to the north and require some southerly source for the flowing water. To this interesting

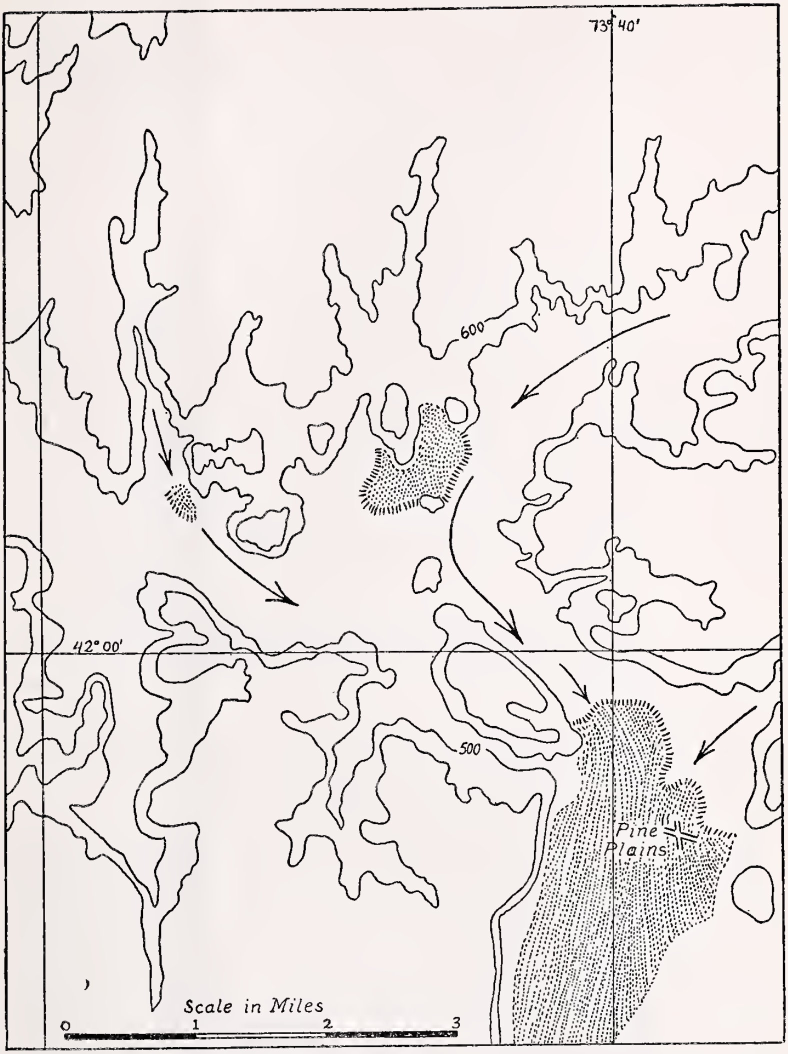


Figure 77 Sketch map showing that the residual ice, being higher on the west (*i.e.* toward the Hudson valley) directed the lines of superglacial drainage southward out of the Roeliff Jansen Kill basin. In the area shown (A of the Index Map in Figure 69 page 198) ice still filled the valley up to approximately the 500-foot contour. The 500-foot and 600-foot contours are introduced to indicate land above the demonstrable covering of ice, and the arrows fly with the drainage. Dotted areas represent waterlaid sand and gravel deposits mentioned in the text; the ice-contact margins are hachured. The meridian along which the division between the Catskill and Copake quadrangles is made, appears just inside the left-hand edge of the sketch-map. The terrace at Elizaville (three and one-half miles farther east) is believed to be a contemporary deposit.

terrace (in which both Spring lakes and the two Twin lakes [figure 5] are ice-block basins) little or nothing was added from the ice-filled Roeliff Jansen valley above Elizaville, obviously because the ice in it was turning the drainage southward at Pine Plains.

Ice in the valley of Doove kill appears to have been crossed by a meltwater stream just west of Snyderville. The suggestion of a channel along the hillside terminating at the northern Twin lake is especially strong when viewed from north of the kill.

This is enough, perhaps to show that in this latitude a cross section of the ice was not that of a tongue confined to the valley. High ice on the east drained down onto the 250-foot terrace while contributary drainage from the western side would have been strictly superglacial (except that it might have touched some of the hills projecting through the ice). In consequence, the only evidence of these water courses which could be preserved through all subsequent changes is to be found where they entered the main stream. As stated above, tributaries from the east continued to flow after the river had deserted the course marked by its former bed.

TRANSITION TO LAKE STAGES

Transition from the heavy gravel terrace described in the preceding section to the uppermost lake level is of sufficient importance to warrant particular notice.

Having found no reason to question Woodworth's correlation of our glacial river bed with the plain at Niverville (1905, figure 17, p. 132) we extend that correlation to include all of the essentially contemporaneous deposits which make up the terrace-system northward to East Greenbush drawing attention to the fact that, at its northern end, the gravel terrace lies 136 feet above the 215-foot lake plain while on the Catskill quadrangle the difference is only 36 feet. Since the gravel terraces were made while the valley was still filled with ice up to their respective levels, and since the clay beds could have been laid down only after much of this ice had been removed, it will be from steps in the transition that we may expect to derive reliable data concerning the character of the changes which resulted in lacustrine conditions.

There is hardly room to doubt that the several pools in which the terrace gravels had been trapped were drained by a kind of piracy. When the ice which confined them on the west side was eventually breached, channels at a lower level must have been ready to receive the diverted waters and to carry them off, and these channels must have been developing during the life of the pools. The whole stream bed below a breach would be abandoned (except that it might be used

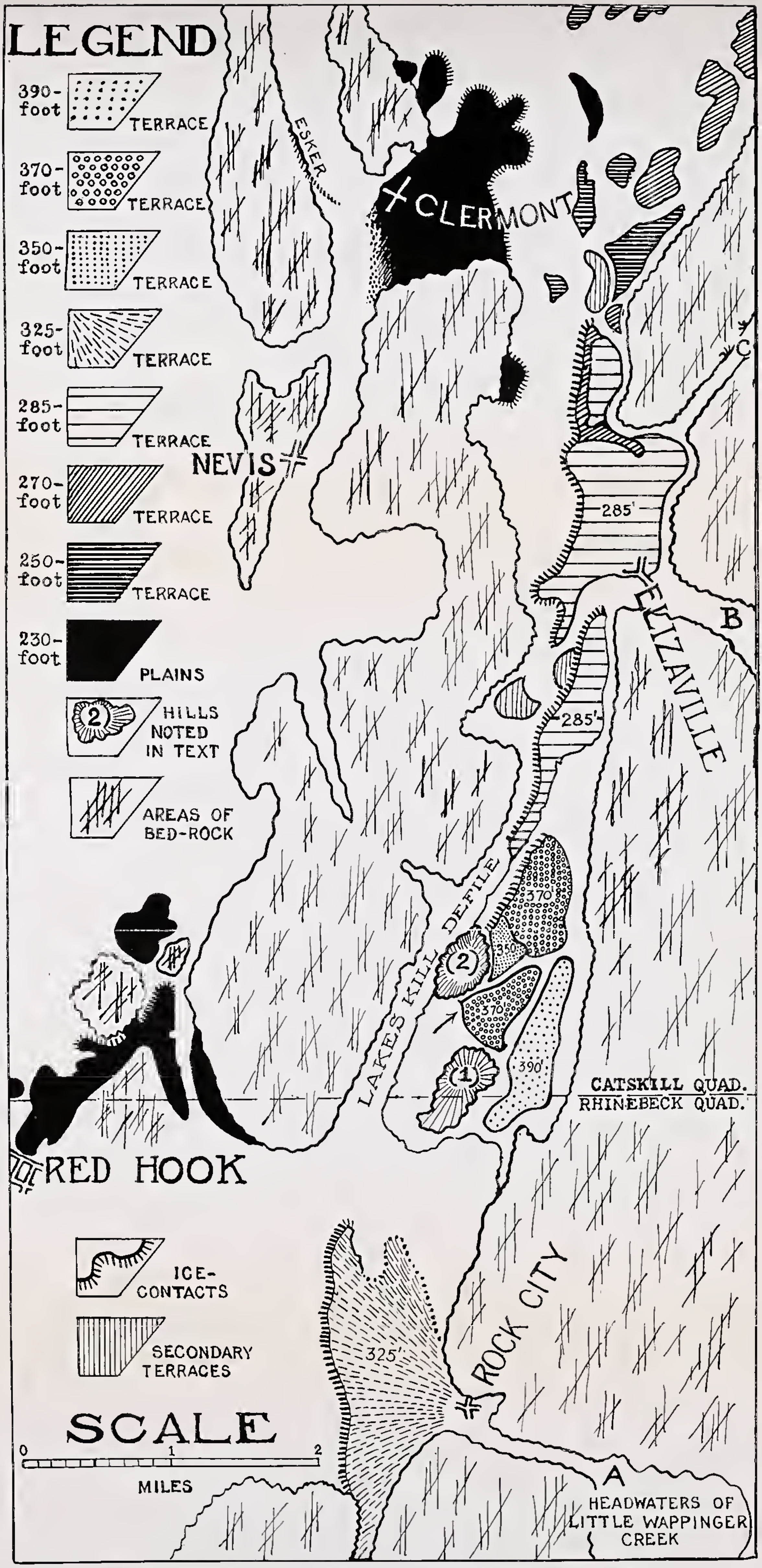


Figure 78 Diagram of ice-confined terraces at the southeastern corner of the Catskill quadrangle and the Shook's Pond terrace west of Rock City. Forced drainage from the Little Wappinger basin, Rhinebeck quadrangle, was constrained to flow northward to Clermont by ice barriers. A: The col crossed by waters from the east. B: The ice filled valley of Roeliff Jansen kill. C: Hillside channel.

by local meltwaters). The new course followed by the stream could be located only if the basement was exposed by its flow.

If we tentatively correlate the 250-foot terraces of the Catskill quadrangle with some phase of the pre-Iroquois drainage or with an Iro-Mohawk discharge earlier than the stage represented by the South Schenectady delta, and if that delta is to be correlated with lower plains which may not have extended as far south as Catskill, we are at liberty to assume that a long and eventful chapter of Pleistocene history is represented in the interval between the 250-foot terraces and the lacustrine beds.

A short distance outside the city limits of Hudson there is an isolated deposit of glacial sand. It is located where the transmission line of the New York Power and Light Corporation crosses U. S. Highway 9, tailing out from the south end of "Mt Ray" and overlooking the depression between that elevation and the Becraft hills. (Below the road leading to the cemeteries a patch of dimpled "kame terrace" suggests that this depression held a mass of residual ice after the breakup which drained the 250-foot water level. The inner face of the sand deposit may owe its steepness to having been banked against this ice.) In 1934 the structure at the tip was exposed above the road leading eastward; the section showed fine, dark sand dipping toward the depression. The top is not flat: it slopes southward from 245 feet at the beginning of the road to the cemeteries (till is exposed in the road cut here) to something less than 220 feet as the continuation of a till ridge descending from the Mt Ray reservoir which Professor Fairchild once identified as a "heavy gravel bar" (1919, p. 35).

Quite apart from considerations of a more general nature concerning the existence of a body of open water at this level subsequent to the removal of the ice, the structure of the accumulation revealed by excavation to a depth of 15 feet does not admit of its being interpreted as a product of waves or shore currents. "Mt Ray" itself appears to be a drumlin (masked in large part by drift sand) and, though the lee slope may be somewhat gravelly, there is no reason to believe that, in point of origin, it has anything in common with the sand bed at its foot. Built as it was by water moving from west to east, the sand bed, if a shore feature, would inevitably have curved eastward as it was extended. As a matter of fact it is exceptionally straight and forms an angle with the trend of the ridge of till to which it is appended.

With the exception of this almost negligible bit of evidence nothing could be found north of the Roeliff Jansen kill to give a clue to the character of the breakup of the ice which had confined the 250-foot pool. Certain sections of the ice along the zone of contact remained intact long after that pool had been drained and lateral insulation by the terrace gravels furnishes a probable explanation. The most notable sections where persistence of this ice is indicated are found northward from the Potts Memorial Hospital (illustrated by figures 71 and 73) and at the Cherry Hill locality (figure 74).

The streams which at these points had been pouring gravels off from the ice ceased to flow with an abruptness which warrants the conclusion that they had suffered piracy at a point some distance to the north of our map. It is not impossible that at this time glacial waters ceased to flow southward. Ice continued to form a barrier across the Roeliff Jansen kill south of Blue Stores long enough to permit the drainage forced into the upper Stony Creek basin to build a gravelly plain at approximately 230 feet A. T. which may be designated the Clermont plain. Another plain at the same level appears at Red Hook. Both deposits seemingly are due to meltwaters brought down from remains of the high ice which formed the eastern slope of an imagined continuation of the now abandoned valley in the ice beyond the point (near Blue Stores) where its traceable course comes to an end. They are regarded by the writer as evidence of local water bodies (or *a* local water body) because the glacial streams corresponding to the modern Claverack and Taghkanic creeks were not held up at this level.

On the sketch map (figure 78) these plains are shown in solid black; both are crossed by U. S. Highway 9 and their more important features may be studied in detail without going far from a road.

The Clermont Plain

It may be taken for granted that the residual ice in the Roeliff Jansen Kill valley above Elizaville contributed very little to the stream which built up the 285-foot and 270-foot terraces. But, after completion of the latter, meltwater from the upper valley, coursing between the ice and those terraces, undercut their ice-contact faces; then flowing over the ice, filled a cavity to form the platform near the mouth of Dogan's kill. It was not, however, until the 250-foot pool was drained that the effects of this flow became prominent. It then made a notable addition to the glacial topography, the Clermont plain.

As may be seen from the sketch map, this plain of sand and fine gravel is in four sections and it is possible that the secondary terraces marked with vertical ruling, though at a somewhat higher level, belong to the same series. It requires no specialized knowledge of physiographic processes to appreciate that the separation of the sections was not caused by dissection of a formerly continuous deposit filling the valley; not only are the original contacts with the ice preserved, but the broad trench below them, now partly floored with recent alluvium, bears only a superficial resemblance to the type of excavation made by a meandering stream.

As far as may be judged from exposures seen in two borrow-pits the materials composing the deposit were washed to the southwest in the general direction of Nevis. But, a short distance beyond Clermont, the sedimentary plain gives place to till and bedrock with no definite boundary.

Half a mile west of Clermont a small esker (see figure 78) comes down from a drumlinized ridge of rock and terminates at the road. Near its tip two shallow ice-block depressions occur, one on either side of the esker which here forms the divide between Roeliff Jansen kill and Stony Creek drainage. The depressions constitute the only direct evidence of the presence of ice found in the Stony Creek basin; they are below the 220-foot contour.

Plain at Red Hook

At this stage a considerable body remained of that "high ice" which had caused the glacial stream which built the 390-foot and 370-foot terraces to flow northward. It lay in the Lakes Kill defile and extended southward beyond the Shook's Pond (325-foot) terrace west of Rock City. Its surface sloped down to the floor of the recently abandoned valley in the ice, which valley appears to have followed a nearly straight course from Nevis to Red Hook (Rhinebeck quadrangle). As this lower, thinner ice broke up over a distance of about two miles north-northeastward from Red Hook, the débris covering it was washed into cavities, filling them up to the level of a pool at 230 feet (A.T.). At least a part of the water which accomplished this work moved northward from the point where now the Lakes kill joins the Saw kill.

Many of the ice contacts here are concealed by sediments deposited after the water level had fallen some 10 or 12 feet, but wherever the abutting ice outlasted the later deposition the contacts are unburied. The trench in which the Saw kill flows below the main highway (U. S. 9) was, in large measure, produced by the melting out of such ice. There are hills of bedrock rising out of the ice-occupied cavity to elevations above that of the glacial plain. They are devoid of any mantle of till, a fact which suggests that they may have been, when first exposed above the lowering ice surface, in the path of a stream.

Typical expression of the characteristic topography is to be found in the vicinity of the highway bridge. Northward, the road is below the level of the plain as far as the second road branching east. On the west, across a depression, lies one of the naked rock hills behind which is a part of the 230-foot deposit. Southward, the road ascends an ice-contact to the plain (at the first house on the right), the edge of which, if followed westward, turns abruptly to the southwest and passes back of the house. Between the low contact slope and the millpond (see map) is another hill of rock which rises above the 260-foot contour and which also appears to have been stripped by water action.

These evidences of a local water level south of Blue Stores serve to show (1) that here the west side of the valley in the ice was still a barrier competent to confine a pool and (2) that the otherwise abandoned glacial river bed was being fed by the melting of ice remaining on or against the slopes of higher ground to the east.

Dissipation of Ice from the Lake Basins

Concerning the details of the process by which the stagnant ice was removed from those areas now covered by lake sediments there is little direct evidence. Some record of its dissipation is found in the stones imbedded in the clays (or lying upon them) which have always been understood to have been dropped from floating ice. In the days when the only type of deglaciation recognized was the slow recession of an "ice front," they were said to have been rafted by icebergs, the implication being that the bergs might have drifted from an ice cliff "far to the north." Although about one-sixth of the weight of a mass of that conglomerate which is basal ice may consist of heavier-than-water materials without causing it to sink, the situations in which some of the larger boulders occur make it difficult to believe that the carrying bergs had moved far, if at all, from the points where they were originally detached from the basement.

Lenses of dark sand (composed largely of bits of shale) and courses of gravel are (rarely) interbedded with the finer sediments. It is inaccurate to state that "in the Hudson valley . . . the clays rest on till or glaciated rock" (Fairchild, 1919, p. 9); this is often the case but amassments of washed sand and gravels underlying the clays are not uncommon; occasionally they occur on top of clay beds.

Such deposits are referable to the time of transition when the lake bottoms were being cleared of ice, but exposures are scattered and, all too often, located in the least accessible places, the gullies and valley bottoms. From such fragmentary evidence as has been brought together the following picture emerges.

Bedrock having been encountered by the meltwater Hudson somewhere south of Rhinebeck, or drainage into the Champlain basin having been opened, a local base level was established which, on the Catskill quadrangle, was only slightly lower than the plains at 230 feet. In the gradually extending dead water the local remains of the glacier broke up and melted. Thick ice filled the gorge and the deeper preglacial side valleys but, over much of the rock terraces, the ice was a comparatively thin mosaic of blocks which, if not actually separated, were potentially detachable. Water, either formed on the under side or penetrating beneath, loosened the mosaic from the basement piecemeal. (There is no reason to believe that the deeper ice was tunneled.) As melting proceeded, each berg so freed was, if not over-freighted with débris and not lying in too shallow water, lifted off the bottom. The first deposits in the space so made were till (dumped) and gravels (washed) from the floating or still anchored ice. Later, as the space enlarged, released rock flours settled in the quiet depths under the ice as well as in open pools. (In this connection the wind must be considered to have been an active agent for distributing the rock flours.) In spite of the very long time during which this lake endured the ice was never entirely removed from its basin; and the irregularity with which open water invaded the ground as the ice disappeared accounts for many features of the topography inadequately explained on the hypothesis that the waters were laving a "receding ice front."

THE LAKE AT 215 FEET

Below the contact zone of the 250-foot gravel terrace northward from Blue Stores stretches a sedimentary plain now drained by the Klein kill and its branches. The surface is sandy but the sand is underlain by clay at varying depths. Two points on it at the divide near Livingston have been levelled respectively at 191 and 196 feet above tidewater. The plain continues into the basin of a nameless tributary to Taghkanic creek where its continuity is interrupted by the area of contemporary ice occupation associated with the bold ice-contacts shown in figures 71 and 73. In the vicinity of Buckley's Corners (Humphreyville) it is again well developed at a slightly lower elevation, as it is also along a small stream flowing eastward through the hiatus in the Cherry Hill esker. East of the esker grading for the roadbed of the main highway has exposed some eight feet of clay.

The lake floor declines northward beyond the limits of our atlas sheet with unfilled areas bridged by ice during deposition at the southeast base of the Becraft hills and in the courses followed by Taghkanic and Claverack creeks. North of the ice-block basin in which the latter flows (both above and below Claverack village) no signs of the former presence of contemporary residual ice were observed.

The water body in which these sediments accumulated appears not to have risen to the top of the Clermont plain which, together with a bedrock area on the west must have formed a peninsula. For the sake of precision in leveling the approximate altitude of a crossroads north of Blue Stores was accepted as that of the actual plane of the lake surface. At four points along the theoretic "shore" the sediments rise in low fans of silt and fine sand which may be located on the topographic map by the broadening of the space representing the interval between 200 and 220 feet (A.T.). Of these one is probably a modern alluvium. Concerning the others it may be said either they are glacial deltas *or there are no deltas associated with the lake*. If they are, their size and composition are indicative of weak streams born of the last remaining ice-masses in the neighborhood, for *lower deltas did not form as the water plane fell.*

What there is of the fan built by the meltwater Roeliff Jansen kill, the outer fringe, is shown in figure 78. Whether the crescentic bluff which serves as a windbreak for Blue Stores is an original feature or a product of subsequent undercutting (like the delta margin preserved at South Schenectady) could not be determined. The path of the modern stream (indicated in part by the arrow) as far as the falls at Bingham Mills is probably entirely postglacial. At the powersite the kill drops into a branch of its old valley.

Figure 79 gives the locations and topographic relations of the two northerly fans. One of these is on the Copake sheet, but must be included if the picture is to be complete. It was evidently built by meltwater coming from the northeast over ice. The other is to be ascribed to flow out of the Taghkanic valley, also over ice.

During this lake stage the ice which lay between the upper contact shown in figure 74 and the Cherry Hill esker was broken up and melted down nearer to the water level. A gravelly plain which formed at that level around a smaller (western) ice block is hidden by trees in the photograph but is shown in the explanatory diagram and can be identified easily on the topographic map. The topography is not such as could have been produced in an ice-free body of water having its surface at or near this plain. Except for distant elevations (shown in stipple in the diagram) no bedrock appears in the view.

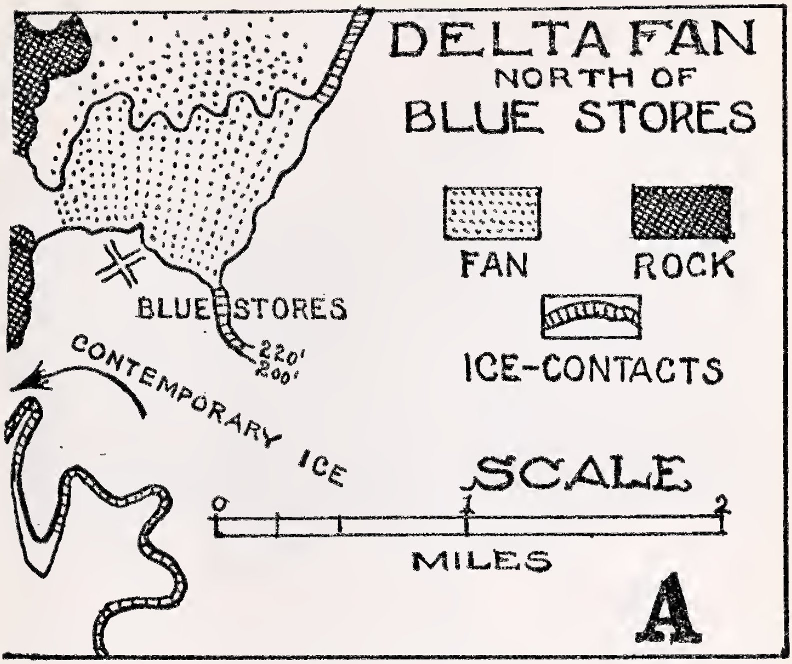


Figure 79 Delta fan north of Blue Stores

The higher glacial materials rise above the water plane and the ice-block depressions fall below it (Cherry Hill pond lies below the 160-foot contour), yet there are no horizontal etchings on the hill-sides to fix a shore line and no trace of lacustrine sediments over the lower ground. Indeed, the undercutting of the lower ice-contact, if accomplished by running water, must be held to be evidence that the ice which filled the cavity *was melting after the water level had fallen below the foot of the bank,* for there is no discoverable origin for flowing water other than meltwater produced locally. At the extreme right of the picture a gentle beachlike slope declines north-ward from the state road to lower claybeds (black in the diagram) which are interpreted as belonging to a later series.

As previously stated the large amount of ice remaining in this part of the lake basin after clay depositing had ceased is inconsistent with the idea that the lake was proglacial and "began on the south in the waters standing in front of the retreating ice sheet" (Wood-worth, 1905, p. 176). Farther north in the Hudson valley there is abundant evidence that masses of ice outlasted the "Lake Albany" episode, but south of the Mohawk river, except in the gorge, the masses were, for the most part, small; and the inconspicuous pits

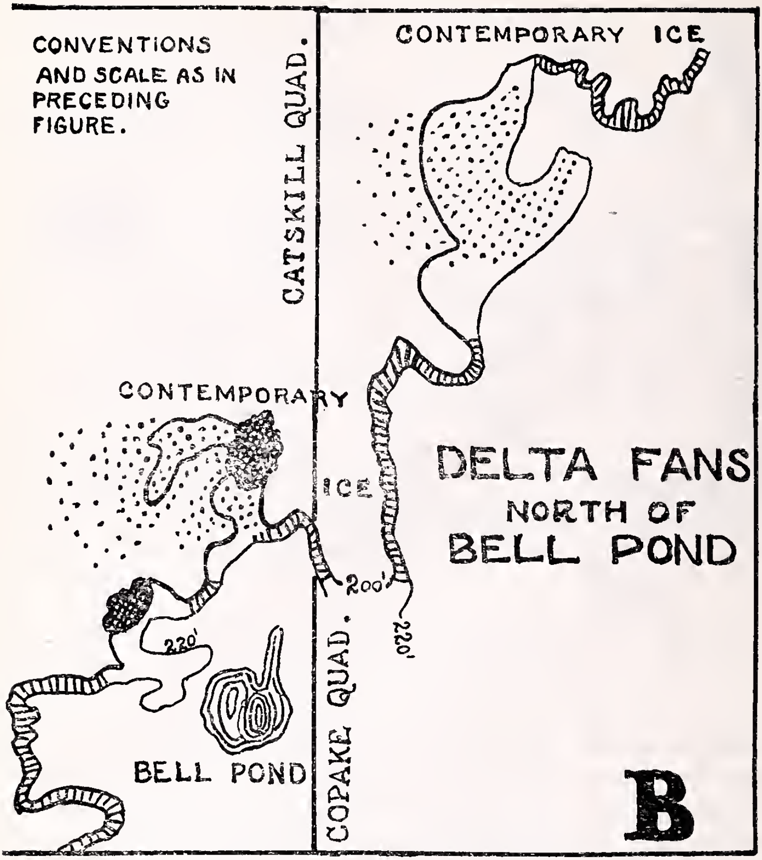


Figure 80 Delta fans north of Bell pond

which record their former presence are not always caught by contours spaced with a 20-foot interval. Nowhere in this district is the record of persisting ice so pronounced as on the Catskill quadrangle, and, instead of being the locus of Lake Albany's beginning, we repeat, the area appears to have been a comparatively late addition to its basin. In view of the proximity of the ice-plugged section of the gorge on the south this is not unlikely.

The impression of late origin is strengthened by the formations south of the Clermont peninsula where clay, if present at all in the deposits to be referred to the highest lake stage, is subordinated to fine sand. The indefinite divide between Stony creek and the Saw kill just under the 220-foot contour is on one of the sand plains so nearly flush with the theoretic surface of the lake that the absence of

Figure 81 Ice-contact slope east of the Potts Memorial Hospital. Looking southwest from the area of contemporary ice-occupation. See page 202.

Figure 82 Bell pond and Manor hill. The pond occupies an ice-block depression (kettle). Looking north.

wave and current-wrought features along its northern margin seems to preclude the possibility of its having formed the shore of even a narrow lead of open water. Westward the plain runs out into till-covered ground at the same level with no topographic expression at the line of change; southward it terminates against elements of the 230-foot plain or at the brink of the area of ice occupation through which the Saw kill flows.

Postglacial changes in the Stony Creek basin above highway 9G have obscured the condition in which it was left by the final melting of residual ice but there are several facts which suggest that it was not wholly open to sediment-depositing waters during the highest lake stage.

In view of the conditions found east of the river on the Catskill and Rhinebeck quadrangles it is not unreasonable to conclude that "Lake Albany" gradually extended its basin southward.

High Level Lake Floor West of the Hudson

Over the western rock terrace clays, with the usual topping of sand, fill most of the depressions between ridges of bedrock and have their outer margin against the Hamilton scarp which, beginning on the north at Vedder hill, trends west of south to Mt Marion where it passes out of the quadrangle. Along the eastern base of this escarpment a belt of weak shales (Bakoven, formerly known as Marcellus black shale) was deeply excavated by preglacial streams the combined valleys of which afforded a long, narrow basin for the reception of glacial lake sediments. It would seem that here, if anywhere, we might expect to find traces of a water level above the clay beds analogous to the fans and plains east of the Hudson, yet the deltalike accumulations at the corresponding level were ice-bound, and the meltwater streams which built them must have ceased to flow before the ice disappeared; for during the period of open water when the clays were being deposited they did not redistribute the materials of the terraces in free deltas.

Further discussion of the lacustrine beds in the "Bakoven valley" is given in the chapter on glaciation by Chadwick in Part II, a discussion which need not be repeated here. It remains, however, for the writer to note one point on which he desires to record disagreement, and to clarify the views expressed in an earlier section relative to the propriety of using ice-confined terraces in the determination of water planes extending beyond them. Chadwick accepts the ice-contact terraces in the courses of the Platte and Beaver kills as reliable indexes of the high "Lake Albany" shore. Of course, they may very well be just that; none of the known conditions excludes the possibility of ice sheeted over by water extending from one side of the valley to the other. In its simplest form the concept is employed in the final section of this chapter. If correlations across masses of ice were to be considered illegitimate, there is little likelihood that the history of the lacustrine beds would ever be worked out. Objection may, however, be raised to profiles which have been passed through selected ice-confined deposits and which purport to demonstrate the character and amount of displacement suffered by the glacial horizontal since "Lake Albany" was in existence. Following DeGeer's exposition of the method used by him in establishing *isobases,* profiles have been run through the Hudson and Champlain valleys by Merrill, Upham, Peet, Woodworth and Fairchild and all of them have ignored the possibility of hinges. Postulating a continuous warp or tilt of the earth's crust from the edge of the continental shelf to the top of the uplifted dome in Quebec, those who have made profiles have been content to let them pass *above* and *below* deposits *of equal value with those selected,* deposits which, if taken into consideration, would show the profiles to have either a merely local significance or none at all. Chadwick's profile of the Lake Albany shore passes higher than certain terraces at the north and lower than others of like import on the south. When made in advance of detailed field work along the whole of any proposed profile, I look upon the method as too arbitrary to be reliable.

SECONDARY WATER LEVELS

Reopening of the valley by slow wasting of the ice, gradually lowered the barriers controlling the height of the clay-depositing waters. As previously stated (and for the reasons given, see page 195) the succession of fugitive lakes appearing with halts in the removal of the ice dams has left too little in the way of evidence of shore lines to make it possible to reconstruct the outlines of those lakes. And the fact that contemporary ice still occupied sections of the gorge above Rhinebeck adds to the difficulty of reconstruction since parts of any given shore may have been of ice.

The Jefferson Heights delta (at 170 feet A. T.) proclaims the former existence of a secondary water plane and offers an exceptional opportunity for the study of phenomena associated with these lower water levels. Its sandy top overlies clays which belong to a series represented in Catskill village opposite the delta but *not* found along the east bank of the river between Mt Merino and Greendale. Directly across from the village are clean, unscarred drumlin slopes which do not support the idea that formerly these clays were banked against them and have since been eroded away. Behind (east of) the drumlins there is a narrow strip of clay, but the slopes rising from the river have every appearance of having been ice-covered when the water level stood at 170 feet. South Bay at Hudson (city), the Imbocht, Duck cove and the bays south of Tivoli are not normal stream erosion features and are interpreted as having been occupied by protrusions from the remnant ice tongue in the gorge.

A few miles north of our quadrangle (at Stuyvesant) the east bank (only) of the river is formed by glaciofluvial gravels having a strong southward dip. The deposit was made against ice on the west and the water level indicated is the same as that of the Jefferson Heights delta. It is inferred that these beds constitute *a delta-terrace built by the principal southward flowing stream* where it entered the 170-foot lake. The locality should be critically examined by anyone who is inclined to accept the hypothesis that at this time the Hudson valley was carrying a torrential flood derived in large part from the Lake Iroquois waters which spilled over at Rome into the Mohawk valley. There is nothing here to confirm the hypothesis.

In support of the contention that glacial drainage using the Mohawk valley may have been diverted into the Champlain basin while the Hudson valley below Kingston was still blocked by wasted remains of the ice sheet, attention is called to those topographic relations that suggest the possibility of a stagnant marginal girdle over New England and part of New York while the central field of the ice sheet was withdrawing across the submerged St Lawrence valley. "If the outermost marginal areas lie at a higher elevation than interior areas, the separation of the former from the latter is made easier...This [facilitation]...is further increased when the higher elevation in question is solid ground while the recession of the main ice takes place across a water surface" (Ahlmann, 1938, p. 330-31; trans. by R. Ruedemann).

During the late glacial invasion of the sea into the St Lawrence and Champlain valleys, shore lines were developed much more strongly and continuously against the northeastern flanks of the Adirondacks (*e.g.*, on the Mooers quadrangle) than along the Atlantic coast, the contract arguing that there was open water north of New York State while the coast was still more or less protected from wave action by the unmelted basal portion of the glacier's periphery.

The strange discontinuity and obscurity of strandlines at the upper limit of late glacial marine submergence has been remarked by almost every investigator of the records, from Quebec and Nova Scotia down to Massachusetts...If now we apply the theory that the ice sheet uncovered the coast by thinning down upon it, the late glacial blanket of ice comes to have a new meaning, and the zone thus shielded from wave action acquires a breadth and degree of permanency that seems adequate [to account for the discontinuity of strandlines] (J. W. Goldthwait, 1938, p. 367-68).

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THE ECONOMIC GEOLOGY OF THE CATSKILL QUADRANGLE

By David H. Newland

The mineral materials of economic value that occur within the Catskill quadrangle are mostly of the nonmetallic class, such as limestone, sandstone, clay, molding sand and building sand and gravel. Of the metals only iron is known to be present in the form of siderite or carbonate ore. This was mined in commercial quantity in a small district south of Hudson, but the deposits have been inoperative for the past 35 years. The production of nonmetallics is notable principally for the limestone used in portland cement manufacture, notably in Hudson and vicinity and to the south of Catskill.

IRON ORE

The deposits of iron carbonate are found along the western slopes of the series of hills that rise to the south of Hudson, including Church hill, Pless hill and Mt Tom, the more important. They include as the largest the Burden mines, worked by the Burden Iron Company, between 1875 and 1901. The ore was roasted locally to rid it of sulphur and increase the iron content by driving off the carbon dioxide and shipped to Troy where the company operated a furnace and iron works.

The ore is a gray compact siderite, accompanied by more or less quartz, calcite and pyrite, occurring as bands and lenses from eight to 40 feet thick conformably interbedded with quartzite and quartz shales of the Schodack series. There appears to be only a single seam, though this is faulted, folded and squeezed so that the body is discontinuous and subject to widening and thinning along both strike and dip. The total distance within which ore appears, north and south, is about four miles. The deposits lie some 300 to 500 feet above the Hudson river and a mile or more from the east bank. There are stretches along the ore horizon that show iron-stained ferruginous sandstone in place of the usual carbonate. The foot and hanging walls usually consist of thin layers of siliceous limestone or limy grit.

A study of thin sections of the ore reveals the carbonate of iron to be present in the form of minute rhombohedra inclosed in a matrix of colloidal silica carrying a small amount of carbonaceous material. The latter is in the form of a hydrocarbon volatile at moderate heat. There is little doubt the iron, silica and carbon exist much in the condition in which they were originally deposited and that the ore band represents an original element of the stratigraphic succession, accumulated along with the shales, limestone and sandstone by deposition in the Cambrian seas.

The ore was worked by opencuts and drifts driven at different levels reached through inclined shafts. Some five or six separate workings may be recognized, the largest on the western and southern slopes of Mt Tom, where the old mine settlement of Burden was located.

The Burden mines in their main period of operation of about 25 years yielded, it is estimated on the basis of actual shipments, roundly 1,000,000 tons of ore. Some 600,000 tons are known to have been produced up to the year 1889.

A sample of the ore showed on analysis: iron 41.41 per cent; phosphorus 0.159 per cent. This result taken from the reports of the Tenth Census evidently refers to the richer partially limonitized ore from the outcrop. The average run of the original siderite probably does not amount to more than 30 to 35 per cent iron. By roasting the iron content is said to have been raised to 40 to 50 per cent.

LIMESTONE

The existence of limestone beds suitable for cement manufacture close to the Hudson river, along with the necessary clays for supplying alumina and silica to the mixture, has given rise to a large and flourishing industry in the environs of Catskill and Hudson. There are altogether five of these plants, four of which have been recently operative and one (situated at Alsen) that is now closed. The plants on the east side of the river near Hudson include those of the Lone Star Cement Corporation and the Universal Cement Company. South of Catskill some five or six miles distant are the Acme unit of the North American Cement Corporation and the works of the Alpha Portland Cement Company. All are large plants which supply a high-grade product to the metropolitan and New England markets chiefly.

The cement quarries are situated in the ledges close by that expose the Helderbergian and topmost Silurian limestones, including the Manlius, Coeymans, New Scotland, Becraft and Port Ewen beds in substantial thickness. The Becraft limestone which has a relatively high content of calcium carbonate (90 per cent or over) and at the same time is low in magnesia usually contributes the most important element to the cement mixture.

The Hudson River region it may be noted has long been prominent in the cement trade. The first plant to manufacture portland cement in the country was built at Carthage Landing near Beacon, whereas natural cement was manufactured in the district centering about Kingston during the early part of the 19th century. This district for a long time held a prominent place in that trade, but the industry gradually fell off as the demand for portland cement increased.

Aside from cement limestone quarries supply material for road making and concrete.

SANDSTONE

The output of sandstone, mainly of the kind known as "bluestone" obtained from the Devonian formations of the Catskill mountains, was at one time of substantial importance in the area. Catskill and Saugerties were the chief distributing centers. The bluestone has a well-marked capacity for splitting or cleaving along planes parallel to the bedding, so as to be obtainable in thin smooth slabs adapted for flagging, curbing and other kinds of street work.

The Catskill bluestone has a fine compact texture, low porosity and small content of the more soluble ingredients like calcium carbonate so that it resists discoloration and wear to a marked extent. Its natural color is mostly a dark bluish gray or drab, somewhat somber for building stone except as used for steps, pavement, sills etc. where the dark shades are not particularly objectionable.

SAND AND GRAVEL

These materials are obtainable in many places for road building and concrete, but their use has diminished as crushed stone and the Long Island sand and gravel became obtainable at low cost. The local deposits are likely to carry a substantial portion of silt and shale so as to be rather inferior except after washing and then hardly equal to the high quartz sands found along the shores and beaches of Long Island which have already undergone a natural process of grading and purification by wave action. Sands from that source are now marketed along the lower and middle Hudson at a cost that enables the product to compete with the local supplies.

CLAY

This material is found abundantly along the inner valley of the Hudson river in terraces that extend back for some distance from the shores. The clays represent the accumulation in the floodwaters of late Pleistocene time. They contain a considerable percentage of the fluxing ingredients—lime, iron, magnesia etc.—and as a rule are suitable only for the manufacture of building brick of the commoner sorts. Yards are found along the riverbanks on both sides, though many have been inoperative during recent years.

MOLDING SAND

Minor quantities of molding sand have been taken from the district where it occurs as a top layer of the terraced beds, directly overlying the clay. The Catskill area, however, has never ranked as an important producer of this material, compared with the region in Albany and Saratoga counties which ranks as one of the most important in the east.

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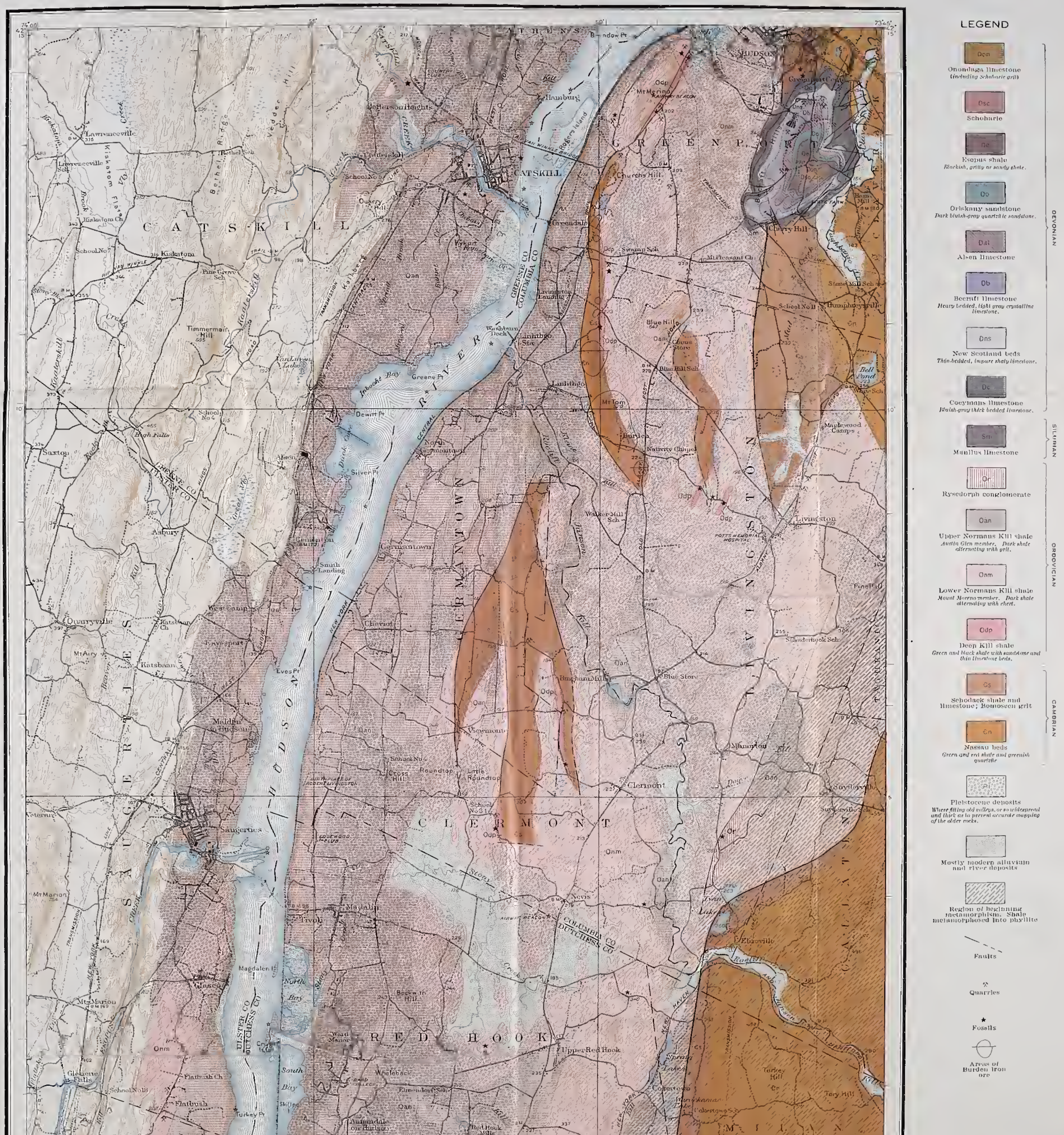
Geologic Map of the Catskill
and Kaaterskill Quadrangles



Topography by U. S. Geological Survey and the State of New York, 1933 and 1934 (revised)

Geology by R. Ruedemann, 1928-1936

GEOLOGIC MAP OF THE CATSKILL QUADRANGLE

Scale $\frac{1}{62500}$

Contour interval 20 feet
Datum is mean sea level