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CHARLES C. ADAMS, *Director*

GLACIAL GEOLOGY OF THE CATSKILLS

BY

JOHN LYON RICH

Temporary Geologist, New York State Museum

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ILLUSTRATIONS

GLACIAL GEOLOGY OF THE CATSKILLS

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INTRODUCTION

The Catskill mountains, situated close to the great centers of population and easily accessible, are a wonderful natural vacation ground.

Rising abruptly from near tidewater in the Hudson valley to heights of over 4000 feet, they offer rugged mountain scenery, opportunities for brisk climbing and considerable tracts of primeval wilderness. Their rounded, forest-clad slopes, their sparkling streams and the beautiful agricultural valleys in their less rugged parts give them a charm that is not easily surpassed (figure 8).

Besides their natural wildness and beauty, the Catskills hold endless possibilities of interest and fascination for those who can read the record left in them by the glaciers which, during the glacial period, some 20,000 to 50,000 years ago, covered them completely, then gradually melted out in a most complex and irregular fashion, leaving mountain glaciers of the Alpine type perched here and there on the sheltered slopes of the higher peaks. The glaciers ponded the waters of the mountain valleys and produced a multitude of lakes, whose former presence can now be traced by the gravel deposits emptied into them by streams, by beaches along the hillsides and by notches and channels cut by their outlet streams. Even the plunge basins formed where the glacial waters cascaded over long-abandoned waterfalls may now be found.

The unraveling of these past events from the scattered records that they have left is a most fascinating occupation which may well add to the interest of a vacation in the mountains and serve as the stimulus for many a vacation "hike".

The Catskill area, on account of its location with respect to the movements of the glaciers, is one of the most interesting in the entire country for the variety and complexity of its glacial phenomena.

In this report the principal glacial features of the Catskills, as determined by more than five months' study in the field, have been mapped and described. The field work was done in as much detail as seemed practicable for the purpose in view, but the possibilities of the area are by no means exhausted. Many problems need further study. Some of the opinions expressed in this report will undoubtedly be modified as more facts are accumulated, and a whole fascinating field, that of unraveling the exact chronology of the various glacial lakes by means of the laminated lake clays, has not been touched. By making available the broader features of the glacial history of the entire Catskill region, this report should serve as a basis from which these further studies may start.

It has been thought best, at the risk of some repetition, to present the details for the various parts of the area in the form of local descriptions arranged according to the principal drainage basins, so that anyone visiting any particular locality can readily find a discussion of that locality. The broader results of the survey are treated in the more general chapters.

THE GLACIAL PERIOD

The glacial features of the Catskills are products of the glacial period or "ice age" which affected the whole world during the past million years, more or less, and which even now is only in its waning stages, with great ice sheets still covering most of Greenland and the Antarctic continent.

The reasons for the lowering of world temperatures which brought on the ice age are not fully understood, but we know that the climate has fluctuated widely during the past million years so that there was not merely one glacial period, but at least four, between which were periods of warmer climate when the ice sheets may have been entirely melted away and during at least one of which, as we know from plant-bearing clays found near Toronto, the climate became even warmer than it is today. Not only were there the great climatic fluctuations that brought on the four glacial epochs with their warmer interglacial intervals, but there were smaller fluctuations superposed on the larger ones and continuing even into historic times. To these minor climatic fluctuations the ice sheets responded by advancing or readvancing during the colder spells and by halting or retreating during the warmer ones.

The great ice sheets of the glacial period were very similar to those which now cover Greenland and Antarctica. In North America, during one or another of the four glacial epochs, they covered most of the continent north of a line extending, roughly, from Long Island, N. Y., to northwestern Pennsylvania, thence down the Ohio valley to the Mississippi, thence up Missouri river to near the Canadian boundary, thence westward to the Pacific.[1] They appear to have spread out from at least three great centers located respectively in Labrador, west of Hudson bay, and over the Canadian Rockies. New York State lies in the area covered by ice from the Labradorean center.

The ice sheets of the glacial period, like those still remaining, seem to have had the form of very broad, flat domes, steeper around the margins, whose tendency to be built higher in their flatter central portions by the accumulation of the snow that fell upon them was counterbalanced by an outward flow of the lower part of the ice similar to that of thick tar. Ice, although brittle when not under great pressure, flows slowly under its own weight if thick enough.

This outward-spreading ice around the margins of the ice sheets, backed by the weight of the accumulating snow on the dome behind it, rode forward relentlessly, pushing over and between obstacles in its path, crossing minor hills and valleys, and even riding up over the highest mountains in New England and New York (which were low compared with the height of the central parts of the ice sheets, perhaps 10,000 feet), and scoring and abrading the land over which they passed like a giant rasp shod with boulders and sand set in a matrix of moving ice.

The spreading and outward flow of the margins of the ice sheets continued until, in the southerly latitudes, points were reached where the annual melting equalled the forward movement. There the position of the ice front halted in equilibrium between the forward flow and the melting. Along the edge of the ice where it stood for any considerable time in this position of equilibrium, large quantities of boulders, sand, clay and other products of the wear of the ice on the rocks over which it rode were concentrated as the ice carried them forward in a steady stream and dropped them as it melted. These accumulations of glacier-borne débris, which are called moraines, may be found wherever the ice front remained stationary for a time. They afford one of the most reliable means by which we can trace the former positions of the ice front.

The position of the ice margin, being controlled by the balance between forward movement and melting, was very sensitive to climatic fluctuations. During warm spells the melting exceeded the rate of forward movement and the edge of the ice sheet was melted back; during colder spells the melting could not keep pace with the

[1] For further information on glaciers and the glacial period see any good textbook of geology.

forward movement and the ice front advanced, perhaps overriding moraines previously formed.

As the conditions that caused the glacial periods came to an end, melting gained the ascendency and the ice sheet gradually withdrew, although the ice in it was all the time moving forward. The withdrawal was not without long halts and occasional readvances caused by climatic fluctuations and recorded in successive belts of moraines.

THE GLACIAL PERIOD IN NEW YORK

In New York State most of the records left by the continental ice sheets belong to the latest, or Wisconsin, epoch. Some, and perhaps all, of the earlier ice sheets covered the State, but their records are generally obscure, having been mostly obliterated by the ice of the Wisconsin epoch.

The ice entered the State from the north or slightly east of north and moved, in general, southward and southwestward. Its movements, particularly in the earlier and later parts of each epoch, were influenced greatly by the broader features of the topography such as the Champlain-Hudson lowland, which furnished a low and easy path across the eastern part of the State; the Ontario lowland; and the Mohawk valley. The Adirondacks stood as a barrier that separated the strongest ice flow into the Champlain-Hudson and the Ontario lobes, and the Catskills stood as a similar barrier that directed strong ice streams westward up the lower Mohawk valley and southward down the Hudson (Rich '14; Brigham '29).

During the stage when the ice sheets had their maximum extent, all these highlands were buried under the ice, but even then the strongest flow must have been along the lowland paths just outlined because they offered fewer obstacles to flow and because the ice was thicker there and consequently under greater pressure in its lower parts so that it flowed more freely than over the highlands where it was relatively thin.

Along the margins of the ice sheet the smaller elements of the topography greatly influenced the shape of the ice front and its flow. Lobes of ice pushed forward down valleys, bulbs were formed opposite narrow gaps, and lakes were impounded in valleys of streams flowing toward the ice. In the rougher areas the shape of the ice front was irregular and these irregularities were constantly shifting as the ice melted farther and farther back and uncovered new topography.

Because the topography exercised so great an influence on the details of ice movement in the later stages when the moraines were being formed, it will be well before beginning the study of the glacial features of the Catskills to fix clearly in mind their principal topographic features.

PHYSIOGRAPHY OF THE CATSKILLS

The Catskill group of mountains stands at the northeast end of the great Allegheny plateau, which extends as a definite physiographic unit all the way from Tennessee along the western border of the folded Appalachians. The Catskills rise considerably higher than the neighboring parts of the plateau and hence constitute a distinct unit, but they are, nevertheless, structurally a part of it.

At the eastern border of the Catskills the plateau breaks off abruptly into the Hudson Valley lowlands. It also breaks down into lower lands south and southeast of the Catskills, but to the northwest and west the plateau, at a general level about 2000 feet below the summits of the higher mountains, extends unbroken across central New York and northwestern Pennsylvania.

The present mountainous form of the Catskills is due entirely to the action of streams in carving deep valleys in the flat-lying rocks of the uplifted plateau. The fact that the mountains rise about 2000 feet above the adjacent parts of the Allegheny plateau seems to be due to the superior resistance of the rocks of which they are composed.

An interesting geological story relating to the origin of these rocks and suggesting a reason for their exceptional resistance to erosion, also brings out clearly the striking changes which time has wrought in the landscape.

At the time the sediments that now form the rocks of the Catskills were being deposited, high mountains existed in what is now New England and southeastern New York, and a shallow sea covered western New York and Pennsylvania and extended into the Mississippi valley. Between those ancient mountains and the open sea, in the region now occupied by the Catskills was a great and slowly sinking delta or alluvial fan upon which the rivers from the mountains to the east were spreading gravel, sand and mud, much as the rivers from the Sierra Nevada mountains are doing in the Valley of California today. These alluvial materials, which accumulated to a thickness of several thousand feet as the land subsided, were relatively coarse on the eastern side nearer the mountains, but became finer, grading into sand and mud in a westerly or seaward direction. Deposition on the delta gradually slowed and eventually ceased as the mountains were worn low. Finally, in the course of ages, the ancient Catskill delta was uplifted and now stands higher than the mountainous region of New England whence its constituents were derived.

The rocks of the eastern Catskills, being the coarser, landward part of this ancient delta, contain considerable cemented gravel, or conglomerate, especially the upper beds (figure 16). Such rock is very resistant to erosion, not only because it is composed of erosion-resistant materials such as quartz pebbles, but also because it is porous so that a large part of the rain falling upon it soaks in and hence stream erosion is at a minimum. It is to this resistant nature of its rocks that the superior elevation of the Catskill portion of the plateau is attributed.

Westward the conglomerate becomes finer and then grades into sandstone, while the proportions of shale become larger. This change in the character of the materials has caused a lesser resistance to erosion and consequently the mountains have been worn lower toward the west. The Catskill sandstones are mostly cross-bedded and slabby (figure 9).

Although the rocks of the Catskills are prevailingly flat-lying, there are slight variations from the horizontal both locally and regionally that have profoundly influenced the physiography of the range (Rich '15, p. 137–66).

Viewed in a broad way, the Catskills lie in the eastern end of a great synclinal trough with the rocks dipping in toward them, from the northeast off the Adirondack uplift, from a little south of east off the strongly folded area in the Hudson valley, and from the southeast off the continuation of this folded belt where it swings to the southwest into the general trend of the folded Appalachians.

These structural relations, through the control which they exercised on the attitude of the rocks and therefore on the activities of stream erosion, are responsible for the major topographic features of the area. The Catskill group as a whole is essentially a curved, outward-facing cuesta with abrupt scarps facing the northeast, east and southeast, and with a maturely dissected central portion sloping gradually to the southwest (figure 1).

The outer northeastward-facing escarpment, extending from North Dome, near the Kaaterskill lakes, to Leonard hill has been called the Northeastern escarpment (Rich '15, p. 137–66) and is so mentioned in this report. Another, parallel to it and extending from Plattekill mountain through Hunter, West Kill, Balsam, Vly, Bloomberg and Utsayantha mountains to Potter mountain, (called by A. Guyot ('80) "the central chain of all the Catskills") is here

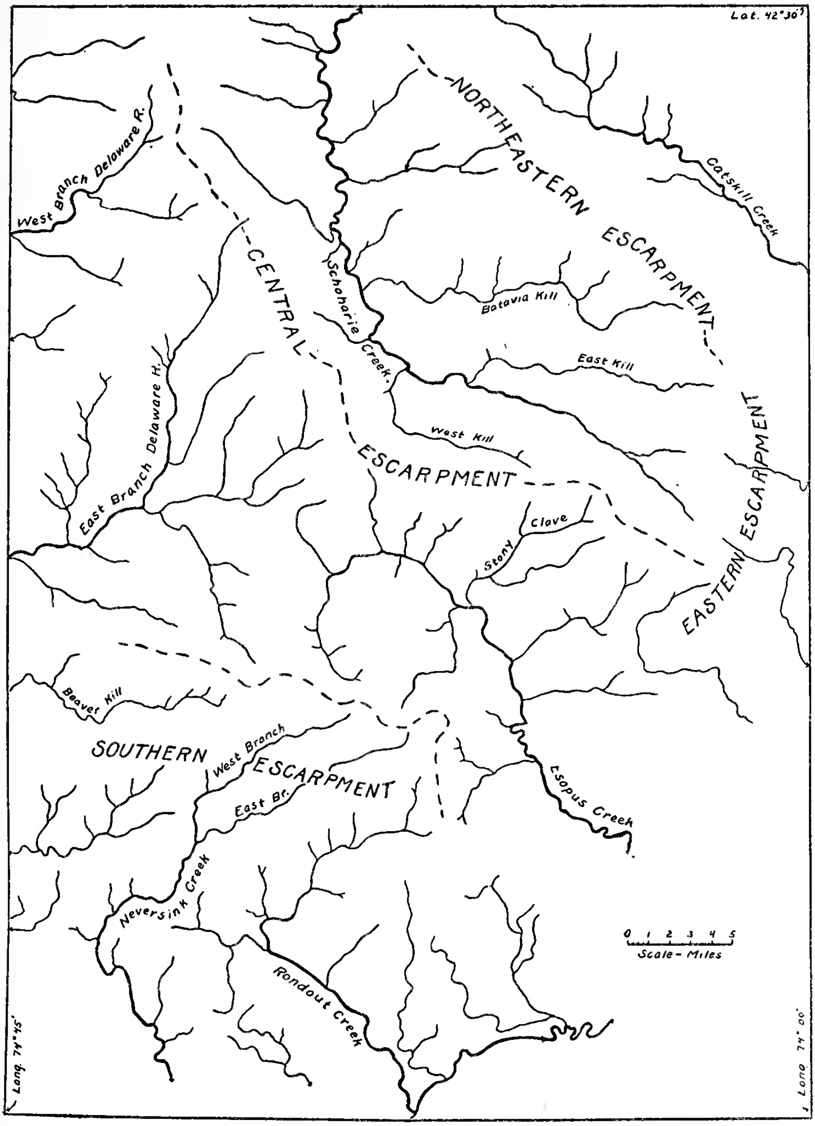

Figure 1 Sketch map showing principal physiographic and drainage features of the Catskills

referred to as the Central escarpment. Both are cuestas due to the outcrop of resistant rocks dipping southwestward. The cuesta nature of the western half of the Central escarpment is unmistakable, but that of the eastern half is not so clear.

The east-facing escarpment or "mural front," extending in a straight line N. 20° E. from Overlook mountain to Sleepy hollow, is a very striking physiographic feature that is believed to owe its straightness to a structural cause, namely, the sharp upfolding of the rocks immediately east of it along this strike.

The south-facing scarp of the Catskills, extending westward from Mombaccus mountain, is irregular and rather indefinite and probably is controlled more by rock resistance than by structure.

DRAINAGE

The northern Catskills are drained by Schoharie creek and its tributaries, which, in a general way, flow parallel to the base of the Central escarpment and drain the region between it and the Northeastern escarpment. These streams flow nearly parallel to the strike of the rocks and their courses have evidently been determined by the same structural features that are responsible for the escarpments. Below Gilboa, however, the Schoharie takes a northward course more or less directly across the strike of the rocks.

The Central escarpment, throughout its length, forms a divide between the waters of the Schoharie and those of Delaware river and Esopus creek. It is, however, cut by three deep notches, at Grand gorge, Deep notch, and Stony clove, which now form important paths of communication and which played important parts in the glacial history of the region.

The east and west branches of Delaware river, which drain the western Catskills, head on the Central escarpment and flow in a general southwesterly direction. They have numerous tributaries, which, in general, are longer on the north than on the south sides of the main streams.

Esopus creek, flowing eastward into the Hudson, has a relatively short, steep course. It drains the highest and most rugged parts of the Catskills; its northern tributaries rising on the south side of the Central escarpment, and its southern tributaries in the high southern range.

The pattern of the Esopus and its tributaries is entirely different from that of the other streams in the region, being symmetrically dendritic, or treelike, while that of the other streams, particularly in the northern and western Catskills, is noticeably unsymmetrical, the tributaries entering from the north being much longer than those from the south.

A symmetrical drainage pattern, like that of the Esopus system generally indicates horizontal rocks. In this connection it is significant that the Esopus lies nearly in the center of the broad U made by the curving outer escarpments (figure 1), and between the area of southwesterly dipping rocks of the northern Catskills and that of northwesternly dipping rocks along their southeast side.

In the southern Catskills the valleys of the upper course of Rondout creek and those of the east and west branches of Neversink creek are all essentially parallel to the strike of the rocks of the southeast-facing scarp, showing again a probable structural control of the drainage.

DRAINAGE CHANGES

The instances of stream piracy at Kaaterskill clove and Plattekill clove described by Darton ('96) have become classic. Another instance of stream capture is that of the headwaters of Beaver kill, which empties into Esopus creek at Mount Pleasant. Saw kill, which now rises in Echo lake, was formerly the head of Beaver kill. At some time previous to the glacial period this portion of the stream was captured at Shady by a short, swift stream leading more directly to the Hudson.

It is possible that part of the upper watershed of Esopus creek was once tributary to the East branch of Delaware river through the gap at Pine Hill and has been captured by the Esopus on account of its shorter, steeper course.

Another probable instance of stream piracy is found about two miles northwest of Claryville (Neversink quadrangle) where it appears as if West branch of Neversink creek had formerly flowed straight on through a valley now occupied by Fir brook and had later been captured by a short tributary from East branch.

THE TWO THOUSAND-FOOT PENEPLAIN

The picture of the topography of the Catskills is not complete without consideration of another feature that is responsible for some of the most conspicuous elements of the Catskill scenery, namely the remnants of an extensive erosional plain now standing at an elevation of about 2000 feet above sea level, which encircles the Catskills on all sides but the east and extends up all the principal valleys.

This erosional plain, or peneplain as it is called, was produced at a time, probably in the late Tertiary period of geologic history, when the land stood some 2000 feet lower than now for so long a time that all the Allegheny plateau, except parts like the eastern Catskills underlain by especially resistant rocks or those parts near the principal stream divides, was reduced by the action of rain, frost and streams to a low, rolling plain. This plain included all the region immediately north of the Catskills and extended up all the tributaries of Schoharie creek, making broad, open valleys five or six miles wide along the upper Schoharie creek, Manor kill, Batavia kill, East kill, and other tributaries, between which were narrow mountain spurs up to 2000 feet in height.

In the drainage area of Delaware river, which includes practically all of the southwestern Catskills, the peneplain was not so well developed as along Schoharie creek and its tributaries. The region seems to have been reduced only to low hills instead of a plain, and to have lain 300 or 400 feet higher than the plains north of the Central escarpment. This greater elevation and less advanced stage of erosion were probably due to the greater distance from the sea by way of Delaware river. But though not so distinct as in the valley of Schoharie creek, the remnants of the peneplain are nevertheless prominent features of the topography of the southwestern Catskills.

In the valley of Esopus creek indications of the peneplain are recognized in the prominent shoulders at the ends of long spurs which slope gently down from the higher mountains (figure 10). All these spurs are narrow, and the shoulders have elevations ranging from 2000 to 2600 feet, indicating that for some reason, possibly the resistant nature of the rock, peneplanation was never far advanced in this valley (compare also figure 8). It is possible, however, that when the peneplain was being formed, part of the area now drained by Esopus creek drained westward past Pine Hill into the East branch of Delaware river, as has already been suggested, and this may explain the higher elevation of the peneplain remnants in the Esopus valley.

At the time of the maximum development of the peneplain, the Catskills must have been a region of subdued mountains, the highest of which rose not much over 2000 feet above the neighboring broad, open valleys. The Central and Northeastern escarpments must have had much their present appearance, because they are still surrounded by extensive remnants of the plain. The Catskills as a whole rose above the broad expanse of plain that had been developed on the Allegheny plateau to the north and west.

The formation of the peneplain was brought to a close by an uplift of the land to nearly its present level. This gave all the streams an opportunity to begin deepening their channels and they cut narrow, V-shaped valleys in the bottoms of the broader valleys that they occupied before the uplift. These sharply cut valleys beneath the peneplain level are best seen in the drainage areas of Schoharie creek (figure 11) and Esopus creek, where the shorter distance to tidewater along these streams gave them a greater cutting power than was possessed by the southwestward-flowing Delaware and Neversink streams.

After having cut its valley about 700 feet below the level of the peneplain, Schoharie creek seems to have reached grade and, for a time, to have become engaged in widening its valley. This halt in the uplift of the land lasted long enough for the main Schoharie valley to be opened out to a width of from one to one and one-half miles. Remnants of a rock bench formed at this stage are conspicuous in the valley of Schoharie creek below Gilboa (figure 12). They stand at elevations between 1200 and 1300 feet above sea level, and about 300 feet above the present stream. Corresponding rock benches have not been recognized along other streams.

Later the uplift of the land was resumed and Schoharie creek cut another sharp valley within the one just described. Borings by the New York City Water Supply Commission in the neighborhood of Prattsville and Gilboa have shown that the valley was cut to a depth of about 200 feet below the present stream before the advent of the glaciers filled the channel with débris, which the stream is still engaged in clearing out. As a rule, all the larger streams of the entire Catskill area had cut their valleys 50 to 200 feet below their present level before the glacial invasion.

A feature characteristic of nearly all the valleys of the Catskills except those drained by Esopus creek is that up-stream, near their heads, they widen out and become more mature in form. This is especially well shown by the valley of Schoharie creek. At Gilboa and Prattsville it is deep and narrow, with steep walls 500 to 700 feet high, whereas farther up, in the neighborhood of Tannersville and above, the valley is wide and open with gentle slopes gradually becoming steeper toward the mountains. Similar conditions are found in the valleys of the upper tributaries of Delaware river (figure 13).

The reason for this condition seems to be that the revival of stream cutting which followed the uplift of the peneplain was slow in reaching the headwaters, and meanwhile the valleys had continued widening out.

Between the broad, open heads of the valleys and the steep-sided parts below, remnants of the peneplain appear as low benches along the sides of the valleys 50 to 200 feet or more above the streams. These benches, where covered by glacial deposits, as is common, are difficult to distinguish from thick accumulations of glacial drift. In many instances it is impossible to tell whether a given form is produced by thick drift or by a rock bench. Such benches are well developed in the upper Schoharie valley and in the valleys of West kill and East kill.

RELATION OF TOPOGRAPHY TO DIRECTION OF ICE MOVEMENT

Summarizing briefly the larger topographic and drainage features of the Catskills in relation to the movement of the continental ice sheet, which in this region was in a general southwesterly and southerly direction, it will be noted that the Northeastern escarpment and the Central escarpment stand almost at right angles to the direction of glacial movement, as do also the valleys of the upper Schoharie and its tributaries. The valleys in the region drained by the headwaters of the east and west branches of Delaware river and of Neversink creek lie approximately parallel to the direction of ice movement. The Esopus, in general, lies athwart the course of the ice, though some of its tributaries flow in the direction of ice movement and some in the opposite direction. The great Hudson lowland east of the Catskills extends north and south in the direction of ice movement and must, of course, have offered a much easier path than the mountainous regions to the west.

GLACIAL SCRATCHES AND GLACIAL SCOURING

As the ice sheet moved over the land it carried in its base stones and boulders with which, under the pressure of thousands of feet of overlying ice, it scoured, smoothed and polished the rocks over which it rode. The scratches, or striae, thus made on the rocks are reliable indicators of the direction of the ice movement. They are shown on the general map, plate 1, and also on plate 2.

The preservation of the striae depends upon local conditions. They are preserved best on fine-grained sandstone that has been covered by a blanket of glacial material. On the coarser sandstones and conglomerates they are not commonly so distinct, and on the soft shales interbedded with the sandstones they are rarely preserved.

On rock ledges that have been exposed for a long time to the weather, striae are not commonly found, because they have been destroyed by the disintegration of the rock. This is particularly true of the southern and southwestern Catskills, where the glacial scouring seems to have been feeble and where the time since the ice was present seems to have been considerably longer than in the northeastern part of the area. In the southwestern Catskills it is only here and there that striae are found in natural exposure, whereas in the northeastern Catskills, where the ice scouring was intense and apparently more recent, striae are very common even on ledges exposed to the weather.

It is not always easy to tell at a glance the direction of ice movement indicated by glacial striae but certain indications, when found, are fairly reliable. Among the best of these is the gradual deepening of a scratch or groove followed by its sudden ending (figure 14, *B* and *C*). This is produced by a stone or boulder, held in the bottom of the ice, gouging deeper and deeper into the rock until finally it is caught and turned over and suddenly ceases to cut. It is obvious that such scratches will deepen and abruptly disappear in the direction of ice movement.

Other indications of the direction of movement are furnished by chatter marks (figure 15), by "fern leaf" flakings (figure 14, *A*), and by "crag and tail" effects caused by local hard spots in the rock (figure 16).

On steeply sloping or vertical rock ledges where the ice was moving approximately parallel to the face of the ledge, the direction of movement can be determined from the form of curved striae on the ledge (figure 17). The striae curve upward in the direction of ice movement. Instances where the direction of movement was determined in this way are on the rock ledge near the schoolhouse on Fly brook one and one-half miles west of Prattsville, where there was a question whether the striae were made by glaciers ascending the valley or descending it from Bloomberg mountain; and on the west spur of the valley a mile southwest of Spruceton in West Kill valley, where there was a similar question. In the former case the upward curving of the striae showed that the ice which made them was moving up the valley; in the latter, that it was moving down.

It sometimes happens in regions where, under the influence of the local topography, the ice movement at later stages was in a different direction than in the earlier, that on a single rock several sets of striae may be found pointing in different directions. In such instances it is generally not difficult to tell which are the later. The scratches of the earlier set are interrupted and crossed by those of the later. The map shows several regions where such diverging sets of striae are found, notably on Overlook mountain, on the mountain in the neighborhood of Kaaterskill House, and in numerous other places, not all of which are indicated on the map.

THE DIRECTION OF ICE MOVEMENT IN THE CATSKILLS AS INDICATED BY GLACIAL STRIAE

In general, the direction of movement of the ice at the time of its greatest thickness was southwestward, averaging about S. 30° W., as is indicated by the higher striae.

In the drainage area of the West branch of the Delaware river the ice movement was nearly south, varying from south to S. 15° W.

In the basin of the East branch of the Delaware river, including its southern tributary, Beaver kill, the movement was more to the southwest, being S. 20° to 30° W. in the headwaters of the East branch and its tributaries above Arkville, and about the same in the valley of Beaver kill. Along the East branch, however, between Arena and Pine Hill the movement was more to the westward, nearly parallel to the river valley. The striae on the hills in this vicinity average about S. 45° W. On the south side of the pass at Pine Hill, between the valleys of the Esopus and the East branch of the Delaware, the striae, at an elevation of about 2500 feet along the road one mile south of Griffin Corners, point N. 80° W., indicating a westward flow through this pass governed by the local topography.

On the plateau north of the northwestern end of the Northeastern escarpment the striae indicate a general southwesterly movement, but in the valleys of the upper Schoharie creek and its tributaries, bounded as they are on the south by the rugged Central escarpment rising in the direction of ice movement, the striae indicate great diversity of direction, marked on the one hand by a movement southward up Schoharie valley and on the other by a movement southwestward and westward down that valley from the great ice tongue that lay over the Hudson River lowland.

On the hills north of Prattsville the striae indicate ice movement toward the southeast from the Schoharie Valley ice tongue. This ice current was almost directly opposed by ice moving down the valley of Batavia kill, as is indicated by striae trending almost west in that valley.

Through the passes in the range between Batavia kill and East kill and those between East kill and Schoharie creek, the ice movement was nearly south. This southward flowing ice was met in the neighborhood of Tannersville in the upper Schoharie valley by a tongue of ice pushing northwestward from the Hudson Valley lobe through Kaaterskill clove, and by a similar tongue pushing northwestward through Plattekill clove. At the head of each of these cloves the ice spread out in fan shape. In some places, as near the Kaaterskill House, it moved almost due northwest.

In a similar way a tongue of ice from the Hudson Valley lobe pushed northwestward into the valley of the upper Beaver kill and upper Saw kill west of Overlook mountain, in some places, as at Meads, moving almost due northward. In the neighborhood of the mouth of Esopus creek, along the south side of the Ashokan Reservoir, the striae indicate ice movement nearly westward.

Along the southeastern front of the Catskills, south of High Point, the striae show that the ice of the Hudson Valley lobe spread southwestward across the foothills south of the higher mountains. In the pass west of Balsam swamp the movement was slightly north of west, while in the valley of Rondout creek the ice moved northwestward parallel with the course of the valley between Lackawack and Eureka. On the plateau west of Ellenville the movement was due west, while farther south, on the plateau southwest of Ellenville, the ice moved southwest.

A powerful ice current apparently followed the valleys of Rondout creek and Sandburg creek between the Shawangunk mountains and the foothills of the Catskills. The presence of the Shawangunk mountain barrier in the course of the ice of the Hudson Valley lobe presumably directed the strong ice movement northwestward up the Rondout valley toward Eureka.

GLACIAL EROSION

There is a marked difference in the degree of ice scouring or erosion between the region north of the Central escarpment and that to the south. The plateau north of the Catskills and the passes through the Northeastern escarpment and those through the ranges separating the various tributaries of the upper Schoharie are all profoundly scoured by ice (figures 18 and 15). The rock ledges are stripped bare and the soil everywhere is very thin. This scouring is most in evidence where the ice was confined in passing through gaps in the bordering ranges.

Ice scouring was also intense at the head of Schoharie creek, especially in the neighborhood of Kaaterskill lake, where the ice pushed westward from the Hudson Valley lobe. The two Kaaterskill lakes are apparently rock basins excavated by ice scour. The upper lake is completely rock-bound; the lower is possibly held in by a bank of drift, but is probably mainly a rock basin.

Strong scouring by the ice is also evident in the neighborhood of Little Beaver kill and over all the lowland near the mouth of Esopus creek. High Point (figure 58), which received the full force of the Hudson Valley tongue, was strongly scoured on its eastern side.

Only one of the passes through the Central escarpment shows evidence of strong scouring, namely, Grand gorge, where stripped ledges and thin soil underlain by striated rocks are conspicuous. In the southwestern Catskills no evidences of strong glacial scour were found, and it is worth while to repeat that the contrast in this respect between the southwestern Catskills and the region north of the Central escarpment and along the western side of the Hudson Valley lowland is very striking.

Glacial erosion in the Catskill region seems to have been strongest in the passes through the mountain ranges and weak in the valleys such as that of Schoharie creek. This condition, which contrasts notably with that found by Tarr ('09) and Carney ('09) in the Finger Lakes region of central New York, is probably due to local topographic features, and to the fact that no valleys in this region except the Hudson River lowland afforded free and unrestricted ice movement.

GLACIAL DEPOSITS—UNASSORTED DRIFT

INTRODUCTION

When the ice sheet first advanced over the Catskills, the region was undoubtedly covered with a soil derived from the weathering and disintegration of the sandstone and shale rocks of which the mountains are composed. The moving ice of the glacier scraped off the loose soil, plucked off from the sandstone ledges blocks of all sizes already loosened by weathering, and carried the whole forward in, on and under the ice.

Although, as explained in a preceding chapter, it was only in places where movement was exceptionally vigorous that erosion by the ice was strong enough to scour away the solid, unweathered rock, the aggregate amount of soil and loose rock which the ice picked up was very great.

When the ice melted, all the rock and residual material scraped or plucked off the land was either deposited at the place of melting or carried away by streams. Some of it was piled up as moraines at the ice border; some was carried away as outwash by streams issuing from the melting ice; some was plastered or molded thickly onto the ground beneath; and some was spread out as a sheet of ground moraine, or *till,* over the entire surface not covered by other deposits.

Typical examples of these various glacial deposits, which are distinguished on the map (plate 1), are described in succeeding paragraphs.

MORAINES

Wherever the forward movement of the ice sheet was balanced by melting, the end of the ice remained in approximately the same place for a considerable time, during which the débris carried in, on or under the ice was brought forward to the end and piled up to form *moraines.* These assumed the form of the ice front at the time they were built. Where the ice ended in a valley, its semifluid nature permitted it to extend farther along the valley bottom than along the sides, and consequently the moraines built around its edge swing diagonally down the hillside, across the valley and diagonally up the opposite slope. Such "moraine loops" may be seen forming around the end of almost any mountain glacier at the present time. Where the glaciers have disappeared, as in the Catskills, the moraine loops afford a ready means of determining the direction of ice movement and of marking halts in its recession.

Across the valley bottoms the moraines commonly take the form of distinct ridges, but on the adjacent hillsides they are likely to lose the ridge form and become one-sided embankments dying out within a short distance up the hillside (figures 2, 19 and 20). It is seldom that a moraine can be traced from one valley across the intervening ridge to the next valley. The steeper the ridge and the deeper the valley the less is the chance that the connection from one valley to another can be traced.

There is every gradation among terminal moraines from perfectly distinct ridges, clearly marking the ice border at the time of their formation, to smooth, indefinite deposits of thick drift of general morainic form, but lacking the distinctness of the ridge type. A more detailed description of the principal morainic types is presented in succeeding paragraphs.

Types of moraines and their mode of formation. In the Catskills one finds a great variety of morainic forms corresponding, apparently, to the various conditions of accumulation. Types distinct enough to merit special discussion are: ridge moraines, smooth moraines, hummocky moraines, lateral embankments, wavy moraines, and boulder moraines.

Ridge moraines. The most distinct and unmistakable type of moraine is the sharp ridge which, in the form of a loop, swings across a valley and diagonally up the valley sides. In some places these ridges are as sharp and distinct as railway embankments, and can be traced as easily. They can readily be distinguished from eskers, which may have similar appearance, by their composition, which is stony till instead of gravel.

On the south side of the valley between Hobart and Stamford, ridge moraines are very well developed. Some of them change from the ridge type to the hummocky type as the bottom of the valley is approached. On the plateau at the northwestern end of the Northeastern escarpment, particularly northwest of Mount Safford and southeast of Mackey (Gilboa quadrangle), ridge moraines are pronounced and some of them can be traced for two or three miles. Immediately south of Chichester (Phoenicia quadrangle) is a group of very sharp ridge moraines. Ridge moraines are found at many other places but they are much more conspicuous in the parts of the region that have been most recently occupied by the ice and where ice movement was active.

The conditions necessary for the production of moraines of the ridge type are believed to have been relatively active movement and melting of the ice, so that large quantities of débris were brought forward and dropped without much change in the position of the ice front. It is also clear that the ridge type is characteristic of deposition on land as contrasted with deposition in the waters of glacial lakes.

Smooth moraines. In the southwestern part of the Catskills the prevailing type of moraine is broad and smooth. A hummocky surface is comparatively rare, and the ridge form is seldom found. The moraines of the smooth type not uncommonly have the typical loop form, but, in general, are more massive than the ridge moraines. A typical smooth moraine is shown in figure 21. The smooth moraines, like the ridge type, were formed on land.

Three possible explanations of moraines of the smooth type present themselves. One is that they were formed by ice whose frontal oscillation was great in comparison with the amount of débris that was being deposited, so that the latter was spread rather evenly over a relatively wide zone. Another is that the moraines were formed and subsequently overridden by a readvance of the ice. A third is that they are so much older than the other moraines that they have been smoothed by erosion.

It is thought that all three processes were in operation to produce the smooth moraines. Undoubtedly oscillation would tend to build up a massive, relatively smooth moraine, but it should leave the surface more irregular than is commonly found. In regions well within the belt where the latest Wisconsin ice is known to have been active, overriding probably accounts for many of the smooth moraines. The same is probably true of most of the smooth moraines of the southwestern Catskills (Hobart and Margaretville quadrangles), although the evidence is clear that moraines in this region are more eroded than those in the northeastern Catskills, and therefore away from the stream courses must have lost some of their original roughness.

Hummocky moraines. The hummocky moraine is, perhaps, the type first thought of when moraines are mentioned because it has been so often described in textbooks as the typical moraine.

The results of the study and mapping of the moraines of the Catskills indicate that the hummocky moraine is a specialized form developed either under water or where the end of the glacier, which had become buried under morainic débris and outwash, melted out and allowed the débris to fall down into the hummocky form.

Typical hummocky moraines in the Catskills are almost invariably gravelly and grade insensibly into kames, forming what might be termed kame-moraines (figure 22). Where a moraine was formed on land and away from the influence of strong outwash, it may have the ridge form and be very irregular, but the irregularities are more of the ridge-and-trough than of the hummock-and-hollow type, and the material is stony till rather than gravel or gravelly till.

On the map most of the moraines of the hummocky type are shown as kames because they are more closely related, both in surface form and in composition, to typical kames than to moraines.

Lateral embankments. Lateral moraines continuous for long distances are not common in the Catskills, but short lateral embankments, most of them extending diagonally down the hillsides toward morainic loops in the valleys, are abundant. There are all gradations from moraines that stand out from the hillsides and are tens or hundreds of feet high, to those which can be seen only under favorable conditions of light.

The accompanying profile sketches (figure 2) show the common gradations from sharp ridges in the valleys to indistinct thickenings of the drift high up on the hillsides. The series of profiles as sketched is such as one would find in following almost any one of the well-defined loops diagonally up the hillside until it finally disappears.

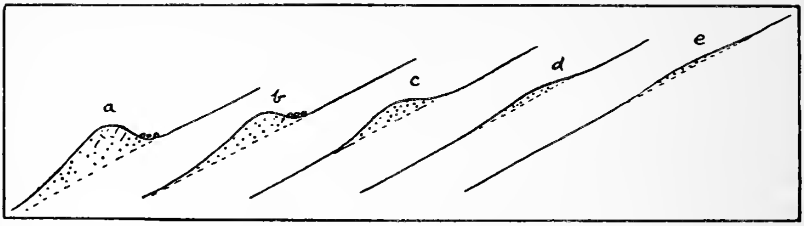

Figure 2 Series of sketch profiles showing how a morainic ridge (a) grades into an embankment (c and d) and then into a mere thickening of the till (e) when followed diagonally up a hillside. Boulders are commonly concentrated between the ridge and the hill as at (b).

As a rule, the morainic embankments show a steep front on the side that was in contact with the ice, although this is not always the case. Whether the steeper slope of the embankment is on the side of the ice contact or on the side toward the hill depends on the relative load of the ice and the position with respect to the end of the loop (figure 3). If the débris load was relatively light and was being carried mainly in or upon the ice, the tendency would be toward deposition at and against the edge of the ice (X, figure 3), so that, as the ice gradually shrunk away from the hillside, a more or less flat-topped embankment would be constructed which, when the ice quickly melted away, would show a steep ice contact. If, however, as shown in *Y*, figure 3, the ice was heavily loaded in its basal part so that deposition was mainly subglacial, an embankment would be built up with the steepest slope toward the hillside.

The best examples of the latter condition are the moraines of some of the local glaciers, which seem to have been greatly overloaded in the basal parts. Good examples are found at 1900 feet

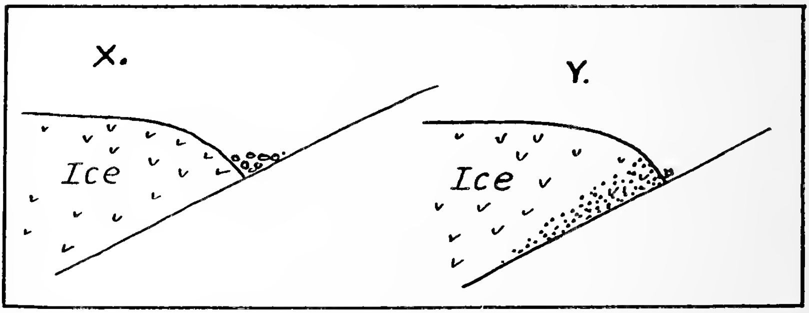

Figure 3 Sketches showing how a morainic embankment might or might not develop a steep, ice-contact slope depending on the nature of the glacial load. Lateral moraine built against relatively clear ice would slump when the ice melted away, leaving a steep slope as at X. If the glacial load were mainly englacial as at Y the steep slope might be toward the hillside.

elevation one and one-quarter miles east-southeast of Jewett Center (Phoenicia quadrangle) and on the northwest slope of Halcott mountain about two and one-half miles above Halcott Center.

Wavy moraines. On hillslopes within the morainic belts, the surface in many places has a gently swelling, wavy form best seen when the sun is low (figure 23). There is every gradation from smooth till to distinct hummocky or ridge moraine, but the most common form is intermediate between the two. Wavy moraine is an accurate descriptive term. It seems to be the form taken by morainic débris in places where the position of the ice was so subject to fluctuations that distinct ridges or embankments were not developed. In places it may be moraine overridden by later ice advances. Evidence of the direction of ice movement is rarely shown.

This type of moraine has been distinguished on the map in only a few places.

Boulder moraines. At many places there are masses of angular and subangular boulders, called boulder moraines or "bear-den" moraines, covering areas ranging upward to several acres (figure 24). From the distribution of these boulder beds it appears that they have been formed in two ways. One has been by the washing action of glacial streams by which the finer materials have been washed away, leaving only the coarser residue of rocks and stones. The other, and more common method of accumulation has been by boulders rolling down the steep frontal slope of the ice and gathering at its base. (Woodworth '96.)

Between morainic loops and the hillsides, as at *b*, figure 2, notable accumulations of boulders are common. The washing action of the streams flowing off the ice and along its edge probably aided in the concentration of the boulders by removing much of the finer material (figure 25).

The boulder moraines described above are entirely different from the talus accumulations found in some of the rougher parts of the mountains.

TILL OR GROUND MORAINE

By far the larger part of the area of the Catskills is covered by till or, as it is sometimes called, ground moraine.

The till is an unassorted mixture of clay, sand, stones and boulders of all shapes and sizes (figure 26). The relative proportions of the constituents depend upon the local conditions and upon the mode of deposition. Where the underlying rocks are mainly shale, the till contains a large proportion of clay. Where sandstones and conglomerates predominate, the till is very stony and locally, as along the headwaters of the West branch of Neversink creek between Winnisook Lodge and Branch, it is composed almost entirely of boulders, most of them rounded by ice or water.

As a rule the Catskill till is very stony, and much of it is unsuited for cultivation for that reason. In the northern and western Catskills the prevalent thin-bedded sandstones (figure 9) yield innumerable thin, flat stones of relatively small size with which the till is heavily charged. In the eastern and southeastern Catskills the massive conglomerates and sandstones which there prevail, yield larger, rounded stones and boulders in such abundance that cultivation is almost impossible even on slopes otherwise favorable. Owing to the prevalence of sandstones and conglomerates in the Catskill rocks, and to the sandy nature of many of the shales, the till is decidedly sandy, and except where mixed with lake clay, always forms a light soil that does not bake.

Sections of the till, except where it is very thin, generally show a more compact portion, the "hardpan," overlain by a less compact portion that grades imperceptibly upward into the surface soil. The line between the hardpan and the looser till above is more or less indefinite but in railway or road cuts its approximate position is often readily recognizable.

It is probable that the compact "hardpan" represents material deposited underneath the ice near its margin, where, owing to its decreasing thickness, the ice was no longer able to carry forward its entire load of débris. The looser material at the top may represent the load of débris that was in or upon the ice at the time of final melting. Being thus let down as the ice melted, it would be compacted only by its own weight, hence its loose texture as compared with the hardpan.

The till ranges in thickness from a mere veneer to several hundred feet. Locally it is absent altogether over small areas. On the passes through the Northeastern escarpment and for distances of a mile or more southwest of them the rock is practically bare. Over the greater part of the upland constituting the old peneplain surface between the Northeastern escarpment and the Central escarpment, the till is thin, ranging on an average probably between six inches and two feet. Here, as also generally over the steeper slopes of the mountains where the till is thin, it is probably composed almost entirely of the englacial material that was present in or upon the ice when it melted.

THICK DRIFT

Accumulations of thick, nonmorainic drift are so prevalent in the mountain valleys that they have been mapped separately, although there is every gradation from till to thick drift, and there is no known difference in mode of origin except that the thick drift was undoubtedly accumulated mainly under the ice and is of the compact, "hardpan" type. It is veneered with the looser till that ordinarily overlies the hardpan.

In mapping, it was not always possible to determine whether a deposit should be classified as till or thick drift. In some places the demarkation between the two is perfectly evident, but in most places there is a complete gradation, and the mapping must represent the best judgment of the geologist. Well records are rarely available to settle the question because the local water supplies come almost exclusively from springs.

As a rule the thick drift has a smooth surface like that of the till, and, except for the alluvium along some of the larger streams, makes the best farming land.

Deposits of thick drift are most commonly found in one or another of the following four situations: in valley bottoms; across the mouths of valleys tributary to a main valley through which there was strong ice movement; in the lee of hill spurs; and in places where the ice sheet had opportunity to spread out after having moved through a pass or narrow valley where its flow was restricted.

Thick drift in valley bottoms. In the Catskills the valley bottoms are generally filled with thick drift, particularly in valleys trending across the direction of ice movement. It is on the lee sides of such valleys (in general on the north sides) that the drift is thickest. The valleys of Town brook and Rose brook (Hobart quadrangle) are good examples. The head of Batavia kill above Big Hollow is also deeply filled with thick drift (figure 27).

Thick drift at mouths of tributary valleys. As strong ice currents moved along some of the principal valleys,—such as the east and west branches of Delaware river, the lower parts of the east and west branches of the Neversink, and the upper Batavia kill between Windham and Red Falls,—they seem to have dragged large quantities of débris along the hillsides and to have deposited it in the lower ends of the tributaries, especially such as enter the main valleys at nearly right angles. The drift thus deposited is thickest on the iceward (north or east) sides of the tributaries and in many instances has pushed them out of their courses to the south or southwest where they tumble into the main valleys through rock gorges and over falls and rapids (figure 28). Numerous waterfalls caused in this way occur along the West branch of the Delaware river between South Kortright and Delhi and along the west side of the East branch of the Delaware river between Hubbell Corners and Margaretville, where almost every stream has a waterfall at its lower end. Falls apparently due to the same cause occur on a tributary of the West branch of the Neversink at Frost Valley (Neversink quadrangle), and at numerous other places.

Some of these tributary valleys, as seen from the opposite hillsides, resemble the "hanging valleys" produced by glacial erosion that have been described by Tarr ('09) for the Ithaca region; but most such valleys in the Catskills are clearly due solely to drift deposits, and it is thought that all of them, except certain valleys tributary to the streams below Grand gorge, Deep notch and Peekamoose gorge, were caused by deposition. The hanging valleys opening into the gorges named above were produced by the rapid erosion accomplished by the swollen glacial streams that once flowed through the gorges.

Thick drift in the lee of hill spurs. When the ice moved in the general direction of a valley system, it very commonly deposited a trail of thick drift in the lee of the spur between two tributaries. The principle governing deposition in such positions is the same as that involved in the deposition across the mouths of tributary valleys as described in the preceding paragraph.

Thick drift formed under spreading ice. Wherever the topography is such that the ice could spread out after having crossed a pass or traversed a narrow part of a valley, its ability to transport its load of débris was decreased and some of the load was deposited beneath the ice. Thick drift formed under such conditions has a smooth profile, rising highest, as a rule, in the middle of the valley. The shape of the deposit and the smoothness of its surface point clearly to subglacial deposition.

Thick drift deposits of this type are numerous. Among them may be mentioned that which fills the valley bottom in the form of a low, smooth ridge heading in the pass between Kaaterskill Junction and East Jewett (Katterskill quadrangle), and a similar deposit near the head of Mad brook north of Windham.

Thick drift of composite type. In many places in the valley bottoms glacial deposits of mixed origin have been mapped as thick drift. Most notable of these are the thick deposits in Schoharie valley around Gilboa. There the material is a complex mixture of till and stratified lake deposits, overlain in most places by till. Borings made by the New York City Board of Water Supply in testing for its proposed tunnel have revealed this drift composed partly of till and partly of lake clay and sand to depths of over 200 feet beneath the present valley bottoms. Since these deposits are mantled by till and have no distinctive surface form, they could be mapped only as thick drift.

In a few places the material mapped as thick drift seems to have been moraine overridden and smoothed by later advances of the ice.

DRUMLINS

A drumlin is a specialized form of thick drift having a regular oval plan, and a symmetrical, half-egg shaped profile. Drumlins are not commonly supposed to occur in mountainous or hilly regions, but they are abundant in the northern Catskills opposite the gaps in the Northeastern escarpment. Other groups lie across the valley of East kill above Beaches Corner and on the plateau west of Ellenville.

The most significant feature of the distribution of the drumlins is that they lie a short distance within (northward from) the belts of strong terminal moraines and persistently occur at points where the ice had opportunity to spread radially after having crossed a pass or emerged from a narrow valley. Thick drift has been described as common in the latter situations. As a matter of fact, there is every gradation from thick drift with no distinctive topographic form, through deposits that are slightly convex upward, to typical drumlins (figure 29). The difference is one of degree only, not one of kind.

As examples of typical drumlins associated with passes, those south of the passes leading southward from Hensonville and Big Hollow may be mentioned. There are numerous drumlins north and northeast of Windham (figure 30), in Patchin hollow, and near Mackey north of Gilboa.

The distribution of drumlins in the Catskills is like that observed by Penck and Brückner ('09) in that the drumlins occur a short distance within the belt of terminal moraines where the débris load became so great in comparison with the carrying power of the ice that some of it had to be deposited upon the ground beneath, probably by a plastering-on process as suggested by Russell ('97).

Ability to carry the débris load would naturally be less in places where the ice spread out after emerging from a narrow pass, hence the prevalence of drumlins and thick drift in such situations.

None of the Catskill drumlins shows evidence of having been formed by the carving out of preexisting glacial deposits. Although, as urged by several writers (Tarr '94; Upham '92), some drumlins may have had such an origin, that explanation does not fit the facts in the Catskills.

An instructive variation of the drumlin type of glacial deposit is found in the valley of East kill near Beaches Corner. There ice crossing that valley from the passes south of Hensonville and Big Hollow toward that north of Hunter left a series of washboard-like ridges across the valley parallel to the direction of ice movement. These differ from drumlins only in that the blunter stoss end and the trailing lee end are here replaced by the two sides of the valley, and consequently the typical drumlin form is not completely developed.

DRIFT PEDESTALS

A type of thick drift which, so far as the writer has been able to learn, has not been noted previously except in Greenland, is one which, following Chamberlin, will be called the drift pedestal or *pedestal.*

Most of the drift pedestals are situated either in short steep mountain valleys, generally near their lower ends, or on hill slopes opposite passes through which the ice pushed a small inactive tongue ending within a short distance from the pass, as, for example, immediately north of the gap at Meads (Kaaterskill quadrangle).

The typical pedestal (figures 33, 53, 54, 55) lies in or near the mouth of a steep mountain valley. As seen from below, it presents a steep front, which may be as much as 100 to 150 feet high, and gives the impression of being a morainic bar across the valley. The front is generally convex down-valley, and the center is generally, although not always, higher than the sides.

On ascending the steep front of a pedestal one is likely to be surprised to find, not a hollow behind a morainic bar, as appears from below, but a smooth surface of thick drift sloping gently up the valley with no signs of moraines or any hollow behind the steep frontal slope.

The inclination of the top or "tread" of a pedestal varies with conditions. Some are nearly flat, while some of the smaller ones are nearly as steep as the fronts.

That the pedestals are composed of drift rather than of rock is proved by the fact that the mountain streams commonly flow through them in deep gorges cut in drift. In many instances the convex top of the pedestal has turned the stream over against the valley side, where it is cutting a gorge, of which one side and the bottom are rock and the other side is the drift of the pedestal. A good example of this condition is found on the east side of the pedestal immediately north of West Kill mountain (Phoenicia quadrangle).

Some of the longer valleys in the higher mountains contain several pedestals. In ascending such a valley one climbs the steep front of a pedestal, emerges upon a relatively flat or gently rising tread, climbs another front to another tread and so on to the upper end of the valley. The upper valley of Alder creek in the southern half of the Margaretville quadrangle furnishes the best example of a series of pedestals in a single valley.

These pedestal steps in the valley bottoms are similar in form to the rock steps in the bottoms of strongly glaciated mountain valleys.

A significant modification of the typical pedestal was noted at the heads of the valleys of Alder creek and Beecher brook (figure 4). Here the plan of the front slope of the pedestal, instead of being

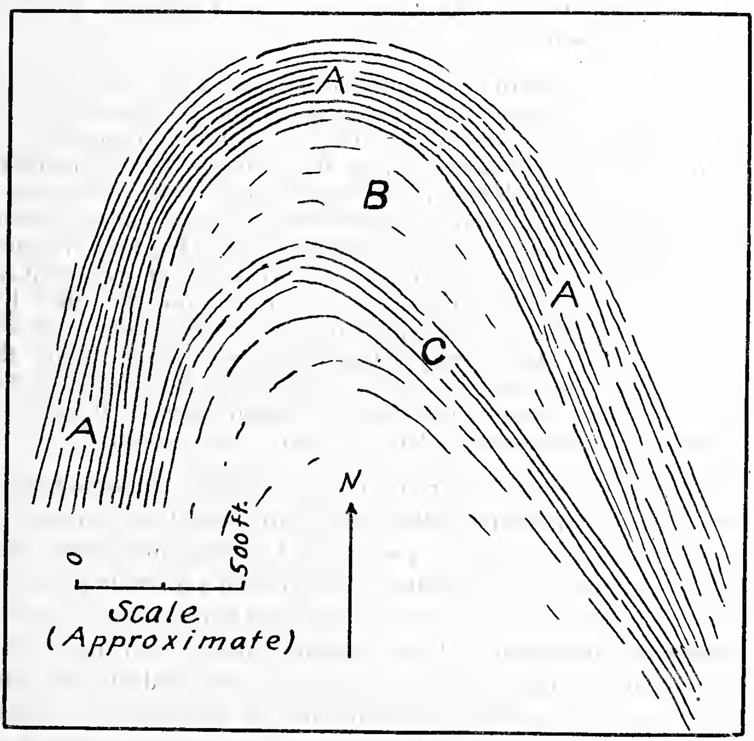

Figure 4 Contour sketch showing horseshoe-shaped pedestal at head of Beecher brook. A: Steep cirque(?) wall at head of valley; B: Gently sloping horseshoe-shaped pedestal; C: Steep, rocky front of pedestal.

convex down-valley, is concave and the tread of the pedestal is horseshoe-shaped. In fact, it has exactly the form taken by the small "horseshoe" glaciers that now represent the last phase of glaciation in some of our western mountains, notably in Glacier National park.

A feature commonly associated with the drift pedestals is a mass of boulders of all sizes that forms a fringe around the outer edge and at the foot of the pedestal (figure 33). The position of these boulders suggests that they have rolled off the front of a glacier which once stood upon the pedestal, and it is thought that such was their origin.

One of the best examples of a pedestal with a marginal fringe of boulders is found at an elevation of 2260 feet at the head of Elk creek, about two and one-half miles east-northeast of Halcott Center (Phoenicia quadrangle).

Topographic forms very similar to the pedestals of the Catskills were found in Greenland by Chamberlin and Salisbury. Referring to them Chamberlin ('95, p. 66–67) says:

There appears here an interesting phenomenon which was frequently noted farther northward—the construction of a causeway by the glacier through the accumulation of its own débris beneath it. In their upper parts the glaciers appear to fit snugly in their respective valleys, and they doubtless have carried along with themselves all débris that may have been loosened beneath them; but on reaching the lower gradients near the sea level much of this has been deposited, so that they are now creeping out on embankments of their own construction. It is perhaps not necessary to suppose that they have built these up actually beneath themselves, as they may have constructed them by successive terminal deposits. When shorter than they now are, they may have thrown down their material at their front edges, and subsequently have advanced upon it, building out the terminal accumulation in front as they slowly advanced.

The same features, referred to as "morainic embankments or 'pedestals' as Chamberlin called them" are also described and pictured by Salisbury ('96). Two typical photographs from Salisbury's paper are here reproduced for comparison with the photographs of similar features in the Catskills (figures 31 and 32).

Origin of pedestals. Most, although not all, of the Catskill pedestals appear to have been formed by small, local glaciers, probably because the conditions necessary for the formation of pedestals were characteristic of the majority of the local glaciers, although not confined to them.

Whether a given glacier built a pedestal or an ordinary moraine seems to have depended upon the nature of its movement and upon the load that it was carrying.

The following characteristics of pedestals indicate that they were formed by the deposition of till beneath the end of a glacier where movement was not vigorous and where the ice was unable to move all the débris contained in its basal part: They are composed of till of the typical thick drift type; where well-developed they tend to take the form of drumlins, being higher in the center than at the sides of the valleys; they are common at the lower ends of mountain valleys where the ice spread out in the form of a bulb, giving conditions favorable for the dropping of the subglacial load; and, finally, they are symmetrically related to the valleys in which they lie, showing that they were deposited by glaciers occupying those valleys and flowing down them, either as tongues from the continental ice sheet or as local glaciers.

The possibility that the pedestals are morainic embankments built into the mountain valleys by the continental glacier has been considered, but such an explanation has been rejected. Some deposits resembling pedestals can be thus explained but the majority can not, for the following reasons: Many of the typical pedestals are convex down-valley against the direction of movement of the continental glacier; pedestals rarely have hollows behind them as would be a common condition if they were lateral embankments built by the continental glacier; the pedestals are symmetrical with respect to the valleys in which they occur; and many of them bear small but perfectly distinct moraines of local glaciers superimposed upon the pedestals, and there is every gradation between moraines of local glaciers where the moraine is conspicuous and the pedestal feature subordinate, through those where the pedestal form is predominant and the moraine, although distinct, is subordinate, to those where only the pedestal is recognizable.

In figure 34 is shown a profile of a small but perfect pedestal on the top of which are small moraine loops clearly produced by a local glacier. Figure 35 is a view along the top of the pedestal showing a small crescentic pond held in by one of these moraine loops. The valley in which these photos were taken faces northward and the loops are convex northward, proving conclusively that the deposit is not a product of the continental glacier.

The reason the local glaciers were prone to build pedestal instead of loop moraines is believed to have been that they were relatively inactive and were heavily loaded with till previously deposited in the mountain valleys by the continental glacier.

Drift steps in the valley bottoms, although they may not have the typical pedestal form, are believed to have been produced by the same process.

Forms similar to many of the pedestals might have been produced by the overriding of the moraines of local glaciers by later advances of the same glaciers, or even by the continental glacier. It is quite possible that some pedestals originated in that way.

GLACIAL DEPOSITS—ASSORTED DRIFT

INTRODUCTION

Owing to the presence of large volumes of water round the edges of the glaciers, either as streams derived from the melting ice or as lakes caused by the glacial blocking of stream valleys, there was abundant opportunity for water-sorting of the glacial débris. As a result of such sorting, a variety of types of stratified drift was formed, some of them under the ice, some around its edges and some in bordering lakes. Such deposits range in texture all the way from the coarsest outwash gravels to the finest lake clays.

Of the varieties of assorted drift that have been recognized and distinguished on the map, the following are the most important: outwash plains and valley trains; deltas; kames; eskers; and lake clays.

OUTWASH PLAINS AND VALLEY TRAINS

Streams that flow from beneath existing glaciers are heavily loaded as a rule with coarse gravel, much of which is deposited within a short distance, owing to the decrease in velocity of the streams as they emerge from the confines of the ice tunnels in which they have been flowing. Deposition takes place mainly in the stream beds, building them up and forcing the streams to spread out in braided fashion into numerous channels, and to shift their courses continually. By this process deposits of gravel are built up which, if not confined, spread out in fan form making *outwash plains,* or, if held to narrow width by valley walls, making what are known as *valley trains.*

The composition of a valley train depends upon the size and swiftness of the stream that formed it, and ranges from coarse rounded boulders to sand. It is coarsest at the point where the stream emerged from the glacier.

In the Catskills numerous valley trains of gravel and boulders testify to the former presence of powerful glacial streams. In general, valley trains are most conspicuous around the outer margins of the principal morainic belts, where the ice stood for long periods discharging enormous quantities of water heavily burdened with gravel.

Valley trains are useful aids in deciphering the glacial history of a region because they show the direction of ice movement and indicate that the ice ended on land instead of in the waters of a glacial lake.

Only a few of the larger areas of glacial outwash are described below. Many others are mentioned in the chapters of local descriptions.

The glacial stream which flowed southward from the terminal moraine at Summitville (Ellenville quadrangle) carried an enormous amount of gravel and built a valley train that extended for many miles down the valley of Basher kill. This valley train was reworked and in part cut away by the waters of the Summitville Lake outlet stream that followed the same course, but its former presence and great size are evident.

A number of areas along the east front of the Catskills south of High Point are covered by coarse outwash gravels. Along the East branch of the Delaware river between Hubbell Corners and Roxbury, and for many miles below Margaretville, terrace remnants of outwash gravel are conspicuous. Along the West branch of the Delaware river, outwash valley trains are found between Hobart and a point about three miles above Bloomville; for a few miles below Bloomville; and near East Delhi. The distribution of the outwash in the Delaware valley is typical in that it lies between prominent moraine loops that cross the valley. Below each of these loops the outwash train extends for several miles down stream to the next moraine.

In some places, as in the lower end of Hobart village, the upper end of an outwash plain is pitted by small depressions that could not have been present when the plain was forming without becoming filled with gravel. The general explanation for such "pitted plains," which is here accepted, is that they were formed by the melting out of blocks of ice that had become buried under the outwash deposits.

The outwash was not always spread out at the end of a glacial tongue. In many instances outwash deposits were built up along the margin of an ice tongue in the depression between it and the valley side, especially where small tributary valleys or reentrants in the hillsides created small embayments.

When the ice which supported one side of such deposits melted away, that side slumped down, leaving the remainder as a marginal outwash terrace extending along the hillside (figure 36). The tops of such terraces generally slope gently downward in the direction of ice movement, but those built into small lakes bordering the glacier are practically level. Marginal terraces, as a rule, are small and of irregular distribution, corresponding to the varying local conditions under which they were formed.

On the map, outwash valley trains and high-level river terraces have been given the same symbol. The river terraces are confined to the larger stream valleys and any outwash deposits shown on the map which are not along such streams are true glacial outwash. Along the larger streams it was sometimes difficult to determine whether a deposit was terrace or true outwash. The shortcomings of the map in not differentiating between terraces and outwash will be overcome in part by the local descriptions where the origin of the various deposits is discussed.

DELTAS

Wherever a stream discharges into a body of standing water, the checking of its velocity causes all but the finest of its sediment load to be deposited in the form of a delta. Typical deltas have flat tops at or just below water level, and steep fronts where the material carried forward across the flat delta top by the stream is dropped and slides down into deeper water. The materials of which deltas are composed are sand, gravel and clay, of varying texture in different parts and in different deltas, depending upon the nature of the material supplied by the streams.

Sand and fine gravel are the commonest materials in the glacial deltas of the Catskills. The steeply-dipping "foreset" beds, which were deposited on the delta fronts as they were built outward, are generally sand. Beyond them, in deeper water, fine clay was deposited and later buried as the delta was built outward. The top of a delta is commonly gravel spread by the stream as it flowed across the delta to the front.

If a delta is built into a water body which subsequently disappears, the delta remains as mute evidence of the former presence of the water body, and its flat top is an accurate register of the former water level (figure 37).

Deltas are by far the most important aids in deciphering the glacial history in regions like the Catskills where, on account of the complex topography, many glacial lakes were held in the mountain valleys by the shifting ice barriers. Every ice-born stream entering one of these lakes built a delta. Owing to the fluctuations of the lake levels, there were enough distinct water levels to make it possible to establish the contemporaneity of the positions of the ice front in widely separated places.

It is of course desirable, but in some instances difficult, to distinguish between deltas built into open water and flat-topped deposits of gravel that were formed as marginal terraces in small embayments along the ice margin, but in most instances a study of the surroundings and of the shape of the deposit reveals the true relations. The lobate front and the increasing fineness of material toward the front, which are characteristic of deltas, are not found in marginal terraces.

As the study of the Catskills progressed, it became more and more evident that the larger deltas had all been fed by outwash streams, heavily loaded with sand and gravel, which emerged from the glacier not far distant. Under such circumstances large deltas were built up very quickly. That such was the case is indicated by the fact that in a given water body, deltas built by streams from the ice are large, while those built by streams not supplied by the glacier are so small that they are difficult to find.

A somewhat puzzling phenomenon displayed by many of the deltas is a hollow or a series of pits in the delta surface on the side from which the delta-building stream came (figure 38). These are so situated that had they been present while the delta was being built they must necessarily have been filled.

The most reasonable explanation of these pits is that the delta began to form round the end of an ice tongue extending into the lake and that part of the ice became buried under the gravels. Later, as the glacier receded, gravel was carried across the buried ice and built out into the main body of the delta. At some time after the glacier had ceased to supply outwash to the delta, the ice melted out and the gravel slumped, forming pits.

Deltas that are pitted in this way or have a hollow on the upstream side may be found at Windham, at Ashland, at East Ashland, at the upper end of the big delta of Platter kill north of Gilboa, and elsewhere. The condition is common.

In the chapters of local descriptions some of the most interesting deltas are more fully described. The finest display of hanging deltas of different sizes and at various levels is in the valley of Keyser kill north of Broome Center (Gilboa quadrangle), where ten distinct deltas are visible in a single view.

KAMES

Kames are masses of gravel and sand having the form either of isolated cone-shaped mounds or of irregular mounds and hollows. They are distinguished from moraines by their gravelly composition and "knob and kettle" topography; from deltas by their lack of flat tops; and from eskers, which are long, narrow, winding ridges and are composed of the same materials, they are distinguished by their form.

Lone kames. The isolated cones, or lone kames, are striking in their symmetry of form and in their common lack of association with other glacial deposits (figure 39). A symmetrical cone shape is common, and they range in size from small mounds only 10 or 15 feet high and a few yards across, to masses over 100 feet high and several acres in extent.

Where the internal structure is revealed, they are found to be made up of irregularly stratified gravel and sand. Many of the smaller kames are veneered by a thin layer of till, which is believed to indicate that they were formed beneath the ice (see p. 41).

The distribution of lone kames seems erratic. Although generally associated with moraines, they not uncommonly stand alone, without association with any other glacial deposits except till. Where associated with moraines, they are likely to be on the inner sides of the morainic loops. Where alone, they are likely to be at or near the junction of two valleys which extend in the direction of ice movement.

A count of the lone kames mapped showed that of the total of 53, 26 were associated with morainic loops, eight were at valley junctions, and 19 were in various other situations, mostly in the bottoms of the larger valleys.

The explanation of lone kames that seems best to meet the facts of composition and distribution is the one commonly accepted, namely, that they were formed in vertical caverns within the glacier hollowed out by streams falling from the surface to the bottom. Such caverns are being formed by the "moulins" of modern glaciers.

On existing glaciers it is common for moulins and small lakes to form in the hollow between two streams of ice which join from valleys trending in the direction of movement. If these were to become filled with gravel and the ice were then to melt away without much movement, kames would be formed in just such situations as many of those noted in the Catskills.

If lone kames are formed by the filling of hollows on the surface of the ice or the filling of subglacial caverns made by moulins, their preservation would seem to require that the ice be practically stagnant and melt away with little or no movement. This requirement probably explains why lone kames are not more common. It may also explain why they occur so commonly on the inner sides of morainic loops, the connection being that after a forward movement and the building of a morainic loop there seems to be a tendency for a glacier tongue to become stagnant—a condition favorable to the preservation of any kames which may have formed in or on it.

The veneer of till which was found on many of the lone kames (figure 40) is believed to indicate that they were formed in subglacial caverns, the till being the débris which was in the ice above them and was let down upon them as the ice melted.

Marginal kames. Marginal kames are hummocky deposits of sand and gravel generally found along the hillsides in such situations that it is clear that they were formed by the accumulation of sand and gravel between the ice tongue and the hill. In origin, they are closely related to outwash gravel terraces, of which they are not uncommonly found to be parts. Their mode of formation is quite different from that of lone kames and it is only because of the general use of the word "kame" for all kinds of hummocky "knob and kettle" glacial deposits that these and the "kame-moraines" are classed as kames.

The mode of formation of marginal kames seems to have been that, in favorable places along the ice margin, depressions became filled with sand and gravel, which, as the filling proceeded, encroached upon and buried more or less of the ice. In some instances the entire gravel accumulation may have been in depressions on the surface of the ice. When the ice melted, these gravels were dropped down to form the characteristic knobs and kettles.

Areas of marginal kames are numerous. Among the most conspicuous may be mentioned the north side of the Beaver Kill valley west of Lake Hill (Kaaterskill quadrangle); the north side of the Rondout valley between Eureka and Montela (Slide Mountain quadrangle); the eastern base of the Catskill scarp between Sampsonville and Wawarsing (Slide Mountain quadrangle); the hillslope north of Kaaterskill Junction (Kaaterskill quadrangle); and the East branch of the Delaware river between Margaretville and Arena.

The gradation from a typical outwash terrace to marginal kames is illustrated on the north side of the latter valley about two and one-half miles east of Arena, where, along the base of the hill, a typical outwash terrace of coarse gravel 50 to 200 feet wide and sloping down stream at about 20 feet to a mile, breaks off on its valleyward side into a large mass of hummocky kames clearly due to the melting out of buried ice.

Kame-moraines. Along many of the larger stream valleys where the ice ended in lakes or in open valleys where much water and outwash gravel were produced by the melting ice, the terminal deposits formed at the ends of the ice tongues are not typical morainic loops but are irregular masses composed largely of stratified sand and gravel, commonly having a "knob and kettle" topography and being in every way more closely related to kames than to typical moraines. Such deposits are here called kame-moraines.

Kame-moraines have different forms depending on the conditions under which they were deposited. Where an ice tongue ending in a lake halted and built a moraine, that moraine generally took the form of hummocky kame-moraine (figure 41), but it is more subdued in form than that produced by the melting out of buried ice. At other places where the ice ended in water, large, irregular masses of sand and gravel appear to have been formed below water level where subglacial streams discharged into the lake (figure 42). Kame-moraines apparently formed in this way show all gradations from lone kames to considerable masses of "knob and kettle" kame-moraine. Examples may be seen about two miles above the mouth of Elk creek (Delhi quadrangle); at the mouth of Rose brook (Hobart quadrangle); and at numerous places in the valleys of Manor kill and Batavia kill below the level of Grand Gorge lake (1600 feet).

The large mass of kame-moraine at the mouth of Rose brook appears to have been formed where a subglacial stream discharged into a lake formed by the ponding of the Rose Brook valley. In this instance an esker (p. 43) formed by the deposition of gravel in the subglacial stream tunnel, leads up to the kames.

In open valleys where glacial outwash was plentiful and valley trains were being built, distinct ridgelike moraine loops may in many instances be traced down the valley sides to near the bottom where they change into hummocky kame-moraines. Such conditions are noticeable along the West branch of the Delaware river between Stamford and Delhi (figure 22); along the East branch of the Delaware river, especially for a few miles below Roxbury; and on Little Beaver kill above and below Yankeetown (Kaaterskill quadrangle).

Kame-moraines in open valleys like those mentioned above, probably were formed by the melting out of buried ice from beneath stratified deposits of sand and gravel laid down either as outwash or as fillings of local depressions in a morainic complex.

The "interior flats" described by Tarr and Martin ('14) around many of the Alaskan glaciers present conditions favorable for the deposition of stratified materials over buried ice. Similar conditions around the ends of the Catskill ice tongues are believed to have led to the formation of many of the kame-moraines, especially of large masses like those below Stamford and east of Broome Center, which lie close inside large morainic loops.

It was noted in the field without any adequate explanation presenting itself at the time, that a great many of these kame-moraines, where opened, reveal coarse gravel of outwash type resting on fine cross-bedded sand and gravel as in figure 43. If these kames were formed as described above, the coarse gravel at the top represents the outwash gravel spread out over the surface of the "interior flats" after the depressions had become filled and before the buried ice melted out.

Large masses of hummocky kame-moraine are quite common immediately on the iceward side of large morainic loops, where they are believed to have been produced by the burial of a portion of the ice by gravel shortly after the formation of the loops. Good examples are to be seen about a mile below Stamford and also on the plateau about two and a half miles east of Broome Center.

ESKERS

Eskers are winding ridges of gravel and sand that mark the course of stream tunnels beneath or within the glacier which became wholly or partly filled with sand and gravel before the ice melted away. They are not very common in the Catskills, but several good specimens were observed.

The largest esker, and one of the most interesting on account of its extremely winding form, lies about a quarter of a mile south of the village of West Conesville (Gilboa quadrangle) (figures 44 and 45). This esker has not been opened, but the surface is composed of moderately coarse gravel. It is smallest at the west end and increases in size toward the east where it joins a large mass of gravelly drift, possibly a delta, half a mile southeast of West Conesville, which is believed to have been built up in standing water by débris discharged by the esker stream. The esker is about 100 feet high in the highest part. Another large esker is found not far away in the Schoharie valley on the west side of Mount Royal. It lies on a steep hillside and is not so nearly perfect as that at West Conesville, but is very large. It is not continuous for the whole distance through which it can be traced, but is broken into a number of kamelike knobs. It leads eastward into a mass of kames which occupy a reentrant in the valley on the south side of Mount Royal (figure 46).

Another esker, which is treaceable for more than a mile, lies in the valley of the East branch of the Delaware river about two and one-half miles below Roxbury (figure 47). It is situated in the midst of a group of kames with which it is closely associated. Its presence and preservation here indicate that the ice was stagnant at the time of final melting, because the esker would have been destroyed by any considerable movement of the ice after it was formed.

LAKE CLAYS

The lake clays were formed from the fine glacial "rock flour" which was carried into the lakes in large quantities by the streams issuing from beneath the ice. The clay seems to have been deposited surprisingly near the mouths of the streams by which it was emptied into the lakes. In many places there are deposits up to 100 feet thick of pure, stratified lake clay. Most of it is red, corresponding to the color of the Catskill rocks, but some in the neighborhood of Gilboa is blue (figure 48).

No attempt has been made to show on the map all the areas where the surface is covered with lake clay, but in a few places, mainly in the Schoharie valley around Gilboa and Prattsville, the clays are so conspicuous that the principal deposits have been shown.

The largest single mass of the clay exposed at the surface is that known as "Clay hill" about one and one-half miles below Prattsville (figure 11, in middle distance and to left). Here the clay forms a mantle with thickness ranging up to more than 30 feet, and possibly much more, overlying a mass of moraine and stratified sand and gravel. The clay is finely laminated and very pure. Its color is red, indicating derivation from glacial waters carrying débris mainly from the local rocks. Another large mass of lake clay lies on the hill three-quarters of a mile west of Gilboa, and a third covers a square mile or more in the Schoharie valley south of Mine kill (figure 49). Much of what is mapped as thick drift in the valley between Manor kill Falls and Manor kill is lake clay, but some of it is covered by a thin veneer of till.

Borings made by the New York City Board of Water Supply have revealed the fact that in the valley of Schoharie creek and its tributaries between Prattsville and Deep Notch thick deposits of lake clay are concealed by a veneer of a few feet of till.

The valley of Esopus creek between Shandaken and the Ashokan Reservoir also has thick deposits of lake clay, over most of which is a veneer of till. These are shown on the map as "thick drift" because the till veneer made separation impracticable.

Much lake clay is associated with the deltas in the valley of Rondout creek between Napanoch and Kerhonkson.

Where thick deposits of clay or thick drift containing much clay are undercut by streams they exhibit a strong tendency to slump. The landslide topography so produced is readily recognized by the presence of a semicircular scar at the top and a confused mass of irregular mounds at the bottom. Close observation is, however, sometimes necessary to distinguish such landslide topography from moraine.

LOCAL DESCRIPTIONS—NEVERSINK AND DELAWARE DRAINAGE

In this and following chapters such local details are assembled from the field notes as have a bearing on glacial history, but are not readily apparent from a study of the map alone. The distribution of moraines and other features which can be noted readily by inspection of the map are mentioned only incidentally.

The arrangement of the local descriptions is based upon stream drainage and topography because the principal drainage basins are convenient geographical units for description and also because, on account of the influence of topography on the movements of the ice, they are natural units of glacial action.

The general order of the descriptions follows that of the retreat of the ice across the region from the south and west toward the north and east.

EAST BRANCH, NEVERSINK CREEK (NEVERSINK AND SLIDE MOUNTAIN QUADRANGLES)

The valley of the East branch of Neversink creek was examined only in a reconnaissance way from its junction with the West branch below Claryville to its head east of Slide mountain.

The moraine pattern in the valley bottom indicates that ice moved down the valley for its entire length above Claryville. At the time of maximum glaciation, however, the ice probably moved nearly southward diagonally across the valley, as is indicated by striae on the pass at Red hill.

In the lower end of the valley, between Claryville and Ladleton, not much moraine is found and the drift appears older than in the northern Catskills. For instance, south of Claryville, along the lower part of the hill slope, an indistinct terrace of red shale is submaturely dissected by gullying streams. The dissection must be postglacial because the terrace is smoothly veneered with drift, but it seems to be more advanced than would have been possible had the region not been exposed for a much longer time than that since glaciation in the northern Catskills, where the glacial evidences are very fresh and where little postglacial erosion has been accomplished. Farther upstream, about one and one-half miles below Ladleton, a mass of thick drift on the south side of the valley shows similar submature dissection. A conspicuous terrace in this part of the valley at an elevation of about 1850 feet proves to be rock with a veneer of till.

Another feature which is believed to indicate comparative antiquity of the glaciation in this part of the valley is that the postglacial flood-plains of the streams are very wide and the alluvial fans built upon them by the short steep tributary streams are exceptionally large. This is particularly noticeable in the main valley of the Neversink about two miles below Claryville.

This condition is in every way similar to that found by Tarr ('09) in the southern part of the Watkins Glen-Catatonk region south of the belt of "valley-head" moraines, where the floodplains are wide, and where large alluvial fans have been built upon them by the tributary streams.

At Ladleton, and for about two miles above, the valley is choked with massive moraine deposited by ice moving down the valley. Farther upstream the valley bottom is filled with smooth thick drift, some of it possibly morainic, to a point above the mouth of Tray Mill brook where a massive moraine loop swings down from the northern hillside partly across the valley. The moraine is bordered below by a wide gravel plain, probably partly outwash. Above the moraine, smooth thick drift fills the valley bottom for a distance of three-quarters of a mile. On the spur above the junction of Deer Shanty brook a distinct morainic loop was found and another smaller one about one and one-half miles farther up. From Deer Shanty brook to the bend south of Slide mountain the stream has a wide floodplain. The valley sides and the bottoms of the tributary valleys are plastered with thick drift.

Near the head of the valley a large and very distinct loop of ridge-moraine swings out from the east side. Above this for some distance is indefinite moraine and beyond that is thick drift grading upstream into a mass of rounded boulders which, in the form of a pedestal, fills the entire upper end of the valley to the divide between Slide and Cornell mountains.

WEST BRANCH, NEVERSINK CREEK (NEVERSINK, SLIDE MOUNTAIN AND PHOENICIA QUADRANGLES)

For the first three miles above its junction with the East branch, the West branch of Neversink creek is flowing in a deep, narrow valley in which there was little opportunity for the accumulation of glacial débris. In that section of the valley from the mouth of Fall brook to the mouth of Biscuit creek, the bottom of the valley contains a moderate amount of thick drift, some of it weakly morainic in appearance. A large accumulation of smooth, thick drift has turned High Fall brook to the southwest side of its valley, where it is cutting a rock gorge.

The section of the valley from Fall brook to Biscuit creek has a wide floodplain bordered here and there by low stream or outwash terraces. Large alluvial fans are found at the mouths of tributary streams.

Beginning at a point about a mile below Branch, and extending upstream for more than a mile, is a massive, fresh-appearing moraine with distinct loops convex down the valley. Half a mile below Branch the moraine has so choked the valley that the stream has been forced over against the rock on the south side, where it is beginning to cut a rock gorge. For most of the distance through the moraine the stream has been unable to do more than clear a narrow passage for itself. This condition indicates that the moraine at Branch is very recent. It is in striking contrast with the wide floodplain below the moraine; with the submature dissection of the drift near Claryville; and with the large alluvial fans already described. The fact that the stream is being forced to cut a rock gorge through the moraine at Branch might explain the appearance of recency were it not that the cutting of the rock gorge is only beginning, and the downcutting by the stream can not have been long delayed from that cause.

On the basis of the facts stated above, it is believed that the moraines at Branch and Ladleton mark the limits of the more recent glaciation and are much younger than the drift farther down the valleys.

For two miles above the moraine at Branch the stream has a wide floodplain which appears to have been built partly as a result of the choking of the stream by the moraine. On the north side of the valley the floodplain is bordered by deposits of thick drift of subdued morainic form composed mainly of large, partly rounded boulders. At the head of the valley, at Winnisook Lodge, several small distinct morainic loops were formed by a small tongue of ice which pushed into the pass from the north.

Examination of the valley of Biscuit creek was not completed. Large morainic loops were found on the east side of the valley, but their origin was not determined.

Evidences that glaciers of the latest epoch failed to override Slide mountain. On an ascent of Slide mountain from the west side in 1916 it was noted that distinct signs of glaciation were lacking above about 3900 feet and that above that elevation large numbers of rounded boulders of the local arkosic sandstone and conglomerate showed signs of considerable weathering, being crumbly and stained by iron. The soil on the top was found to be a sandy gravel derived from the disintegration of the arkose conglomerate of which the mountain top is composed.

In the spring of 1919 another ascent was made from the east side and the following observations, quoted from the field notes, were made before it was recalled that similar features had been noted on the other side three years before: "Above 3900 feet noted *marked* change in soil. Numerous fresh boulders characteristic below were replaced by weathered slope with less prominent ledges and with a gravelly soil composed largely of quartz pebbles weathered from the conglomerate. The latter is disintegrating and is stained yellowish."

In view of the fact that glacial boulders of the same conglomerate which have been exposed at the surface of the drift in the neighboring valleys ever since the ice retreated show no marked signs of weathering, the belief seems justified that the ice of the latest glacial epoch failed to override Slide mountain, and that the mountain stood out as a nunatak about 300 feet above the ice sheet.

Since the above paragraphs were written, Chadwick ('28) has reported that recent excavations for the foundation of an observation tower on the extreme summit of Slide mountain, 4205 feet above tide, revealed distinct glacial striae, proving that at some stage the glacier completely submerged the highest peak of the Catskills. On the basis of the evidence presented in the preceding paragraphs, however, together with that of the more ancient appearance of the drift to the southwest, near Claryville, the writer is inclined to believe that these striae are the marks of a pre-Wisconsin or, at most, an Early Wisconsin glacier and not of the more recent glaciation which is recorded in most parts of the Catskills.

BEAVER KILL (MARGARETVILLE QUADRANGLE)

The mapping of the Beaver Kill valley was of a semidetailed nature only, particular attention having been centered on the evidences for or against possible local glaciation in the higher valleys.

The striae noted in the southwestern part of the Margaretville quadrangle reveal the fact that, except at the latest stages, the ice moved across the region in a direction about 35 degrees west of south, which corresponds closely with that of the general ice movement in the southwestern Catskills.

The most noticeable characteristic of the glacial deposits in the area drained by Beaver kill is the predominance of the smooth, thick-drift type. Most of the drift has the appearance of having been deposited beneath the ice by being plastered into the valley bottoms while the ice sheet was moving across the region and ending far to the southwest. Some of the drift may be due to the overriding of earlier moraines. Most of the moraines are of the smooth type, although a few sharp ridge-moraines of small size were found.

The almost complete absence of foreign material in the drift is remarkable. Not a single fragment of rock other than that native to the Catskills was noted in the valleys or tributaries of Beaver kill or of Mill brook.

At Little pond and in the valley two miles north of it, the latest ice movement was from the northwest, as is shown by the position of the moraines. A short distance above Little pond a typical pedestal, convex down valley and higher in the middle, seems to have been formed in the ordinary way by an ice tongue pushing southward through the pass west of Touchmenot mountain. This is a good example of a pedestal formed by the continental glacier under the same general conditions of deposition which produced pedestals under many of the local glaciers.

Big pond is held in by a smooth moraine, convex upstream, which seems to tie onto the hill to the southeast as if built by a glacier moving down Beaver kill. Smooth thick drift of drumlinlike form in the valley above the pond seems to have been deposited by ice moving southward.

Between the mouth of the Big Pond stream and Turnwood, the valley is partly choked with thick drift, but faint morainic loops show that the latest ice moved down the valley. In the lower end of the valley of Alder creek morainic terraces indicate that the ice pushed up the valley from the south for a mile or more. Farther up Beaver kill, all the evidence points to the latest ice movement having been southwestward down the valley.

It appears from the distribution of the moraines above described that the region between Little pond and Big pond was the meeting place of ice moving southeastward out of the valley of the East branch of the Delaware river with ice from the east which came down the valley of Beaver kill. This indicates, as should be expected, that the high Catskills exerted a considerable retarding influence on the ice movement, permitting ice from the Delaware valley to push up into the lower end of the Beaver Kill valley.

At Alder lake is a large smooth moraine convex southwestward (figure 50). A swamp behind it was dammed to make the present lake. Above the lake, all the way to the head of the valley, is a series of thick drift steps in the valley bottom. Some of them have distinct pedestal form. At the valley head is a horseshoe-shaped step already described in connection with the discussion of pedestals (p. 33).

Whether the Alder Lake moraine and the steps in the valley above it were produced by a local glacier or by a tongue from the continental glacier pushing over the pass at the head of the valley, seems impossible to determine with certainty, but the following features point toward a local origin: (1) the distinct cirque forms at the head of the valley; (2) the topography of the mountains at the head of the valley which offers no low pass through which a long tongue of ice might be expected to have been pushed; (3) ice from the continental glacier would have been more likely to have pushed into the valley over the low pass at Cross mountain than over the high divide at the head of the Alder Creek valley.

In the valley of Beaver kill between Turnwood and Hardenburg is much smooth thick drift. About a mile below Hardenburg a large mass of this drift has forced the stream out of its course and caused it to cut a gorge in the rocks on the south side of the valley. Half a mile farther upstream a bar of thick drift deposited by ice moving down the valley has blocked the mouth of a tributary stream entering from the north.

Between Hardenburg and the mouth of Beecher brook is much moraine having a fresh appearance and distinct ridge form. On the spur east of the mouth of Beecher brook, distinct moraine loops show movement down the valley of Beaver kill.

In the valley of Beecher brook, about a mile above its mouth, is a large mass of thick drift whose origin is not clear. It may be a terminal moraine built by a local glacier descending the valley, or it may possibly have been deposited beneath the continental glacier. A yellowish, weathered appearance of the till was noted. On the northwest side of this thick drift mass is an outwash plain leading up to the moraine that holds in the lake. North of the outwash plain are several ridge-moraines descending toward the southwest. Beecher lake is held in by a moraine of the smooth type which, however, swings away from the hill on the west as a distinct ridge.

In the upper end of the valley is a typical pedestal whose top is at about 2900 feet. The front is steep and composed of large boulders. From the top of the pedestal a flat valley bottom rises gradually to the steep rock walls (cirque?) which encircle the head of the valley. On the east side of the flat above the pedestal are indistinct lateral moraines.

The valley of Beecher brook was quite certainly occupied by a local glacier that descended at least to the moraine that holds in the lake, and possibly for its whole length.

From Beecher brook to the junction of the outlet stream from Balsam lake, the Beaver Kill valley has considerable thick drift but no prominent moraines.

Balsam lake is held in by a combination of smooth thick drift and distinct moraine loops. On the west side of the lake the loops are very distinct, but on the east side the drift is smooth. At the upper end of the lake a low but distinct morainic loop extends across the valley. Near the head of the valley is a large pedestal, convex down valley, and highest in the center. Its down-valley slope, which is about 200 feet high, is composed of large boulders. Its top rises about ten feet above the level of a swamp, formerly a small lake, which it impounds. The head of the valley is precipitous and cirque-like in form.

The valley of Black creek has considerable thick drift and several "steps" of drift, but no distinct moraines were found. Some of the drift terraces start on the west side of the valley and swing diagonally upstream and downward in a manner difficult to account for.

Directly above the mouth of Black creek is considerable thick drift or indistinct moraine shaped by ice moving down the Beaver

Kill valley. The latter valley, all the way to its head, is floored with smooth thick drift. Vly pond and Tunis pond are shallow lakes formed by irregular deposition of this drift, seemingly resulting from ice moving down the main valley building out trails of thick drift from the hill spurs on the north side and partly blocking drainage from that direction.

At the head of the Beaver Kill valley, in the pass between Graham mountain and Doubletop mountain, is a huge bouldery moraine or pedestal. It is highest in the center. The south side, which is very steep and between 200 and 300 feet high, is composed exclusively of large boulders. In composition it resembles the pedestal at the head of the valley above Balsam lake and also the boulder mass in the pass on the east side of Slide mountain. It appears to have been formed by a tongue of ice pushed into the pass from the north.

At the pass leading out of the head of the valley toward the south (one and one-fourth miles southeast of Tunis pond) is a small morainic loop projecting southward, which proves that the latest ice did not enter the Beaver Kill valley from the southeast.

If the last glacier to occupy the upper Beaver Kill valley was of local origin and ended in the belt of moraines between Hardenburg and the mouth of Beecher brook, as is thought probable, it is likely that large terminal moraines will be found in the upper part of the valley of Fall brook (Neversink quadrangle) opposite the pass just mentioned.

MILL BROOK

The valley of Mill brook was examined with much care in the hope that it would shed definite light on the problem of local glaciation, in as much as the height of the southern bounding ridge and the exposure of the valley are such as would have favored the development of local glaciers.

As a whole, the valley is characterized by deposits of smooth thick drift with small, though distinct, ridge moraines superposed upon it in a few places.

Below Grant Mills much thick drift is found in the valley, but it is nonmorainic. The large mass of moraine half a mile below Grant Mills seems to have been made by ice pushing up the valley, but the relations are not very clear and are partly obscured by landsliding. Short ridge moraines on the hill spur north of Grant Mills were built by ice moving either southward or westward down the valley.

Between Grant Mills and Belle Ayr several small ridge moraines in the valley bottom indicate movement down-valley. In the valley which enters Mill brook at the county line is a large moraine evidently built by ice pushing into the valley from the southeast. On the hill spur east of the mouth of this valley are several very sharp and distinct ridge moraines that could have been formed only by an ice tongue moving down the valley. In the valley bottom below, however, is a larger, although rather smooth, morainic mass that seems to have been formed by ice moving up the valley, although its appearance may be deceptive.

On the hill spur north of the valley half a mile east of Belle Ayr are small but unmistakable morainic ridges made by a glacier moving northwestward down the valley.

In the valley at the head of Mill brook, northeast of Balsam Roundtop, is a large and very distinct moraine formed by a local glacier. It is convex northward, is smooth on top, and the top rises about 30 feet above a swamp which it impounds. On the east side a sharp morainic ridge separates from the hillside at the lower end of the moraine and extends diagonally downward to the northwest. Where it separates from the hill it is composed of boulders, probably due to the washing effect of glacial waters.

The valley south of Belle Ayr has a large pedestal (figure 33) that was evidently formed by a local glacier. The next valley to the west has a pedestal just above its junction with the main valley, but is smooth in its upper part. The western tributary of the next lower valley has a beautiful little pedestal, with a small ridge-moraine on top of it at 2250 feet, which is so situated that it must have been formed by a small local glacier. Two less perfect pedestals in the eastern branch of this valley are also thought to be products of a local glacier.

The passes leading into the head of Mill Brook valley from Cold Spring hollow and from Dry Brook were examined for signs of glacial erosion and strong scouring such as should be expected if the ice that moved down the valley had come through these passes, but no signs of scouring and no striae were found.

The ice that moved down Mill brook to a point near Grant Mills is believed to have been a short-lived local glacier fed from the high mountains at the head of the valley. That it was not part of the continental glacier is indicated by the lack of scouring on the passes leading into the valley and by the fact that there is evidence that Dry Brook valley, to the east, was itself occupied by a local glacier for most of its length.

That the lower end of the valley was clear when the local glacier was present is shown by the lack of evidence of standing water there.

COLD SPRING HOLLOW

Cold Spring hollow seems to have been occupied for its entire length by a local glacier that overrode and smoothed any glacial deposits which may previously have been present, and which built a large terminal moraine at the mouth of the valley. The valley contains much thick drift, but the only distinct morainic forms noted were at its head and its lower end.

Certain features at the head of Cold Spring hollow (figure 5) indicate that the valley was first occupied by the continental glacier, which entered it from the northwest, and later by a local glacier,

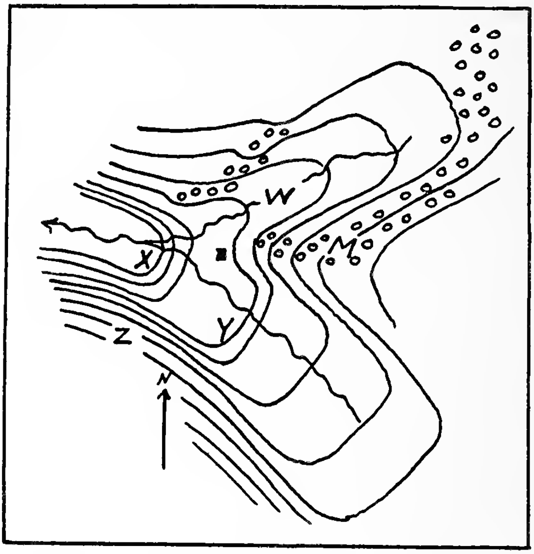

Figure 5 Sketch from notes showing conditions at head of Cold Spring hollow indicating local glaciation. "Steps" in valley bottom at X (40 feet) and Y (30 feet); over-steepened slope at Z with talus at base; and small moraine of local (?) glacier north of house partly inclosing bowl-shaped basin at W. Moraine (M) crosses head of valley as if built by the continental glacier.

which descended from Dry Brook ridge, overriding and partly effacing the earlier glacial deposits. As indicated in the sketch, the left, or south, branch of the valley has a flat bottom with distinct "steps" and its southern wall is oversteepened as if by strong glacial scouring. This is one of the comparatively few instances where the local glaciers were active enough to produce distinct erosional forms.

At the mouth of the valley is a large moraine of such shape and so situated (figure 6) that its formation by a local glacier in Cold Spring hollow is the only explanation that seems to fit the facts.

DRY BROOK

Dry brook is a long, northward flowing stream that heads among the highest peaks of the southern Catskills. It is so situated with respect to topography and the direction of movement of the continental glacier that any moraines in its valley that are convex downstream must have been formed by a local glacier.

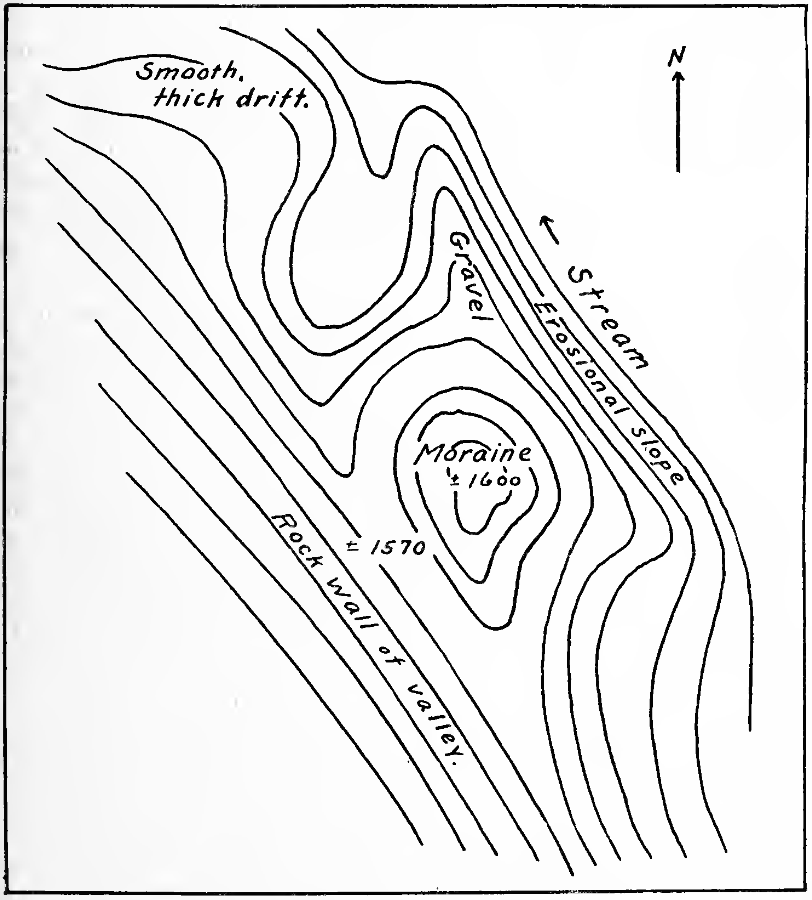

Figure 6 Sketch from field notes showing glacial deposit at mouth of Cold Spring hollow whose form indicates that it was built by ice descending that valley

About a mile above the mouth of the valley is the lower end of a belt of moraines, which at the sharp bend in the stream, forms a distinct loop convex down-valley, indicating deposition by a local glacier moving northward. The fact that the moraine is composed of stony till instead of gravel also indicates northward movement at this loop, for if a tongue of the continental glacier had pushed into the valley from the north it would have impounded a lake in the valley and the moraine, having been built into this lake, would have been gravelly.

For a mile below the village of Dry Brook the valley bottom is partly filled with thick drift. On the east side indistinct morainic embankments appear to have been formed by ice from the north. In Rider hollow (figure 21) the bulk of the evidence was interpreted as indicating movement down the valley at the latest stage, but a massive morainic bar across the tributary valley on the south slope of Belle Ayr mountain was certainly formed by continental ice from the north. It appears from this and other evidence that deposits made by the continental glacier pushing into the valley from the north are only partly obscured by those of the short-lived local glacier.

For about two miles above Dry Brook, considerable thick drift and moraine, some of it distinctly convex down-valley, was found. Farther up are a few small morainic embankments also indicating northward ice movement, but the bulk of the glacial débris in the upper Dry Brook valley is smooth, thick drift.

At Furlough lake is a perfect moraine of a local glacier, convex northward, swinging down from the hills on either side and rising in the center about 30 feet above the lake level. The northern, or down-valley side of the moraine is very steep and about 200 feet high. The whole forms a distinct pedestal and is an excellent example of an intermediate stage between a pedestal and a simple loop moraine.

The distribution of glacial deposits in Dry Brook valley is explained as follows: At an earlier stage the continental glacier occupied the valley and, on retreating, left a moderate amount of drift in the valley bottom and some morainic loops and embankments, which, in general, were convex southward. At a later stage a local glacier moved northward down the valley as far as the big morainic loop near its mouth, smoothing and overriding, although not entirely obliterating the deposits previously made. This local glacier must have been short-lived and must have melted away rapidly, for it left few distinct moraines in its retreat. The local glacier at Furlough lake, which originated on a comparatively low mountain, may never have extended farther than the lake. This would explain the distinct moraine in this small valley, while no similar moraines are found in the upper ends of the valleys heading in the higher mountains to the east. Their moraines are farther down the valley, below Dry Brook.

PLATTE KILL (MARGARETVILLE QUADRANGLE)

The Platte Kill valley is so situated that its lower end lay in the path of vigorous ice movement down the valley of the East branch of the Delaware river, which has left its mark in strong scouring and striations on the hills on both sides of the lower Platte kill. The upper end of the valley is bounded by high mountains that shielded it from active ice movement. During the waning stages of the glacier the valley was accessible only through a few relatively high gaps on its eastern side.

For the first two miles above its mouth the valley is deeply filled with thick drift having a smooth top 100 to 150 feet above the stream. This must have been formed either beneath the ice by a plastering-on process or it must be overridden moraine.

Tributary valleys from the west—Canada hollow, Palmer hollow and the lower half of Weaver hollow—have considerable thick drift in their bottoms arranged in the form of smooth bars extending across the valleys from the east or northeast to west or southwest. At the lower ends of Palmer and Weaver hollows these point distinctly up-valley and are shown on the map as morainic loops, although they are of the smooth, broad type. In the upper half of Weaver hollow indistinct morainic embankments point down-valley. These are believed to have been formed by a short-lived local glacier heading on Mount Pisgah.

Two miles below New Kingston are massive, smooth morainic loops which appear to have been formed by an ice tongue which pushed over the pass from the east and a short distance up the valley.

Above a point half a mile below New Kingston the most distinct moraines are convex down-valley, but they are mostly of the smooth type and difficult to interpret. Near the head of the valley, in both branches, indistinct morainic embankments extend diagonally down the hillside northward and have what appear to be ice-contact fronts facing southward. Their position suggests that ice from the pass at the head of Bragg hollow sent tongues, in bulb form, at the same time, up toward the head of the valley and down toward New Kingston.

The valleys entering from the west at New Kingston contain very little drift. None of it is morainic.

In general, it is clear that at some stage ice pushed into the Platte Kill valley from the east above New Kingston and from the southeast in the lower part of the valley. Such conditions should have been favorable for the formation of glacial lakes, but no evidences of them were found. In fact, no noticeable gravel deposits were found in the valley except the two small kames below New Kingston and the gravel terraces at the mouth of Weaver hollow. The latter are probably postglacial stream terraces, although it is possible that they may be outwash from a small ice remnant that may have lain in the valley after the continental glacier had retreated.

These features, coupled with the remarkably smooth and overridden appearance of most of the moraine loops and thick drift bars, suggest the hypothesis that the deposits in the Platte Kill valley are in part what may be called subglacial drag moraines formed beneath the ice in the lee of hill spurs and at other points where the transporting power of the ice was decreased.

Above a point about half a mile below New Kingston several small morainic ridges and embankments were found whose position and relation to the smooth moraines already described suggest that a local glacier descending from the mountains at its head occupied the valley for a short time. Such an interpretation has been expressed on plate 2.

BUSH KILL AND ITS TRIBUTARIES (MARGARETVILLE AND PHOENICIA QUADRANGLES)

Between Arkville and Fleischmanns the valley of Bush kill is relatively free of glacial deposits except for a few small morainic ridges pointing westward and a pronounced gravel terrace along the north side of the valley. The terrace slopes gently westward and seems to have been formed at the edge of a rather stagnant ice mass lying in the valley, whose south side probably lay higher than the north on account of the shading effect of Fleischmann mountain.

At the mouth of Red kill is a pitted outwash plain. Considerable outwash, in terrace form, is found also at Griffin Corners.

As should be expected from its position in the lee of Halcott mountain, Emory brook has no important moraines. For a similar reason, moraines are conspicuously lacking in the upper part of the Red Kill valley.

The valley of Vly creek, however, which heads in the Central escarpment, held an active ice tongue which built large terminal moraines at Griffin Corners. At the head of the valley, west of Vly mountain, are massive moraines. Associated with these is a large kame having a flat top at 2160 feet. Curiously enough, kames are found at this same elevation at the head of Red kill and in the valley to the east of it (figure 39). In as much as no other evidence of the presence of a water body at this level could be found, it is probable that this accordance in elevation is entirely a coincidence.

The moraines in the valley of Vly creek are distinct and ridgelike, in which respect they contrast strongly with those in the valley of Platte kill.

At the head of Elk creek, east of Halcott Center, two small local glaciers descended the north slope of Halcott mountain.

BATAVIA KILL (MARGARETVILLE AND HOBART QUADRANGLES)

Batavia kill heads on the south side of a high part of the Central escarpment and extends parallel with the direction of ice movement to its junction with the Delaware at Kelly Corners. Although there are no low passes through the escarpment at the head of the valley, an active tongue of ice descended it and built a remarkable group of moraines that now choke its lower end. At Kelly Corners the ice spread out into the Delaware valley in the form of a bulb that appears to have pushed down valley, possibly to about one mile above Arkville, and up the valley for a short distance. In doing so it appears to have blocked drainage in the Delaware valley and may have been partly responsible for the abundance of kames and gravel terraces farther up that valley.

Most of the moraines in the lower Batavia Kill valley are fresh and distinct, with numerous loops of the ridge type. In the upper half of the valley smooth thick drift is the prevailing glacial deposit.

EAST BRANCH OF THE DELAWARE RIVER BETWEEN ARENA AND GRAND GORGE (MARGARETVILLE AND HOBART QUADRANGLES)

The East branch of the Delaware river flows in the general direction of the ice movement and at the close of glaciation the ice front retreated up the valley. After the ice had completely melted out, the valley was occupied for a considerable time by a good-sized river that flowed through Grand gorge from a glacial lake in the Schoharie valley, and considerably modified the glacial deposits in the valley bottom.

Between Arena and Margaretville the most conspicuous features are gravel terraces that border the valley at elevations ranging from about 1350 feet at Arena to 1380 feet near Margaretville. In many places these terraces were built upon the ice and slumped down into kames when the ice melted away.

The gravel terraces are remarkably uniform in elevation and may once have been parts of a continuous outwash plain, probably connected with the gravel terrace in the lower Bush Kill valley.

Nothing was found within the area of the Margaretville quadrangle to explain adequately the formation of an outwash plain so high above the level of the present stream, but some obstruction in the valley below may account for it, or it may be that cutting by the Grand Gorge lake outlet stream lowered the valley bottom considerably since the outwash plains were formed.

The strong moraines opposite the mouth of Batavia kill have already been mentioned. The bulb that spread out in the Delaware valley at this point did not extend more than three-quarters of a mile northward, for beyond that the morainic loops in the valley are convex southward.

From Halcottsville to More Settlement, a distance of ten miles up the valley, there is much moraine that forms many distinct loops swinging down from the hillsides and part way across the valley bottom. Many of the loops end in masses of kame-moraine. Kames are prominent features of the drift between Halcottsville and Roxbury.

The mass of kames and eskers stretching down valley from a point three miles below Roxbury occurs in a part of the valley that, on the east side, has the smoothed appearance of having been overridden by a readvance of the glacier. The association of kames and eskers with evidences of overriding has possible significance in connection with the development of the kames and especially of the long esker associated with them (figure 47). In a long narrow valley like this, supplied mainly through the narrow pass at Grand gorge, a moderate readvance of the main ice sheet north of the pass might make itself felt at Roxbury in a spasmodic way like the recent advance of certain of the Alaskan glaciers in response to earthquake shaking. (Tarr '07.) Such an advance, as in the case of the Alaskan glaciers, would be likely to be succeeded by a period of stagnation during which the ice would slowly melt down by surface ablation. Conditions would then be favorable for the burial of its basal part under outwash gravels (forming kames when the ice melted out) and for the preservation of gravel deposits (eskers) made in subglacial tunnels.

Such an explanation is suggested for the kames and eskers south of Roxbury associated with what appear to be overridden moraines.

At Grand gorge and southward to More Settlement are evidences of vigorous glacial scouring. The lower portion of the Grand Gorge pass is a beautiful, rock-walled fossil river channel (figures 51 and 52) that was the outlet of a glacial lake in the Schoharie valley.

Tributary valleys on the west side of the East branch between Margaretville and Grand gorge are relatively free from moraines except for morainic bars and loops across the mouths of some of them. Smooth thick drift is common in the valley bottoms, and in the southern part of the area, north of Margaretville and west of Kelly Corners, there are many of the smooth, thick drift bars such as are found in the valley of Platte kill and its tributaries to the west. It is thought that these were formed during a phase of glaciation earlier than that which produced the moraines at Griffin Corners and Kelly Corners.

In view of its situation, Meeker hollow is remarkably free from lateral moraines like those found in the valleys both above and below it. Possibly this is because the spur between the Meeker Hollow and the West Settlement streams is narrow and could furnish little débris to the ice margin while West Settlement valley caught most of that which was being carried from farther north. A beautiful pedestal (figures 53, 54 and 55) a mile below the head of Meeker hollow indicates the former presence of a local glacier.

Montgomery hollow, east of Hubbell Corners, is occupied by strong morainic loops whose western convexity indicates that they were formed by an ice tongue pushing through the pass north of Bloomberg mountain. A glacial channel leading westward from the top of the pass shows that for a time glacial waters were discharged through this gap.

LITTLE DELAWARE (DELHI, HOBART, AND MARGARETVILLE QUADRANGLES)

The valley of the Little Delaware, like that of the Platte kill, is sheltered in the lee of the higher Catskills. Striae and moraines indicate that the ice movement was everywhere down the valley, or across it to the south-southwest in the earlier stages.

The lower end of the valley from its junction with the West branch of the Delaware river to Lake Delaware shows a series of morainic ridges and loops, all convex westward down the valley. They are best developed on the south side of the stream. Rather smooth ridges of stony till sloping gradually down the hillsides to the valley bottom are the prevailing forms.

The valleys north of Bovina Center contain much smooth thick drift and some moraines, most of which are of the smooth type, though a few small but distinct ridges were noted. A small glacial stream channel leads through the pass at the head of Brush brook.

The record of a well at Bovina Center shows that the drift filling in the valley bottom at that point is about 60 feet deep.

The cemetery about a mile southeast of Bovina Center is on a large morainic loop of stony till that appears to have been built by ice moving out of the valley of Coulter brook. Other moraines farther up that valley indicate movement toward the northwest. Whether these moraines were built by a tongue of the continental glacier pushing over the pass from the southeast or by a local glacier from the north side of Mount Pisgah is uncertain, but in view of the direction of the general ice movement here and farther east, the latter seems the most probable.

From the mouth of Coulter brook to Bovina the valley is considerably choked with moraine, part of which has the form of distinct loops convex southwestward. In the valley of Mountain brook, a mile southeast of Bovina, remarkably distinct morainic loops stretch across a shallow tributary valley. They were built by ice from the north and northeast.

A mile northeast of Bovina is a typical example of a massive moraine of the smooth type. From that point to its head, the valley bottom is filled with thick drift. Stream cuts made through this and through the moraine below are so wide that the conclusion seems warranted that the drift here has been exposed to erosion for a considerably longer time than that in many parts of the Catskills. Conditions in that respect are like those in the lower valley of the Neversink and in the upper Platte kill.

At the head of the valley is a massive moraine of the pedestal type, whose origin—whether from the continental glacier or from a local glacier descending the north slope of the mountain—could not be determined with certainty.

ROSE BROOK (HOBART QUADRANGLE)

At the lower end of the Rose Brook valley is a group of prominent moraines and several large kames that are so related to the surrounding topography that it is evident they were formed at the end of an ice lobe which pushed a short distance up the valley from the north. The kames were probably built into a lake impounded in the Rose Brook valley by this ice lobe.

All of the valley except the lower end is characterized by smooth thick drift, here and there slightly wavy in contour. At the head of the valley, one and one-half miles north of Relay, is a narrow rock gorge through the pass (figures 13 and 23), which must have been made by a glacial stream flowing southward from the margin of a glacier in the Town Brook valley.

In the low pass three-quarters of a mile south of South Kortright several small glacial channels lead southward into Rose Brook valley.

An examination of the pass at the head of the valley east of Gray hill was made to determine whether there were evidences of glacial movement into the valley from the east. No striae, stripped ledges or other evidences of strong glacial erosion were found.

The valley of Rose brook, like that of the Little Delaware to the south, evidently was not occupied by an active glacier of the latest invasion that built the massive, fresh moraines to the north and east.

TOWN BROOK (HOBART QUADRANGLE)

The lower end of the Town Brook valley contains a mass of kame and moraine somewhat like that at the mouth of Rose brook. Its origin, however, is not so clear.

In its lower course Town brook has been turned aside by a high ridge of sand and gravel (figure 56). A mile south-southeast of Hobart the ridge ties onto the southern wall of the valley at about 1820 feet, whence it swings out northward and northwestward across the valley toward a large kame at the Hobart cemetery, with which it may once have been continuous. On the opposite (northeast) side of the stream the hillsides are covered with rolling moraine. An indistinct, but rather massive loop of kamelike moraine is found half a mile upstream from the ridge just described, and another a mile still farther upstream. Small kames appear at two other points farther up the valley, in each case near the junction of tributary valleys.

The big, gravelly moraine at the lower end of the valley is so situated that it could not have been built as a moraine at the end of an ice tongue from the north or northeast pushing into the lower end of Town Brook valley. It has every appearance of having been built at the end of a glacier moving from the east down that valley. Yet the topography at the head of the valley and the known direction of movement of the continental glacier do not lend support to the theory that a tongue from the continental glacier moved down the valley, for the continental glacier would have had freer access to the valley from the north or northeast.

A local glacier occupying Town Brook valley might have built such a moraine at its lower end, and such is believed to have been its origin, but that explanation was at first rejected because the mountains bordering the valley seemed too low to have supported a local glacier of such size and, moreover, no distinct retreatal moraines, pedestals or other signs of local glaciers were found in the upper part of the valley.

The explanation finally adopted as most likely is that the valley was occupied by a marginal local glacier of the wind-drift type, nourished mainly by snow drifted into the reentrant in which the valley lies (see plate 2) by the strong winds of the glacial anticyclone (compare p. 115–18).

The gravelly kamelike character of the moraines in the lower half of the valley suggests that they were built into a lake caused by the damming of the valley by the continental glacier. Independent evidence of the presence of such a water body is a small delta at 1830 feet on Reservoir brook, which received its gravel supply from the northeast and which appears to have been built into a lake held in the Town Brook valley by ice lying across the lower end of the valley. A small glacial channel across the divide one and one-half miles south of Hobart at about the level of the delta was probably cut by a temporary outlet of this lake.

Except for the deposits just described and the kames already mentioned, the valley of Town brook, like that of Rose brook, is remarkably free from moraine or other glacial deposits except smooth thick drift that covers most of the bottom and lower slopes of the valley.

The southeastern pass at the head of the valley was examined for signs of ice movement over it from the east, but none was found. Striae on the pass north of McGregor mountain show that at one stage ice entered the valley from the northeast.

WEST BRANCH OF DELAWARE RIVER (DELHI AND HOBART QUADRANGLES)

Below Riverdale the Delaware valley was mapped only in a reconnaissance way.

From Delhi to the mouth of Elk creek strong morainic ridges on the east side of the valley swing, as a rule, down the hillside and merge into kame-moraines as they turn out across the valley. Near East Delhi outwash terraces are prominent.

A tongue of ice pushed north for nearly two miles up the valley of Elk creek, building morainic loops and a mass of kames at its end.

A belt of very prominent morainic loops and ridges is found near Bloomville and another near South Kortright. Considerable outwash gravel in terraces occurs along the north side of the valley between these places.

From South Kortright to Hobart the valley bottom is filled with outwash gravel that had its source mainly in the glacial tongue which built the series of moraines extending all the way from Hobart to and through the pass at the head of the valley beyond Stamford.

Between Hobart and Stamford these moraines take the form of stony ridges extending diagonally down the hillsides on the south side of the valley. One of these ridges, ending near Hobart, could be traced for one and one-half miles. It has an average inclination of 200 feet to a mile. Farther up the valley, south of Stamford, several of the morainic embankments and ridges have a very low down-valley inclination. They appear to have been built by ice that came from a direction only a little east of north and lay banked rather flatly against the mountains on the south side of the valley.

In the low passes east of Stamford and east of Utsayantha lake are many remarkably perfect morainic loops. The phenomenon of "frayed moraines" described by Tarr ('09) is here well illustrated. On the spur of Bald hill east of Mine Hill pond is a sharp morainic ridge that grades westward into an indistinct embankment or flattening of the hillslope where it descends along the steep side of the mountain and frays out into several separate morainic loops as it approaches the bottom of the valley.

Farther north, opposite the gap south of Potter hill, a perfect morainic loop marks the position of the end of an ice tongue which pushed for a short distance through the gap. The loop incloses a small swamp, formerly a lake.

Another tongue of ice pushed southward through the pass at the head of Lamb brook. A series of morainic loops in that valley marks successive stages of its retreat, and a fossil stream channel and waterfall at the pass show that a marginal stream from the glacier flowed through the gap for some time after the ice had withdrawn.

In general, moraines are much better developed on the south than on the north side of the valley of the West branch of the Delaware river. This is probably because the ice came into the valley from the northeast at nearly a right angle to its course so that the débris accumulating along its margin was banked along the south side of the valley.

The highest distinct morainic bars on the hillslope south of the pass east of Stamford lie at an elevation of 2250 feet. It is possible that these bars mark the highest point reached by the ice of the latest glacial epoch in this region, or at least of the pronounced moraine-building stage whose moraines lie along the West branch of the Delaware river; the valley of the East branch of the Delaware river above Arkville; and the valleys of Batavia kill and Vly creek already described.

LOCAL DESCRIPTIONS—RONDOUT DRAINAGE

In order to understand the meaning of certain glacial features of the southern Catskills, it became necessary to trace the glacial history of the region south and southwest of the mountains drained by Rondout creek and its tributaries. Owing to lack of time, this region was mapped only in a reconnaissance way but enough time was given to it so that it is thought that most of the major glacial features were seen.

SUMMITVILLE TO NAPANOCH (ELLENVILLE QUADRANGLE)

Between Summitville and Phillipsport is a huge mass of gravelly moraine from which an extensive outwash valley train leads southward toward Port Jervis. The moraine has a rather flat top at an elevation of about 720 feet, the flatness probably being due to a surface veneer of outwash gravels. It evidently represents a long-continued stand of the ice and, as will be pointed out in a following section, may be the terminal moraine of the Late Wisconsin epoch.

East of Summitville, on the east side of the moraine, is a good-sized remnant of what must have been an extensive outwash plain formed while the moraine was being built. Its top has an elevation between 600 and 620 feet. All but this remnant has been cut away and destroyed by a lake outlet stream which later occupied the pass at Summitville.

This lake, which is here called Summitville lake, was held in the valley of Rondout creek and its tributaries during the time the ice was melting back from the Phillipsport moraine to some place in the vicinity of High Falls, where the next lower outlet could have been uncovered.

The Summitville Lake outlet begins on the west side of the moraine half way between Phillipsport and Summitville. Its bottom has an elevation of about 540 feet. The channel widens southward so that below Summitville it occupies the entire width of the valley bottom—about three-quarters of a mile. An alluvial fan built by Gumaer brook, together with headward cutting by the stream from the north, has reversed the drainage of the head of the channel.

During the life of Summitville lake the outlet stream must have deepened its channel considerably at the divide, for there is a progressive decrease in the elevations of the tops of the deltas built into the lake from about 650 feet for the earliest delta, west of Phillipsport, to 600 feet for the delta at Honk lake and 580 feet for that two miles north of Wawarsing.

Marginal stream drainage was active along the west side of the tongue of ice that built the Phillipsport moraine. Along the route followed by the railroad as far as the turn into Sandburg creek, fossil stream channels made by this drainage are conspicuous. Each of the two channels followed by the railroad—which at an earlier stage may have been one—heads in a small gravel outwash plain formed by the filling of a shallow embayment between the ice and the hill. Each channel is cut in rock and ends in a delta built into Summitville lake. According to W. B. Heroy (verbal communication), a similar channel is found behind the knob where the railroad turns into Sandburg valley.

In the valley of Sandburg creek are a number of deltas whose relations were not determined further than that their tops are higher than the outlet at Summitville and that at least some of them face eastward. These must have been built into a lake held in Sandburg valley by the ice tongue which built the Phillipsport moraine.

Between the Phillipsport moraine and the junction of Homowack kill with Sandburg creek, the valley is choked with massive kame-moraine, some of which has a covering of lake clay. Below this point, nearly to Ellenville, the valley bottom is a broad alluvial plan. Moraines and kame-moraines on the north side of the valley are disposed in loops pointing southward.

The part of the loop south of Ellenville that rises above 400 feet seems to be typical moraine, but below that level it is a pitted plain having an even top at about 400 feet. The pitted plain may correlate with the terraces a mile north of Napanoch and with the broad deltas at about 400 feet north of Kerhonkson. If so, the moraine south of Ellenville must have been partly reworked by the waters of a lake at that level while ice still lay buried beneath it. Later melting out of the ice is supposed to have caused the present pitted surface.

Strong morainic loops in the valley of Beer kill, west of Ellenville, indicate that a lobe of ice from the east pushed part way up that valley.

At the junction of the east and west branches of Beer kill is a delta whose top stands at 620 feet. It slopes eastward, showing that it must have been formed by a stream descending from the plateau at Hanging Rock falls. The Rondout stream, together with any marginal glacial drainage that it may have been carrying, was probably diverted to this course for a short time while the ice lay across the mouth of the Rondout valley at Napanoch between the time of the abandonment of the outlet at 1270 feet two and one-half miles southwest of Beaverdam pond[1] (Neversink quadrangle) and the establishment of drainage around the east side of the hill west of Honk lake. This drainage may have come down Botsford brook for a time. It appears also to have come in part through the channel at the southeast end of Cedar swamp.

At the mouth of the Beer Kill valley, on either side, are deltas at 580 feet. The one on the south side of the stream is only a remnant, but that on the north is very large. North of the cemetery is another at the same level.

These deltas appear to have been built into Summitville lake while the ice front was in their immediate vicinity. They were undoubtedly supplied by powerful marginal glacial streams carrying the Rondout drainage as well as that from the ice. Their lack of continuity along the hillside proves that they were formed while glacier ice was present.

At the mouth of the Rondout at Napanoch is a large delta. It was built into Summitville lake by Rondout creek and perhaps in part by glacial drainage from the ice margin to the northeast. That it was built mainly by Rondout creek is proved by its rise and the gradation of its top into terraces along that stream.

PLATEAU WEST OF NAPANOCH (ELLENVILLE QUADRANGLE)

A reconnaissance examination, in the course of which most of the roads on the part of the plateau between Sandburg creek and Rondout creek in the area of the Ellenville and Slide mountain quadrangles were traversed, revealed the fact that the ice spread over

[1] This outlet was not seen, but is inferred from the map.

the plateau in fan shape,—northwestward along the Rondout valley; nearly west over the central part of the plateau near Greenfield; and southwestward farther south.

No important moraines such as might be correlated with the terminal moraine at Phillipsport lie on the part of the plateau examined. They must lie farther to the south and west.

Over most of the plateau the drift is thin and in many places the rocks are bare and have been strongly scoured.

Drumlins, approximately parallel to the glacial striae, are moderately abundant. Their general situation here, not far within the terminal morainic belt and on the plateau where the velocity of the ice was checked after its ascent from the deep valleys to the east, is in accord with the general principles of drumlin formation already set forth.

The largest moraine noted on the plateau lies a short distance northeast of Ulster Heights. It could be traced for only a short distance.

RONDOUT VALLEY ABOVE NAPANOCH (SLIDE MOUNTAIN AND NEVERSINK QUADRANGLES)

On the hillslope north of the Rondout valley between Lackawack and Eureka extensive moraines and kame-moraines were built along the north side of the ice tongue that pushed up the valley from the southeast. At Sholam, the highest distinct moraine is a sharp ridge at 1320 feet. On Trout brook, north of Montela, the highest distinct moraine lies at about 1340 feet. Below it at about 1240 feet is a marginal outwash terrace whose presence at this level proves that at the time the terrace was formed the ice had melted back far enough to uncover one of the cols below this level to the south. At that time it probably ended near Grahamsville.

On the hill crossed by the Ulster-Sullivan county line, are very massive accumulations of moraine and kame-moraine, whose upper limit is at about 1160 feet. Less distinct, gravelly moraines are found in the bottom of the valley northward from here to the pass west of East mountain.

Around Grahamsville and from there to the divide two miles west-southwest of Curry are very massive moraines, whose lateral representatives are conspicuous in the valleys north of Unionville and northwest of Grahamsville.

These moraines and those on the divide west of Curry may represent the extreme limits of the ice at the time the moraine at Phillipsport was built, and may also be the terminal moraine of the Late

Wisconsin stage (see p. 120-23, 130-31). They are probably to be correlated with the moraines at Griffin Corners and Kelly Corners on the East branch of the Delaware river, and with those lying along the south side of the valley of the West branch of that river.

A traverse of the road from Grahamsville along the east slope of Denman mountain to the pass at Red hill failed to reveal any important moraines. This, together with the direction of the striae in the pass at Red hill, seems to prove that the ice tongue whose terminal moraines are west of Curry did not lie high along the east slope of Denman mountain and did not push over the divide at Red hill into the Neversink valley. It evidently came from the southeast, up the Rondout valley.

Lateral moraines corresponding to the strong terminal moraines west of Grahamsville were not found along the upper Rondout valley. The locality was not examined in detail and some moraines may have been missed, but enough was seen to make it reasonably certain that no strong moraines are present—a condition believed to have been due to stagnation of the ice in the Rondout valley above Eureka. Thick drift and weak morainic terraces are found between Eureka and Sundown, and there is considerable moraine at Bull Run, but its relations have not been determined.

On the whole, the distribution of the moraines and the direction of the striae in the region northwest of Ellenville make it appear that the Shawangunk Mountain mass, lying in the path of the Hudson Valley glacial lobe, deflected the ice movement strongly northwestward up the Rondout valley toward Grahamsville. This anomalous direction of ice movement affords an interesting example of the influence of topography on the direction of ice flow.

Whether the moraines at Curry and Grahamsville are contemporaneous with that at Phillipsport was not certainly determined but is strongly suggested. The ice appears to have been so strongly deflected northwestward by the Shawangunk barrier that it extended a surprisingly short distance south along the low valley at Phillipsport.

The whole problem of the ice movement in this region and that immediately to the west, where a number of large glacial cols are indicated, affords a most interesting field for future study.

PEEKAMOOSE GORGE AND GLACIAL STREAM CHANNEL

The Rondout valley from Eureka to Peekamoose gorge shows many evidences of having once been occupied by a powerful stream many times larger than that which now flows through the valley. At Eureka a large terrace of coarse gravel containing boulders ranging in size up to two feet in diameter is a remnant of the bed of the ancient stream channel. Conspicuous water-worn rock terraces are found in the valley bottom below Lowes Corners and again three-quarters of a mile below Bull Run. At the latter locality is a fossil waterfall. Above Bull Run, all the way to the divide two miles east of Peekamoose Lodge, the bottom of the valley is a rock gorge. Small tributary streams cascade over the side of this gorge (figure 57) but the larger streams, like that which enters near Peekamoose Lodge, have cut narrow tributary gorges. A quarter of a mile above Peekamoose Lodge a fossil waterfall is found in the bottom of the main gorge.

At the divide, Peekamoose gorge is choked with talus. On the southeast side the wall of the gorge is obscured for its entire height—about 400 feet—but on the northwest side the talus rises only about 250 feet. Above is a sheer rock cliff.

At the entrance of the gorge, rock is exposed at an elevation of 1640 feet, which probably represents very closely the level of the bottom of the channel before it became choked with talus.

A powerful stream working for a long time must have been required to cut a rock gorge so large and deep as Peekamoose gorge. That stream was the outlet of a lake in Esopus valley, and besides, carried the marginal drainage of the Hudson Valley lobe while the ice was melting down on High Point to a lower outlet at Wagon Wheel gap (Darton '94). It emptied into Summitville lake at Napanoch, building a huge delta already described (see plate 2).

The Peekamoose pass above the gorge shows no signs of strong ice scouring such as should be present if it had been an important channel of ice movement. A careful search was made along the road from the gorge to the top of Breath hill for striae, stripped ledges or other evidences of strong glacial scouring, but none was found. It is therefore safe, in view of the strong scouring that is everywhere evident on the plateau bordering the Rondout valley from Napanoch to Eureka, to conclude that the ice that built the belt of moraines west of Grahamsville and Curry came up the Rondout valley from the southeast, in the direction indicated by the prevailing striae, rather than down the upper Rondout from the direction of Peekamoose gap.

COLS BETWEEN RONDOUT AND NEVERSINK VALLEYS

When an ice tongue from the southeast blocked the Rondout valley between Napanoch and Eureka, the drainage from its end and northern margin was forced to find an outlet westward to the

Neversink. The positions of at least some of these outlet cols can be inferred from the topographic map, but none of them was examined in the field. The highest col lies at 1360 feet one and one-half miles southwest of Curry. The next lower is at about 1290 feet one and one-half miles southwest of Beaverdam pond; another is at the head of the west branch of Beer kill at about 1200 feet; and a fourth may have been at Centerville at about 1170 feet.

While the ice lay in the Rondout valley above Napanoch, it is possible that a lake occupying the present sites of Eureka and Grahamsville may have discharged through the pass at about 1120 feet a mile southeast of Beaverdam pond and thence down Botsford brook and Beer kill to the delta already described below Hanging Rock falls. At a later stage a channel leading into the same delta appears to have been opened at the east end of Cedar swamp.

The detailed investigation of these cols and of the glacial lakes that outflowed through them is an interesting problem for future investigation.

Only one delta corresponding in level with any of the cols was noted, namely, a flat-topped mass of gravel and sand at 1120 feet on the hill northwest of Eureka that was built into standing water at the parting of two lobes of ice, one of which pushed north toward Lowes Corners, the other westward toward Grahamsville. The delta appears to have been fed by a stream from the ice, for it has a typical lobate delta front facing the hill to the northwest. No considerable stream could have been flowing through Peekamoose gorge at this stage without having destroyed the delta.

Deposits of water-worn gravel at 1230 feet along the north side of the valley north of Sundown were probably related to a water level determined by one of these cols.

VERNOOY CREEK AND PLATEAU EAST OF THE UPPER RONDOUT VALLEY (SLIDE MOUNTAIN QUADRANGLE)

Vernooy Creek valley has considerable thick drift in its bottom but no distinct moraines were found except below Brownville.

On the plateau west of Vernooy creek only till and smooth thick drift were found. In the pass west of Balsam swamp and on the hills to the east there has been moderately intense scouring by ice moving toward the west. No moraines were found on the plateau, but a little thick drift occurs in places. South of Balsam swamp an elongated hill, as seen from a distance, appears to be a drumlin.

EASTERN BASE OF THE CATSKILLS FROM NAPANOCH TO HIGH POINT

The keys to the late glacial history of this region are its marginal position with respect to the Hudson Valley ice lobe, and the glacial drainage that flowed along its border and emptied into a lake in the lower Rondout valley which stood at successively lower levels as the ice withdrew (see plate 2).

At the southern end of the Catskill front north of Wawarsing one finds, at various levels on the hillside, a series of channels ending in deltas at the level of Summitville lake. Around Mombaccus many kames and small deltas are found at various levels, which were evidently built along the ice margin when it stood in the immediate vicinity.

All along the Rondout valley from Wawarsing to beyond Kerhonkson large sandplains and deposits of lake clay have a general summit level of about 400 feet. No attempt was made to work out the detailed relations of these deposits.

Along the base of the mountains, west of Sampsonville, are massive lateral moraines—most conspicuous in those valleys which form shallow reentrants in the mountain front. These moraines were formed while ice lay banked against High Point above the level of Wagon Wheel gap. During this time the drainage of the Esopus valley found its outlet through Peekamoose gorge and discharged into Summitville lake at Napanoch.

As the ice banked against the east side of High Point melted down, it eventually uncovered a part of the slope lower than Peekamoose gorge. The outlet of Peekamoose lake was then immediately transferred to this new position where it cut a deep gorge now known as Wagon Wheel gap (figure 58). The gorge must have been started at an elevation of about 1600 feet, but its present bottom is talus at about 1320 feet, and it is estimated that the rock bottom of the gorge is at about 1300 feet. This fixes, approximately, the lowest level of the corresponding lake (Shandaken lake) in the Esopus valley. At the south end of Wagon Wheel gap large fossil waterfalls and cataract basins are still preserved.

When the stream first started flowing through the gap the ice pushing in from the southeast forced it southwestward past Sampsonville, whence it turned southeastward toward Liebhardt and Mombaccus. The channel that it cut at this time is large and distinct. Near its head the rock has been stripped bare over extensive areas. Between Sampsonville and Liebhardt are two fossil waterfalls in the bed of the channel. West and southwest of Liebhardt a large area of coarse stream gravel marks a place where the channel widened. Below this point it has not been traced. Before this channel was abandoned the stream near the head of the channel became concentrated on the southeast side of its bed, where it cut a deep, narrow gorge.

Further melting back of the ice opened a channel down Beaverdam creek, which appears to have been occupied for only a relatively short time. The delta north of Liebhardt was probably built at this stage.

Continued shrinkage of the ice lobe in the Hudson valley finally opened a pass at 780 feet at the foot of High Point (figure 58). A channel leading southward from this pass is well developed and appears to have been occupied for a long time. Its stream flowed past Liebhardt and emptied into the lake somewhere in the neighborhood of Mettacahonts.

The next lower possible col, that at 730 feet north of Kripplebush (Rosendale quadrangle), was not examined.

LOCAL DESCRIPTIONS—ESOPUS DRAINAGE

The portion of the Catskills drained by Esopus creek had a rather complex glacial history, and its glacial deposits are difficult to decipher. This complexity is due in part to the presence in many of the valleys of local glaciers, which in some places seem to have merged with the ice of the continental glacier. Continental ice pushed southward into the Esopus valley through gaps in the Central escarpment and also westward and even northwestward into the lower end of the valley from the Hudson Valley ice lobe.

Much further study is needed before the history of glaciation in the drainage basin of Esopus creek is thoroughly understood.

ESOPUS CREEK AND VALLEYS SOUTH OF IT (PHOENICIA AND SLIDE MOUNTAIN QUADRANGLES)

From High Point to the junction of Bush kill the plain at the base of the mountains has been strongly scoured by ice and has only a thin veneer of till over the rock. Striae indicate that the general ice movement was a little south of west.

In Watson hollow, striae indicate ice movement southwestward up the valley. At the head of the valley opposite the gap south of High Point is a series of prominent morainic ridges formed by a tongue of ice that pushed through the gap from the southeast.

Much of the thick drift in Watson hollow is stratified clay, sand and gravel with a veneer of till.

About a mile below the mouth of Mine hollow a small morainic loop appears to have been formed by a local glacier moving down Watson hollow. No other evidence of the presence of a local glacier in Mine or Watson hollows could be found.

Maltby hollow has a considerable filling of thick drift in the valley bottom. An esker and a small kame were found at the junction of its principal tributary, and a fragment of an eastward-sloping terrace or outwash train of coarse sand and gravel occurs about 60 feet above the stream near the mouth of the valley. The terrace may have been formed as outwash from a local glacier, but no positive evidence for local glaciation was found in Maltby hollow or its tributaries. A large alluvial plain of coarse boulders which may possibly be outwash from a local glacier (figure 59) stretches eastward from the mouth of the valley.

On the east side of Esopus creek about a mile below Boiceville, a railroad cut in thick drift exposes the following section:

	Feet
Loose red till at top	5
Red clay with iceberg boulders, locally crumpled	5 to 10
Red sand	5
Red till containing about 1% of foreign material	50+

The presence of stratified drift between beds of till suggests a local retreat and readvance of the ice, which here ended in a lake.

Traver hollow is floored by smooth thick drift. At the mouth of its southern tributary is a large pedestal that may have been formed by a local glacier, although the evidence is inconclusive.

The Esopus valley from Boiceville to Phoenicia holds extensive deposits of thick drift characterized by smooth surface and indefinite form. Much of it is stratified, largely clay, with a thin veneer of till. Above Longyear distinct morainic loops point northwestward up the valley. A short distance below Phoenicia indistinct loops suggest movement down the valley. Ice from opposite directions probably met at this locality.

The Woodland Creek valley was last occupied by a local glacier that moved northward, down the valley. At Woodland and on the hillslope southeast of it are distinct morainic loops which prove movement down the valley. Farther down, at the junction of Panther kill, are less distinct loops indicating movement in the same direction.

At the mouth of the valley a distinct morainic ridge lies on the west hillslope at 1120 feet, trending S. 60° E. Its situation suggests that it might have been built by a glacier descending Woodland valley and strongly deflected toward the west at its lower end by the curve of the valley wall to the east. It could not have been deposited in this situation by a glacier pushing westward past Phoenicia. The only other alternative is deposition by ice moving southeastward down the Esopus valley. Such movement seems unlikely because the morainic terrace on the opposite hill, north of the Esopus, descends toward the northwest, as if built from the southeast.

The head of the Woodland valley is relatively free of moraine, but has considerable outwash gravel. In the tributary valley that rises on the northeastern slope of Wittenberg mountain is a large pedestal bearing strong evidence of having been formed by a local glacier. Below it the valley bottom is composed of outwash gravel.

The valley of Panther kill has several morainic loops on the north side that point eastward as if built by a local glacier.

In the Esopus valley at Phoenicia is a large morainic terrace south of the stream whose relation is not clear.

In the vicinity of Allaben and Shandaken are morainic loops that obviously were built by glaciers descending Forest valley and Bushnellsville creek and spreading out as bulbs in the Esopus valley.

Moraines and thick drift in Fox hollow are noncommittal in direction. A small delta at 1440 feet at the head of the hollow was probably built into a local lake held in the valley by the ice that built the moraines at Allaben.

Between Shandaken and Big Indian faint morainic loops appear to point westward. They are thought to have been built at the western end of a bulb of ice pushing westward up the valley from the glacial tongue that descended Bushnellsville creek.

Big Indian hollow has very little drift in its lower part. A short distance below Oliverea faint traces of moraine point northward, down the valley. Above Oliverea numerous morainic loops pointing northward prove the presence of a local glacier of considerable size. A small local glacier appears to have descended the north slope of Balsam mountain to a level of about 1500 feet. Its moraines are small, but moderately distinct.

BIRCH CREEK

At the head of Birch creek, north of Rose mountain, is a group of massive moraines formed at the end of a tongue of ice that pushed from the east over the pass leading from Bushnellsville valley. Other moraines in this valley are mainly of the thick drift type and yield uncertain testimony as to the ice movements.

The pass at Grand Hotel, at 1890 feet, was occupied, probably only for a short time, by a stream flowing westward from a lake in the upper Esopus watershed. The channel at the divide is shallow and only 50 to 100 feet wide, and the amount of cutting across the divide has been small. On the west side, however, where the stream cascaded down a steep slope into Emory brook, it cut a considerable gorge in which distinct fossil waterfalls are found.

No certain evidences of local glaciers were discovered in the valleys on the north slopes of Belle Ayr mountain.

BUSHNELLSVILLE VALLEY

The glacial features of the Bushnellsville valley are especially interesting because it heads in one of the three low passes or "notches" that cut the Central escarpment, and was therefore a path of relatively free ice movement.

Sharp morainic loops at Allaben and morainic loops extending northward into Peck hollow prove that a tongue of ice from the Bushnellsville valley spread out in the form of a bulb in the Esopus valley. The moraines near Big Indian formed at the western end of the west lobe of this bulb have already been mentioned. There is no direct evidence that the bulb extended eastward farther than the moraines at Allaben, for the indistinct morainic loops below the mouth of Forest valley may have been built by a glacier from that valley.

At Shandaken is a large delta. The shape of its front shows that it was built into open water to the south by a stream descending Bushnellsville valley. Upstream it grades into an outwash plain that rises gradually toward a mass of moraines below Bushnellsville. These probably mark the position of the end of the ice at the time the earlier parts of the delta were forming. The elevation of the top of the delta—about 1320 feet—corresponds so closely with the level of the lake outlet at Wagon Wheel gap that doubtless the delta was built at the time the lake had its outlet there. From this prominent delta the lake is named Shandaken lake.

On the evidence from the delta and that of the stream channels southeast of High Point, we may conclude that when the ice ended at Bushnellsville its margin lay against High Point at Wagon Wheel gap, passed near Liebhardt and thence into the Rondout valley somewhere in the neighborhood of Kerhonkson or Wawarsing.

Above Bushnellsville, on the hillslope north of the junction of Angle creek, is a small kame or delta with a flat top at about 1820 feet, and an ice-contact slope on the west side. On the top, which stands out a little from the hill to the east, one can readily make out the point where the delta-building stream left the ice. It is uncertain whether this delta was built into a small lake impounded in Angle creek or into the larger water body (Peekamoose lake) whose outlet was at Peekamoose gorge.

Between Angle creek and Deep notch, on the east side of Bushnellsville creek, massive lateral moraines are found. Some of the ridges and embankments are sharp and distinct. Others contain considerable gravel.

DEEP NOTCH

Deep notch is the middle one of the three remarkably narrow and deep defiles that cut the Central escarpment (figure 60). The upper two-thirds of the profile of the notch has a slope of moderate steepness and is believed to be part of a preglacial gap in the range formed by the headward erosion of two streams from opposite sides. The lower third of the notch is essentially a rock gorge that is believed to have been formed mainly by glacial streams, which, as in the case of Peekamoose gorge, were diverted across the notch as a result of glacial interference with normal drainage.

The walls of this lower third of the notch are nearly vertical except where they have been broken down by weathering or are obscured by talus. At the divide the notch is so filled with boulders and talus that it is impossible to determine the elevation of its rock bottom, but it was almost certainly below 1880 feet and may have been considerably lower. It would be convenient to know the original depth of the gorge for it probably was the outlet of a lake in the Schoharie valley at some stage of the glacial retreat, although apparently not at the latest stage, for the gorge appears to have been partly filled with drift since it was abandoned by its stream.

South of the divide, below the two ponds shown on the map, is a steep-walled rock gorge such as only a powerful stream could have cut, but it is partly buried under glacial drift. Its walls are revealed here and there along the valley side where the drift has been removed. On the west side of the valley, for instance, near the junction of the secondary road that enters from the west, and about 250 feet west of the main road, a tributary stream has uncovered the buried rock wall of the gorge. At this point the bottom of Bushnellsville Creek valley is narrow and shows no evidence of the former presence of a larger stream. About a quarter of a mile downstream, however, the valley widens out and the glacial stream channel emerges, so to speak, from its drift cover. It has a flat bottom, steep sides and every appearance of having at one time carried a large stream. The elevation of the channel bottom here must be less than 1700 feet.

Whether the partly buried rock gorge through the notch was cut during earlier glacial epochs—including the advancing stages of the latest epoch—and for some reason was not reoccupied by a stream at the close of that epoch, or whether the channel was cut near the close of the latest glacial epoch and later partly buried by a readvance of the ice over its northern end or by local glaciers after the continental ice had receded, is an unsolved problem.

Whichever of these may be the correct explanation, it remains clear that the "notch" was not an important lake outlet after the final retreat of the ice from it.

PECK HOLLOW

Peck hollow is one of the shorter valleys heading on the south side of the Central escarpment. Its western branch heads in a gap in the range at about 2850 feet; its eastern branch starts on North Dome (3593 feet), one of the higher peaks. The moraines in the valley indicate ice movement southward everywhere except in the lower three-quarters of a mile, where two prominent morainic loops are convex up the valley and show clearly by their form that they were built by ice pushing up the valley from the south. On their western side they grade upward into a terrace that leads around the hill toward Bushnellsville valley, showing that they were built at the end of a bulb of ice that spread down the Esopus from that valley, at least as far as Allaben.

At the lower end of the massive moraine that is crossed by the county line is a small body of sand and gravel whose flat top at about 1330 feet suggests that it is a delta built into Shandaken lake, whose outlet was at Wagon Wheel gap.

Farther upstream the west branch of the valley contains considerable thick drift, which toward the head of the valley, has the form of indistinct pedestals. The absence of distinct moraines in this branch of the valley is conspicuous. Not so, however, with the east branch. At its junction with the west branch a remarkably sharp and distinct, though small, morainic ridge swings down out of the west side of the east branch and out across the west branch as shown on the map (plate 1). It was unmistakably formed at the western edge of ice that descended the east branch and spread out as a bulb where the two branches join—seemingly a local glacier heading on North Dome.

FOREST VALLEY

Forest valley has two principal tributaries joining about two miles above its mouth. One, Broadstreet hollow, heads in a broad, relatively low gap in the Central Escarpment (2460 feet); and the other on the southwest side of West Kill mountain, one of the highest peaks in the range.

That the pass at the head of Broadstreet hollow was an important channel of ice movement is suggested by its broad U-shape, indicating strong scouring by ice, and by a large mass of morainic material that chokes the upper two and one-half miles of the valley south of the pass. The top of the moraine is nearly flat, except that gravelly ridges descending southward from either side have formed a bowl-shaped depression that has been converted into a lake by a small dam. At the south end the moraine is flat-topped and gravelly at about 1835 feet, and at its outer edge is probably a delta built into a lake that stood at that level while the moraine was being built. The front of the delta, about 400 feet high, slopes very steeply to the south. Below the moraine and delta, at the mouth of Broadstreet hollow, are exposures of lake clay veneered with till, indicating considerable fluctuation of the ice margin while the lake waters were present. From this point to the Esopus, the bottom of Forest valley is filled with thick drift and moraine in which the presence of considerable lake clay is suggested by slumping and land-sliding.

In the small tributary valley west of Broadstreet hollow are two pedestals of thick drift or moraine having steep fronts facing the south. The hillside to the west of them has been strongly scoured.

The eastern tributary of Forest valley contains considerable thick drift and indistinct moraine in the lower two miles of its course. The remainder of the valley is floored with smooth thick drift through which the stream flows in a trench 10 to 75 feet deep. The tributary valley heading on West Kill mountain was not ascended, but from the opposite hillside it was seen to be a V-shaped valley with overlapping spurs showing no evidences of glacial erosion. No glacial accumulations other than the ever-present veneer of till were noted.

STONY CLOVE VALLEY (PHOENICIA AND KAATERSKILL QUADRANGLES)

The Stony Clove valley is one of the most interesting in the Catskills on account of the great number and variety of glacial phenomena that it displays. It heads in a remarkable defile, called Stony clove, cut to a depth of about 1400 feet through one of the highest parts of the Central escarpment (figure 61). Its headwater tributaries drain the southern slopes of three of the highest peaks in the Catskills—West Kill mountain, 3777 feet; Hunter mountain, 4025 feet; and Plateau mountain, 3855 feet. Combined in the valley are the effects of the continental glacier pushing through the low pass at Stony clove and of strong local glaciers that appear to have descended the slopes of Hunter and neighboring mountains.

Upstream from a point half a mile above Phoenicia, the Stony Clove valley is choked for about three miles with moraines comprising a remarkable series of ridgelike loops convex down the valley, some of them as sharp and steep as high railway embankments. The steep hillsides near Chichester are plastered with moraine which has been conspicuously exposed by landsliding and stream undercutting.

The lower half of the Ox Clove valley, a tributary entering at Chichester, is choked with moraine deposited by a lobe of ice that pushed up from the Stony Clove valley.

In the neighborhood of Lanesville the most conspicuous glacial feature is a terraced outwash plain, or valley train, the upper terrace of which may be traced from about half a mile below Lanesville upstream to the junction of Stony Clove and Hollow Tree Brook valleys, whence one branch extends for a mile up the latter valley, while another extends for a mile and a half up the Stony Clove valley to the moraine at the mouth of the first large valley leading down from Hunter mountain. From this point to Edgewood the bottom of the Stony Clove valley is partly filled by a series of deltas and a large kame, over 200 feet high, which blocks the valley opposite two morainic ridges descending toward it from the hillside to the south. The kame is believed to have been formed where an ice tongue ended in a lake, building the moraines above lake level and the kame below and up to lake level. Later, as the ice tongue retreated eastward up the valley the deltas appear to have been built into the same body of water. The top of the kame and the flat top of the delta on the hill northeast of it lie at about 1800 feet elevation. The deltas between the kame and Edgewood lie at two levels, approximately 1810 and 1830 feet. Their south fronts are straight and steep, as if built against a body of ice lying south of them in the valley. Bordering the deltas on the north is a mass of kame-moraine with numerous large and small kettle holes.

The deltas above described reveal the former presence of a lake in the Stony Clove valley, the level of which fluctuated between about 1800 feet and 1830 feet. It may be recalled that the deltalike front of the moraine in Broadstreet hollow, the delta in the Bushnellsville valley at Angle creek, and a delta in the Warner Creek valley, all lie at about the same level. These deltas were probably formed in Peekamoose lake, whose outlet was at Peekamoose gorge. It is possible, however, that those in Stony Clove valley were built at a later stage in a local lake impounded by one of the local glaciers descending from Hunter mountain.

About half a mile north of Edgewood a mass of moraine has distinct loops and ridges convex toward the south. North of this body of moraine, and leading into it, is a strip of hummocky kame-moraine bordering the west side of the valley for about three-quarters of a mile, which probably represents a marginal gravel terrace thrown into knob and kettle form by the melting out of its ice support on the east side.

Stony clove is a deep, narrow pass through the range (figure 61, also figures 19 and 20). No evidences of glacial scouring or vigorous ice movement through the pass were noted. Neither is there any sign of the pass having been occupied by a glacial stream after the ice melted out of it. It is evident, therefore, that Stony clove is not a postglacial phenomenon. It may have been cut by glacial streams during the advance of the Wisconsin glaciers or during the advance or retreat of glaciers of an earlier epoch.

The valleys heading on Plateau, Hunter and West Kill mountains present features which, in any region known to have been occupied by mountain glaciers, would be pointed out as the clearest evidence of glacial erosion. U-shaped valleys with oversteepened sides (figure 62) are especially conspicuous on the south side of Hunter mountain. Cirquelike forms are also conspicuous at the heads of several of the valleys, notably those heading on Hunter mountain and the one heading on the southeast side of West Kill mountain. The extensive areas of rock talus masking the steeper slopes of Hunter and Plateau mountains are believed to be due mainly to the oversteepening of the slopes of the valley sides and cirque heads by glacial erosion, thereby exposing the much-jointed rocks to intensive frost action, which led to their rapid disintegration. The valley sides and cirque heads have lost some of their characteristic glacial form as a result of this disintegration.

Further discussion of the evidences of strong erosion by local glaciers in this locality, together with a suggested explanation of the phenomenon, will be presented in the section on local glaciation.

The outwash valley train along Hollow Tree brook, which joins a similar train at an accordant level at Lanesville, has already been described. The Hollow Tree Brook branch heads in a series of moraines that appear to have been formed by glaciers descending the southeast slopes of West Kill mountain. A mile above Lanesville a large valley heading on the south side of West Kill mountain enters the valley of Hollow Tree brook. The lower half of the valley has a distinct V-shape and appears to be free from moraine; but where it joins that of Hollow Tree brook, a narrow, bouldery morainic ridge, 75 to 100 feet high, detaches itself from the southwest spur of the valley and swings down the middle of the valley of Hollow Tree brook for more than a quarter of a mile. The ridge appears to have been built by a local glacier descending the valley under discussion. About three-quarters of a mile farther up Hollow Tree brook a large, hummocky drift mass blocks the east side of the valley. Its top is gravelly and lies at about 1800 feet.

Diamond notch, at the head of Hollow Tree brook, is a sharp stream-cut notch, 200 feet or more in depth, partly choked by talus fallen from its eastern wall. The source and the direction of the stream that cut the notch are not known. No evidences of glacial scouring in or near the notch could be found.

WARNER CREEK

The lower four miles of the valley of Warner creek are comparatively open and free of drift except for indefinitely shaped accumulations of smooth thick drift in the valley bottom. Three-quarters of a mile above the mouth of the valley this thick drift filling makes a distinct "step" in the valley bottom. At the low gap in the south side of the valley at the Greene-Ulster county line a tongue of ice pushed into the Warner valley from the south, building three distinct morainic loops in the gap and a large mass of gravelly moraine and kame-moraine in Warner valley adjacent to the morainic loops. Behind the highest morainic loop on the east side of the gap is a marginal stream channel 50 feet in width leading down into the gravelly moraine in the Warner valley already mentioned.

At a somewhat later stage, a glacial stream of considerable size flowed through the west side of the gap and cascaded down into the Warner valley, where, at a level of about 1740 feet, it built a large delta into a lake (probably Peekamoose lake) which occupied the valley at that time. The delta has a steep, lobate front 160 feet high facing down the valley. The fossil waterfall and plunge basin at the head of the delta are as distinct as if they had only recently been abandoned by their stream.

In the Warner Creek valley, slightly more than half a mile above the gap, is a massive accumulation of stony moraine that appears to have been built by ice moving down the valley from the northeast, although this direction could not be certainly established. This moraine has ponded the stream, causing it to build a wide alluvial flat on its upstream side.

The upper part of the valley, as seen from a distance but not examined in detail, appeared to be floored entirely by smooth thick drift.

BEAVER KILL (PHOENICIA AND KAATERSKILL QUADRANGLES)

Beaver kill is a beheaded stream which at one time rose on the south side of the Central escarpment at its eastern end and entered Esopus creek at Mount Pleasant. The stream in the upper part of the valley, from Shady to Echo lake, has been captured by a stream called Saw kill draining more directly to the Hudson past Bearsville and Woodstock.

Glaciation in the valley of Beaver kill was dominated by ice from the Hudson Valley lobe that pushed westward and northwestward into the valley and against the southern flanks of the Central escarpment.

In the lower three miles of its course, the Beaver Kill valley is filled with smooth thick drift having the appearance of having been overridden by ice since its deposition. Farther upstream, opposite the mouth of Silver hollow, a huge mass of smooth moraine blocks the valley. It has effectively ponded the stream and caused the formation of a wide, smooth alluvial plain stretching upstream for three miles to Cooper lake. Along the north side of the valley between this moraine and the stream from Mink hollow, extensive marginal gravel terraces and kame-moraines were formed along the north side of the ice tongue which here traversed the valley from east to west.

At a later stage of the ice retreat a lobe of ice pushed into the valley through the gap south of Cooper lake and built a series of beautiful morainic loops that now inclose the lake. Outwash from these moraines was spread westward and probably contributed largely to the silting up of the ponded portion of the valley already described. A similar ice tongue undoubtedly pushed up Saw kill past Shady. In the area between these two ice tongues extensive kame-moraines were formed.

An ice tongue also pushed northward through the gap at Meads and built a pedestal moraine opposite the gap.

The valley of Saw kill from Shady to Echo lake has its bottom covered with thick drift and indefinite moraine. Echo lake is held in by a low bar of smooth thick drift without morainic form. At Shady a gravel terrace appears to lead downstream to a large delta, fragments of which are preserved on both sides of the stream half way between Shady and Bearsville. The top of the delta lies at about 880 feet, which corresponds closely with the level of a fossil stream channel leading into the head of the Little Beaver Kill valley. The lake in which the delta was built was evidently held in the valley over Woodstock and Bearsville by the Hudson Valley ice lobe.

A series of remarkably distinct morainic loops in the gap three miles north of Shady as well as those in the gap leading to Warner creek, testify to the westward and northwestward movement of ice from the Hudson Valley lobe around the end of the high Central escarpment.

LITTLE BEAVER KILL (PHOENICIA AND KAATERSKILL QUADRANGLES)

The valley of Little Beaver kill, like that of Beaver kill, was occupied, at least during all the later stages of the ice retreat, by ice moving westward from the Hudson Valley lobe.

In the lower two miles of its course the valley is deeply filled with thick drift, mostly of smooth indefinite form, although moderately distinct morainic loops are found on both sides of the valley near its mouth. A small drumlin rises from the thick drift a mile above the mouth of the valley, and another larger one at Yankeetown. In the stretch above and below Yankeetown, several distinct morainic loops swing down from the hillsides and partly across the valley. The tongue of ice that built these moraines ended in a lake, as is shown by the presence of a distinct delta, whose top lies between 860 and 880 feet, close inside the westernmost morainic loop, and by masses of kames and kame-moraines farther up the valley.

The entire upper end of the valley has been strongly scoured by ice. The soil is very thin, and smooth, bare, striated rock surfaces are common. Little glacial débris of any kind is present.

LOCAL DESCRIPTIONS—SCHOHARIE DRAINAGE

The Schoharie drainage is made up of a number of streams flowing westward between the Central escarpment and the Northeastern escarpment of the Catskills, and joining to form the main Schoharie creek, which flows northward across the Central New York plateau.

The outstanding features of the glaciation of the region were: (1) Ice from the north moving across the plateau and up the Schoharie valley until it met an opposing ice current from the Hudson Valley lobe; (2) ice from the Hudson Valley lobe pushing in to the open east ends of the valleys and through the gaps in the Northeastern escarpment; (3) a complicated series of glacial lakes impounded between these opposing ice lobes; (4) local glaciation in many of the valleys heading in the higher parts of the Central escarpment.

WEST KILL (PHOENICIA QUADRANGLE)

The lower end of the West Kill valley contains massive moraines extending to a height of more than 400 feet on either side. On the west side of the valley, south of Vinegar hill, frayed morainic loops indicate by their position that they were formed by ice from the northeast. Other morainic ridges and embankments on the west side of the valley also appear to have been built from the north by the continental glacier. On the other hand, the large sharp morainic ridge that swings out northwestward from the east wall of the valley at about 1900 feet gives evidence that it was built by a glacier moving northwestward down West Kill valley.

The part of this moraine facing the southwest is very steep and shows signs of slumping, but the position, direction and form of the morainic loops preclude such an explanation for the entire feature. The steep slope is interpreted as an ice-contact slope modified by slumping.

For two miles below and a mile above the town of West Kill, the valley bottom is occupied by outwash valley trains and gravel terraces, while the lower slopes of the hills are mantled with thick drift, composed partly of lake clay veneered with till.

South of West Kill indistinct morainic embankments, sloping in a direction opposite to that of most of the moraines in the valley, are believed to be remnants of moraines built by ice from the north and later overridden by the westward-moving local glacier that appears last to have occupied the valley.

On the north side of the road three-quarters of a mile, and again one and one-half miles, above West Kill, are two very distinct morainic loops with bear-den moraine and other evidences of marginal drainage on their northwest sides, whose position is such as to prove clearly that they were built by a glacier moving down the valley from the east.

From these moraines up the valley past Spruceton to the junction of the tributary valley from the north, the valley bottom and lower slopes are mantled with thick drift, in most places having a smooth, overridden appearance, but here and there, especially on the north side of the valley, showing indistinct morainic loops pointing down the valley.

In the upper mile and a half of the valley, above the northern tributary, rather indistinct moraines point to ice movement in opposing directions—up the valley and down. The latter are the later and more distinct. A stream channel and bear-den moraine on the northwest side of the loop on the north side of the valley prove ice movement from the southeast. In the short steep valleys tributary to West kill on the south, distinct evidences of the descent of local mountain glaciers from the bordering mountains are abundant. Pedestal moraines are found in the lower part of almost every valley. Only small and indistinct terminal moraines are found in these valleys, probably because the terminal moraines are farther down in West Kill valley, and those in the smaller valleys are recessional.

Evidences of strong scouring by these local glaciers are numerous, especially in the valley a mile southwest of Spruceton, where the rock is almost bare over considerable areas and is strongly smoothed and striated. Striae found on the spur west of this valley trend both north-south and east-west. In the valleys on the north slope of West Kill mountain oversteepened rock walls testify to the intense lateral erosion and plucking performed by the local glaciers (figure 79). At an elevation of about 2300 feet on the west side of the valley due north of the highest peak of West Kill mountain, strong glacial scratches on a vertical rock face ascend northward in broad curves (figure 17), proving that the ice at that point was moving upward and outward as it escaped the confines of the narrow part of the valley. This is one of the clearest proofs of the northward flow of the glacier at this point.

An interesting pedestal moraine, apparently the product of a small local glacier, is perched on the south slope of Rusk mountain at an altitude of about 2700 feet. The top of the pedestal has a relatively steep slope, but the front is much steeper. Above it, both on the northwest and the east sides are large talus slopes suggesting a disintegrated cirque wall. A stream channel, apparently too large for the present stream, leads down to West Kill from the pedestal.

The presence of a local glacier on a south-facing slope, exposed to the full effect of the sun, is surprising. It probably is to be explained as a result of drifted snow blown over the mountain from the north, as will be more fully discussed in the section on local glaciation.

The valley of West kill was occupied for almost its whole length by a local glacier moving westward and northward. This glacier built the latest and most conspicuous moraines in the valley, but did not entirely obliterate the moraines formed earlier by the continental glacier.

LITTLE WEST KILL (GILBOA QUADRANGLE)

Little West Kill valley is comparatively free of moraines except for a very massive one at the mouth of the valley and a number of small morainic loops at elevations of 1800 to 2200 feet in the valleys descending the north slopes of Bearpen and Vly mountains.

The bottom and lower slopes of the valley are composed of smooth thick drift having the appearance of having been overridden by ice since its deposition. For a mile and a half above the massive moraine at the mouth of the valley, scattered exposures prove this smooth thick drift to be composed of red lake clay with a five to ten-foot veneer of stony till.

The moraine at the mouth of the valley shows distinct loops curving down from either hillside toward the east in such a way as to indicate its formation by a large local glacier occupying the whole of the Little West Kill valley.

Of the small moraines in the valleys south of the main stream, that in the valley heading in the saddle between Vly and Bearpen mountains is the largest. Two distinct loops, both of which were unmistakably built by a local glacier moving northward down the valley, are found here. A photograph of one of these moraines was published by Johnson ('17).

In the other valleys the moraines are smaller and lie at higher elevations, but all are distinct and clearly the products of local glaciers.

A marginal terrace of gravel, which may mark the upper limit of the local glacier on the north side of the valley, is found at about 1880 feet along the road leading out of the valley toward Prattsville. The terrace slopes eastward at a low angle, showing that it was related to the local glacier rather than to the continental glacier, which undoubtedly occupied the valley at an earlier date.

FLY BROOK AND VALLEYS NORTHWEST OF IT (GILBOA QUADRANGLE)

The remarkable group of moraines at the head of Fly brook has already been described by the writer (Rich '06) and later by Johnson ('17). These moraines were the first recognized convincing evidence of the existence of local and independent mountain glaciers during a period following the retreat of the continental ice. The perfection of the moraines in the Fly Brook valley entitles it to consideration as the type locality for local glaciation in the Catskills.

The moraines indicate that three glaciers descended the northern slopes of Bloomberg and Roundtop mountains. The western glacier appears to have been the largest for it built the largest moraine, but the middle glacier extended as low, or even slightly lower, and built moraines of remarkable distinctness. The moraines built by the eastern glacier are smaller and less distinct, being more nearly of the pedestal type, but the lateral moraine on the west side of this glacier is well defined.

None of these glaciers appears to have lasted long enough to have done any conspicuous erosive work. The material of their moraines was probably derived mostly from the ground moraine left by the earlier continental glacier.

Two views of the moraines of the western glacier are shown in figures 63 and 64. Figure 63 is a view eastward across the moraine, showing its height of 45 feet above the lake and of 90 feet above the outwash plain on the down-valley side, and showing also its convex form northward (toward the left). Figure 64 is a view from the crest of the moraine looking across the lake toward the mountain, and showing the massive, but less distinctly formed recessional moraines.

The moraines of the central glacier are shown in figures 65, 66 and 67. Figure 65 is a view up the valley toward the lower morainic loop where it has been cut through by the stream. Its height at the stream is about 40 feet. Figure 66 is a view eastward across the lower loop of the moraine, showing its northward convexity, its back slope toward the mountains, and, less distinctly, the moraines formed by the eastern glacier, on which the house stands. Figure 67 is a view of the central moraine as seen from upstream. This photograph shows two recessional loops that detach themselves from the eastern lateral moraine and descend toward the stream.

The eastern of the three moraines is less distinct than the other two, as should be expected from the much smaller feeding ground that supplied it.

The adjacent lateral moraines of the eastern and the central glaciers lie parallel to each other and close together for several hundred yards. The road has followed the depression between them.

From the western side of the central loop a low, but distinct, moraine extends westward over the hill spur to join with the terminal loop of the moraine of the western glacier. It thus appears that these two glaciers at their maximum were confluent except at their ends where separate tongues projected downward in each of the valleys.

As will be seen from the illustrations, and as will be at once apparent on the ground, the evidence that the head of Fly Brook valley was occupied by a glacier moving northward is most clear and convincing.

A clue to the date of these moraines is given by a delta in the valley a short distance below them at the level of the glacial lake in the Schoharie valley that had its outlet at Grand gorge (Grand Gorge lake). This delta probably was built by outwash from the local glaciers.

NORTHERN SLOPE OF CENTRAL ESCARPMENT BETWEEN BLOOMBERG MOUNTAIN AND UTSAYANTHA MOUNTAIN (GILBOA AND HOBART QUADRANGLES)

Though the northward-facing range between the gap at the head of Fly brook and that at Grand gorge is lower than Bloomberg and Roundtop mountains, distinct evidences of small local glaciers were found in two of the valleys, namely, in Fall brook at the upper house at about 2100 feet, and in an unnamed valley on the southeast slope of Irish mountain (the second valley north of Fall brook).

The moraine near the head of Fall brook is rather smooth and massive, and about 400 feet wide. By itself it would not furnish unquestionable evidence of its local origin. Such is not true of the moraine on the slope of Irish mountain. Although small, its local origin is perfectly clear. It is an admirable example of a transition form between a pedestal and a loop moraine. As seen from the side (figure 34) it is a typical pedestal, convex down valley, with steep rocky front and nearly flat top, but on the top are low although perfectly distinct morainic loops inclosing a small, crescent-shaped pond having its convexity northward (figure 35).

In the valleys heading on the range between Grand gorge and Mount Utsayantha no distinct evidences of local glaciation were found. Near its head the valley of Jump brook is U-shaped, its bottom is steplike, and considerable thick drift is present, but no loop moraines were noted. If a local glacier ever occupied this valley it must have done so while the continental glacier lay in the valley below, so that its terminal moraines were not preserved.

In the valley heading on the north side of Mount Utsayantha is a pronounced pedestal at about 2300 feet that may have been formed by a local glacier, but its shape does not preclude the possibility of it being a drift bar built across the valley by the continental glacier.

BEAR KILL AND THE PLATEAU BETWEEN IT AND THE SCHOHARIE VALLEY (HOBART AND GILBOA QUADRANGLES)

The direction of the glacial striae and the disposition of the moraines in the valley of Bear kill and on the plateau north of it indicate that in the earlier stages of its retreat the ice moved southwestward across them and through the gap at the head of Bear kill leading to the Delaware river, and that in the later stages it moved westward and northwestward up Bear kill from the Schoharie Valley ice lobe.

The massive moraines lying in the Bear Kill valley from Mayham pond westward to the pass, and on the mountain slopes at either side, point westward and indicate a relatively long halt of the ice front in the vicinity of the pass. As the ice began to retreat from the pass a small tongue entering the valley from the head of Mine kill built a large pedestal moraine similar to those commonly formed by the local glaciers.

Most of the plateau north of Bear kill is covered with thin, stony till, but several sharp morainic loops lie opposite the lower sags in the divide, notably half a mile north and also half a mile east of South Gilboa. At the latter point the morainic loops are remarkably clear, and indicate movement from the east.

Along the valley of Bear kill below South Gilboa Station the moraines show ice movement northwestward up the valley. In one of the northern tributaries of Bear kill the ice actually moved directly northward, up the valley.

An interesting moraine half a mile south of South Gilboa Station shows how the ice developed protruding tongues as it melted lower into the valleys and came more and more under the influence of local topography. Successive stages in the retreat of this ice tongue are shown on the sketch (figure 7).

That there was considerable marginal glacial drainage across the eastern end of the plateau while the ice still lay in Schoharie and Bear Kill valleys is shown by the presence of several shallow, rock-cut stream channels crossing low points of the divide. One of the most interesting of these lies at about 1800 feet across the saddle about two miles N. 70° W. of Gilboa village. Although distinct at both ends, it is blocked in the middle by a low moraine, evidently deposited by a readvance of the ice after the channel had been cut. After this readvance the channel was not again occupied by the stream.

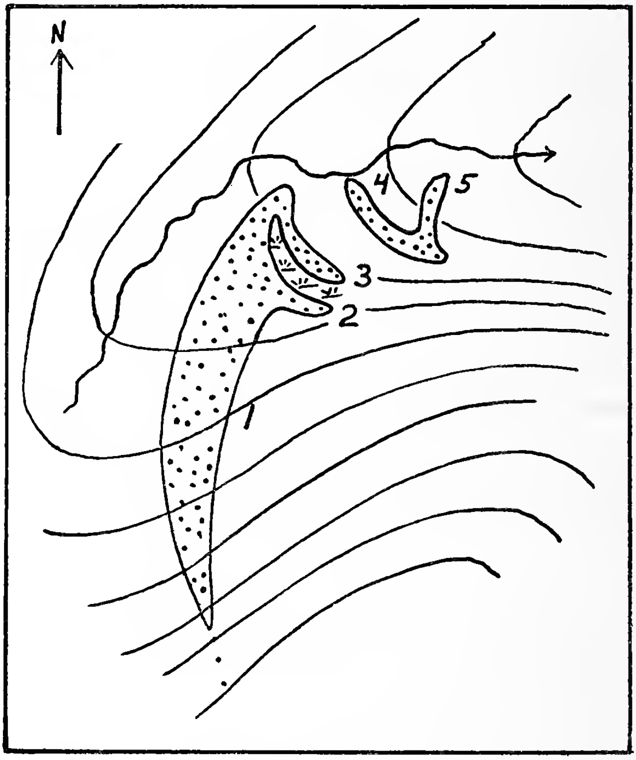

Figure 7 Sketch of moraines half a mile south of South Gilboa Station, showing successive stages on the ice retreat. At stage 1 the ice pushed over the hill into the valley from the east; at later stages it seems to have been confined to a tongue which pushed up the valley. Moraines are stippled

These marginal drainage channels, carrying heavily loaded glacial waters, are thought to have been responsible for the building of deltas, at about 1640 feet, in Grand Gorge lake—one in the valley two miles west of Gilboa and another half a mile northwest of Grand Gorge. Neither of these valleys has any adequate source, other than glacial waters, for so large a volume of delta gravels.

Another delta clearly associated with such a channel is found at about the same level east of the road at the Delaware-Schoharie county line, a mile east of Grand Gorge. A small channel with a fossil waterfall leads to the delta from the north.

Below Grand Gorge the valley of Bear kill is considerably choked with moraine and thick drift whose form in places indicates ice movement northwestward up the valley.

SCHOHARIE VALLEY FROM MINE KILL TO KAATERSKILL JUNCTION (GILBOA, PHOENICIA AND KAATERSKILL QUADRANGLES)

Mine kill, which enters the Schoharie about three and a half miles north of the village of Gilboa, marked the northern limit of the present survey. The portion of the Schoharie valley from Mine kill to Manorkill falls has been deeply filled with glacial deposits of great complexity, including two or more sheets of till with interbedded deposits of sand, gravel, and stratified clay. The working out of the detailed relationships of these deposits and their meaning in connection with the question of multiple glaciation must be left to future investigators. Only a very generalized account of the deposits can be given here.

Since the field work was completed, the New York City Board of Water Supply has made extensive borings and excavations in connection with the construction of the reservoir at Gilboa, and has undoubtedly uncovered much that throws light on the glacial history of the valley.

From Mine kill to Manorkill falls the Schoharie valley is choked with glacial débris to a height of about 250 feet above the stream. The upper surface of the drift makes a rather smooth, flat-topped bench (figure 12), especially conspicuous along the west side of the valley. Not all of the bench, however, is drift, for a rock bench at about the same level is exposed in several places.

Borings by the Board of Water Supply have shown drift filling to extend to a depth of more than 100 feet below the bed of Schoharie creek. The general nature of the drift above creek level is shown by the following sections, the first of which was measured on the east side of the river a mile north of Gilboa, beginning at the top:

	Feet
Clay, stratified; blue and chocolate colored; scattered iceberg (?) boulders	45
Sand, fine, yellow, horizontally stratified	39
Covered	6
Sand, fine, yellow, horizontally stratified with a little clay; clay crumpled in places; scattered iceberg boulders	35
Alluvium, coarse below, fine above; typical flood-plain section twice repeated; zone of springs at base (possibly interglacial)	21
Till, stony	11
Mostly covered; a few exposures of blue clay. From slump phenomena it appears that clay predominates	39
Covered to Schoharie creek	28
	224

The sandy drift of the upper part of the above section makes up the drift hills on both sides of the river in this vicinity.

A second section, quite dissimilar to that given above, was measured south of Gilboa village along the gully that is followed in part by the road to Grand Gorge. Thicknesses given are approximate only. The top of the section is the surface of the smooth, thick drift upland that forms the bench in the valley already alluded to.

	Feet
Till, dull red color, loose texture	20
Till, dense, blue, stony, numerous foreign boulders, especially limestones. (This part of the section is partly covered and has slumped extensively. It probably contains considerable stratified material)	135
Till, blue, compact, very clayey	41
Covered	6
Clay, pure, stratified, drab with streaks of red (fig. 48)	44
Till, blue, clayey, partly covered	12
Covered to level of Gilboa bridge	22

A mantle of pure lake clay covers considerable parts of the drift benches in the neighborhood of Gilboa (figure 49).

As a result of the deep drift filling of the valley, the Schoharie and its tributaries in places have been turned from their original courses and forced to cut new channels through the rocks of their old valley walls. The Schoharie is in such a rock gorge at Gilboa. Mine kill, Platter kill and Manor kill have all been diverted from their preglacial courses in the same way. Mine kill cascades into an older, partly drift-filled gorge at the road. Manor kill enters the Schoharie over a beautiful waterfall (figure 28), now partly buried under the waters of the Gilboa Reservoir. A buried channel of Manor kill appears to lie a short distance south of the falls.

From Manorkill falls to Devasego falls the Schoharie valley is relatively free of drift except for a remarkable series of kames that descend gradually southward into the valley along the western slope of Mount Royal (figure 46). These are believed to be related in origin to the large esker in the valley of Manor kill south of the village of West Conesville. These kames descend the hill in a row as if they were formed along a single subglacial tunnel and are partly isolated fragments of a single esker.

Devasego falls, one of the most attractive scenic features of the region, owes its existence to a large loop of morainic material that crosses the Schoharie valley in such a way that the stream was turned over against the preglacial valley wall, where it is still actively cutting a gorge in the rock.

The Devasego loop is composed of morainic materials on its southern side, and of stratified gravels, sand and clay on its northern and western sides. The top is veneered with a mantle of pure, finely laminated, red lake clay of varying thickness. The loop as a whole is convex northward and ties onto the hill to the southwest in such a way as to suggest that it was built by an ice tongue pushing down the Schoharie from the south and possibly reinforced by ice descending the valley of Fly brook (figure 11).

The composition of the loop, with its gravel and sand on the north side and its veneer of lake clay, further strengthens the evidence that the loop was built by an ice tongue from the south that here ended in a lake, at the same time discharging into the lake large quantities of red glacial rock flour that settled close by to form the veneer of lake clay.

From the Devasego loop southward along Schoharie creek to the mouth of Little West kill, the valley is relatively free of moraine, except for some rather conspicuous loops south of the mouth of Batavia kill that appear to have been formed by ice pushing out of the latter valley into the Schoharie. Borings show that the preglacial bed of the Schoharie valley is nearly 200 feet below the present stream.

Huntersfield creek cascades into the valley at Prattsville. Its preglacial course is thought to lie under the drift to the east of the falls. Before establishing its present course the stream cascaded for a time down the steep valley side a short distance north of the present falls, where its abandoned waterfall is clearly visible.

For a mile and a half above the junction of Little West kill, Schoharie valley is choked with moraine of indefinite form which may correlate with the very pronounced series of morainic ridges and embankments lying on the southern slopes of Patterson ridge at elevations of 2000 to 2200 feet, two miles north of Lexington. To the west the latter series of moraines ends in a small delta at about 1920 feet. Lower ridges, a mile farther east, end in kames and kame-moraines at about the same level. It is evident, therefore, that this ice tongue here entered a lake at the level mentioned. The indefinite form of the moraine in the Schoharie valley above the junction of Little West kill is undoubtedly due to its having been deposited under the waters of this lake.

Borings for the New York City Board of Water Supply have shown that the small valleys tributary to the Schoharie in this part of its course contain drift deposits 150 feet and more in thickness, whose surface appears as smooth till, but whose composition is found to be largely thick, pure lake clay with a till veneer.

In the Schoharie valley at Lexington and for about two miles upstream are moderately large moraines, seemingly pointing westward. They are smooth and subdued in form, like those farther down the valley.

At Jewett Center extensive moraines were formed by a tongue of ice that pushed into the Schoharie valley from the north and spread out in bulb form for a short distance both up and down the valley. Aside from these no important moraines are found in the valley bottom between Lexington and the western outskirts of Hunter village, although smooth thick drift is abundant. A pronounced morainic ridge, probably built at the end of an ice tongue facing eastward, projects northward part way across the valley at the western end of Hunter village.

In the valleys along the northern slopes of Evergreen and Rusk mountains are clear evidences of the former presence of small local glaciers, whose moraines are found at elevations between 1800 and 2100 feet in the valley directly south of Jewett Center (figures 68 and 69). Less distinct moraines and pedestals appear in the next valley to the east. Farther east, in the lower ends of the valleys descending the northern slopes of Rusk mountain pedestal-like forms were found, but no undoubted loops. This is surprising in view of the fact that Rusk mountain is higher than Evergreen mountain, and considerably higher than the mountains that nourished the local glaciers in Little West Kill and Fly Brook valleys. The only explanation that can be suggested is that local glaciers here were contemporaneous with and merged with the ice of the continental glacier.

Between Hunter and the junction of the northern and the southern branches of Schoharie creek, two miles east of Kaaterskill Junction, the bottom of the valley and its lower slopes are mantled with thick drift of smooth indefinite form, except in the immediate vicinity of Kaaterskill Junction, where a complex of moraines has been formed by the meeting of ice tongues from the east and from the west and also, probably, from a local glacier descending the northeastern slope of Hunter mountain.

Movement from the west toward this meeting point is indicated by massive moraines and morainic ridges at about 2000 feet on the south slope of East Jewett range a mile north of Hunter, and by eastward-pointing moraines on the hillside north of Kaaterskill

Junction. Movement westward to the same point is indicated by a series of distinct westward-pointing morainic embankments. Between these and the hill to the north is a large flat-topped accumulation of coarse gravel and sand at about 2050 feet elevation that is thought to have been built into a small marginal lake impounded between the opposing ice tongues and the mountain side.

Half a mile west of Kaaterskill Junction a large morainic ridge projects into the valley from the south. It can be followed as a distinct embankment southwestward up the mountain side to about 1850 feet, above which it becomes a one-sided morainic embankment with the steep slope facing the southeast. Farther south a long mass of rocky moraine occupies the central part of the mountain valley in the form of an elongated pedestal. From the east side of the valley three distinct morainic loops descend diagonally down into the north end of Stony clove (figures 19 and 20).

All these phenomena are interpreted as products of a local glacier originating on the northern slopes of Hunter mountain. It is possible, however, that the lower moraine, west of Kaaterskill Junction, may have been formed in part by a combination of the local glacier with an ice tongue pushing up the valley from the west.

An indistinct moraine of pedestal form at an elevation of about 2000 feet along Mossy brook, south of Hunter, makes a basin-shaped depression, which has been converted by means of a small dam into a storage reservoir. This moraine also is interpreted as the product of a local glacier.

Ice tongues pushed through the passes in the East Jewett range both northwest and northeast of Hunter, and in both built a series of morainic loops. From the eastern pass a drumlinlike ridge of thick drift extends down the center of the valley nearly to Schoharie creek. Glacial drainage channels were cut in both passes after the ice uncovered them. Between the western pass and Schoharie creek are two large deltas, one at about 1770 feet (figure 37) and the other at about 1650 feet, marking successive levels of a lake that occupied the Schoharie valley at the time. A larger delta, whose top lies at about 1865 feet, is found near the mouth of the valley that leads down from the eastern pass, and marks the level of another lake in Schoharie valley. This probably was a smaller body of water impounded between the two opposing ice tongues which met in this vicinity.

SOUTH FORK OF SCHOHARIE CREEK BETWEEN KAATERSKILL JUNCTION AND PLAAT CLOVE (KAATERSKILL QUADRANGLE)

The southern branch of the Schoharie valley also was the meeting place of opposing ice tongues, one pushing into the valley from the northwest round Clum hill out of the northern branch of the Schoharie, and the other pushing down the valley northwestward from the Hudson Valley lobe.

Evidences of the movement up the valley from the northwest are preserved in a series of morainic loops on the south slopes of Clum hill. Movement down the valley from the opposite direction is shown by moraines in the southeastern portion of the valley and by abundant striae pointing northwestward in the neighborhood of Plaat Clove. The most distinct moraines recording this movement were found about two and a half miles northwest of Plaat Clove, where a series of small morainic ridges is preserved with the greatest clearness. A well-defined morainic loop also encircles the head of Plattekill clove at Plaat Clove Post Office.

The exceptionally large mass of gravel, either kame or delta, found a little over a mile east of Elka Park, is believed to have been formed in a temporary body of water lying between these two ice tongues by the débris-laden streams from one or both of them.

The greater part of the valley of the south branch of the Schoharie is floored with smooth thick drift, some of it having the form of drumlins, and much of it having the appearance of older morainic deposits overridden by later ice advances. The valley does not appear to have been the site of any long halt of the ice front.

Evidences of local glaciation in the valleys leading down from the high range of mountains southwest of the valley are much less conspicuous than might be expected. The most distinct evidence is found in the valley of Roaring kill a mile north of Mink hollow (figure 70), where a small moraine loop swings northward across the valley. A larger distinct moraine of a local glacier lies about half a mile northwest of Elka Park in one of the valleys heading on the northeast side of Plateau mountain.

At the head of Plattekill clove the stream enters the clove over a high waterfall, but a short distance to the northeast is a buried gorge, probably a preglacial or interglacial course of one of the streams entering from the north.

NORTH FORK OF SCHOHARIE CREEK BETWEEN KAATERSKILL JUNCTION AND MOUNTAIN HOUSE (KAATERSKILL QUADRANGLE)

The entire valley of the north fork of Schoharie creek, except the heads of its northern tributaries in the neighborhood of Onteora Park, shows the influence of ice moving westward and spreading out fanlike westward and northwestward from the Hudson Valley lobe.

Along the south side of the valley for a mile southwest of Tannersville is considerable typical moraine, while on the north side of the valley, west of Tannersville, only thick drift with two well-developed drumlins and a few isolated small round kames are found. Over most of the area from Tannersville eastward about two miles, nearly to Haines Falls, the till veneer is thin and the rocks show evidences of having been strongly scoured by ice.

One large drumlin and two others less distinct lie southwest of Onteora Park, south of the gap between Onteora mountain and Parker mountain. They were formed by ice moving southward through that gap, presumably at an earlier stage than that in which the westward-pointing moraines near Tannersville were formed. Such a situation appears to be peculiarly favorable for the development of drumlins, presumably because of the decreased carrying capacity of the ice as it spread out after having passed through the narrow gap between the mountains.

At Haines Falls and for a mile to the north a large mass of terminal moraines shows numerous long morainic ridges and embankments. Both moraines and striae indicate movement westward and northwestward.

From the eastern edge of this moraine eastward to the edge of the Catskill scarp at Mountain House, the glacial drift is thin and strong glacial scouring is everywhere evidenced. On the hill south of the Kaaterskill lakes strongly scoured rock surfaces may be observed in many places. The striae show very clearly the influence of local topography on the direction of ice movement, revealing the fact that ice moved northwestward up Kaaterskill clove and spread out thence in fan shape. Striae trending only 23 degrees west of north were recorded north of the clove.

The lower of the Kaaterskill lakes is held in by a dam of smooth thick drift. The upper appears to be a glacially scoured rock basin. Between the two lakes the only place where rock can not be seen is not more than 60 feet wide and even there it probably lies very close to the surface of the ground. Bare rock is exposed almost everywhere around the upper lake.

The bottom and south side of Kaaterskill clove were not examined.

EAST KILL (KAATERSKILL, DURHAM AND PHOENICIA QUADRANGLES)

The conspicuous moraines at the mouth of East kill at Jewett Center have already been mentioned. Another group of rocky morainic ridges east and southeast of Jewett appears to have been built along the eastern side of a tongue of ice that pushed southward over the pass east of Prospect hill into the East Kill valley.

Strong ice movement through this pass is indicated by the thinness of the till veneer and by the strongly scoured condition of the hillsides west, north and northeast of Jewett. A fossil stream channel through the pass indicates that the pass carried glacial drainage for a time.

No important morainic accumulations are found in the East Kill valley east of those already mentioned near Jewett. Minor moraines are found on the south side of the valley about two miles east of Beaches Corner, and also on the southwestern slopes of the Blackhead mountains north of East Jewett. The latter were deposited along the eastern side of a tongue of ice that pushed into the valley through the pass west of the Blackhead mountains and south of Big Hollow. Three-quarters of a mile north of East Jewett, outwash terraces are associated with the moraine and a drainage channel in the moraine leads into a small delta at about 2040 feet, presumably built into a local lake in the upper end of the East Kill valley.

Three other small deltas are found in a space of two miles below East Jewett. Their levels correspond closely with those of the channels and the outwash plains in the pass south of Beaches Corner, which undoubtedly marked the outlets of the lake into which the deltas were built.

Although, with the minor exceptions already described, the glaciers did not leave important moraines in the valley of East kill, they did leave remarkable drift deposits of another type, namely drumlins and smooth thick drift accumulations of drumlinlike form. The part of the valley in the neighborhood of Beaches Corner has been molded into a giant washboard of long, narrow drumlins and drumlinlike ridges stretching from the pass east of Cave mountain across the valley toward the pass south of Beaches Corner.

It is believed that while the ice was building the moraines south of the East Kill valley at Jewett Center and in the passes south of Beaches Corner and East Jewett, it was building up these drumlins beneath its margin where it had lost part of its carrying capacity as it spread out after having squeezed through the gap between Cave mountain and the Blackhead mountains. In harmony with such an explanation, two of the largest and best-formed drumlins lie immediately south of the two lowest passes in this gap.

From East Jewett eastward to the head of the valley, smooth thick drift of indefinite form floors most of the valley and its lower slopes. A typical drumlin extends diagonally across the valley two miles below its head.

Two of the valleys on the south side of Black Dome were examined for evidences of local glaciation, but none was found. The valleys are U-shaped in form, have several pronounced "steps" or sudden changes in slope, and are floored with smooth thick drift. The valley south of Blackhead was not examined.

Crossing the divide at the head of the East Kill valley, and leading into it, is a rocky gorge evidently cut by a glacial stream that was here diverted westward into the East Kill valley from its course along the margin of the Hudson Valley ice lobe.

Mention also should be made of a series of small, but remarkably distinct glacial stream channels crossing the passes south of Big Hollow and south of Hensonville. All are narrow gorges cut in rock. At least part of them appear to have been the outlets of glacial lakes held in the upper end of the valley of Batavia kill above Big Hollow.

BATAVIA KILL (GILBOA AND DURHAM QUADRANGLES)

The valley of Batavia kill, like several of those already described, was the meeting place of conflicting ice currents during the closing stages of the glacial epoch. Ice pushed into the valley from the northwest around the west side of Huntersfield mountain, building a large lateral moraine along its eastern margin near Richmond Corners and apparently ending in the main valley a short distance above Red Falls, where conspicuous morainic loops point eastward up the valley. At the same time a tongue of ice from the same glacier appears to have pushed southward a short distance up Schoharie creek from the mouth of Batavia kill. Meanwhile a tongue of ice moved westward down Batavia kill and over the plateau north of it, meeting the lobe from the west side of Huntersfield mountain in the neighborhood of Red Falls and the valley of Lewis creek.

The valley of Lewis creek became the site of a glacial lake held in between these opposing ice tongues, and in it an interesting series of deltas at several levels was formed. Near the head of the valley large and distinct deltas lie at about 1810 feet and 1740 feet, and a less distinct one at about 1785 feet. Three-quarters of a mile down the valley a small delta is perched on the steep east wall of the valley at about 1720 feet. All of these appear to have been built by drainage from the eastern ice tongue.

In general there is very little glacial drift other than a thin veneer of till on the plateau north of Batavia kill in the stretch between Richmond Corners and the valley of Mad brook north of Windham. The lower ends of the valleys of West hollow and of an unnamed valley entering Batavia kill a mile east of East Ashland do hold considerable moraine, however.

In West hollow, half a mile above its mouth at Ashland, is a good-sized delta, whose top stands at about 1580 feet. It is bisected by the stream, so that there is now an east half and a west half. The east half shows traces of a later water level about 20 feet below the top. That this delta was built at the immediate edge of an ice tongue is indicated by the fact that the west half has kettle holes in its upstream part that must have been formed by the melting out of ice blocks that became buried under the delta gravels.

A similar but larger delta lies at the mouth of the valley a mile northeast of East Ashland. Its top stands at approximately the same level—1580 feet. This delta also appears to have been built at the immediate end of the ice tongue, for its northern side has slumped (figure 38).

Both of these deltas, as well as the larger one at Windham to be described later, lie at the approximate level of the lake outlet channel at Grand gorge, and undoubtedly were built at the margin of the glacier where it discharged into Grand Gorge lake.

In the valley of Batavia kill from Red Falls to Windham, several moraines are found, all pointing westward down the valley. At several places, notably near Ashland, East Ashland and halfway between East Ashland and Windham, morainic loops end in kames in the valley bottom, showing that the ice ended in standing water all of the time while it was melting back up this valley.

The portion of the Batavia Kill watershed north and east of Windham and from Hensonville to East Windham, is characterized by massive, smooth moraines and drumlins, and by evidences of powerful glacial abrasion in and close to the gaps through the northern bounding range, especially the two lower gaps—the one between Mount Pisgah and Mount Nebo (figure 18), and the other at East Windham.

As soon as the ice emerged from these gaps it appears to have spread out and lost its ability to carry its débris load. This caused the formation of a group of a score or more of drumlins a short distance south of the gaps (figure 30).

Beyond the drumlin belt, a short distance north and northeast of Windham, distinct morainic loops are numerous. A series of large smooth morainic ridges descending southward is found on the east side of the valley between Union Society and East Windham.

On the west side of the valley of Mad brook a mile north of the west end of Windham village, the moraine, which here is very massive, takes the form of a huge pedestal rather than of distinct loops.

At Windham the glacier ended in the waters of the Grand Gorge lake, where it built a large delta, whose top stands at about 1600 feet. The east end of the delta bears clear evidence that ice lay there when the delta was built. In melting out it left a hollow fringed on the south by remnants of the delta. (Rich '15, p. 162, figure 13).

About a half mile east of Hensonville a large morainic loop descends the south end of Elm ridge. Adjacent to its upper end at about 1925 feet is a large flat-topped kame or delta. The close correspondence of the level of its top with that of the channel through the gap south of Hensonville suggests that the kame (or delta) marked the point where marginal drainage flowing between the ice and Elm ridge emptied into a lake impounded in the upper Batavia Kill valley by the ice tongue that built the moraine east of Hensonville.

Striae on the south end of Elm ridge show that ice from the East Windham gap bulged eastward into the upper valley of Batavia kill, but no moraines large enough to indicate any long stand of the ice across that part of the valley were noted. It is likely that the striae were mainly the work of ice at earlier stages when it crossed the valley and pushed through the gap west of the Blackhead mountains.

Around Big Hollow and for three miles up stream the valley of Batavia kill is floored with thick drift of smooth indefinite form, some of it having the appearance of overridden moraine (figure 27). Such indistinct forms as were noted suggest deposition by or under ice moving westward down the valley.

Two miles above Big Hollow is a good-sized delta, whose top stands at about 1950 feet. Half a mile farther up the valley another delta stands about 40 feet higher. These levels correspond most closely with those of the channels across the divide south of Hensonville. It is believed that the deltas were formed in a small lake held in Batavia Kill valley by an ice dam at Hensonville and having its outlet through the pass to the south.

Half a mile above the uppermost of these deltas is a distinct morainic loop convex down the valley. It is the lowest of a series of interesting moraines at the head of the valley that clearly were built at the end of an ice tongue that moved northward down the slopes of Blackhead and Black Dome. The most prominent loop forms a small amphitheater in which the house at the head of the valley is situated (figures 71 and 72). West of it is another morainic ridge apparently built by an ice tongue from the same source.

The form of these moraines shows unmistakably that they were built by an ice tongue moving northward. On account of the local topography, a tongue of ice from the continental glacier in the Hudson valley could not have built these moraines, for the lowest and most direct entry into the valley would have been from the north through the gap between Acra Point and Burnt Knob, directly in line with the ice movement in the Hudson valley. Obviously the moraines were formed by a local glacier originating on the slopes of Black Dome and Blackhead. In distinctness the moraines vie with those of Fly brook.

HUNTERSFIELD CREEK (GILBOA QUADRANGLE)

As has already been stated (p. 95), Huntersfield creek is hanging where it enters the Schoharie at Prattsville and its stream cascades down through a rock gorge close to an interesting abandoned gorge and fossil waterfall. For the lower mile and a half of its course the valley bottom is choked with thick drift, generally smooth and indefinite in form. In places along the east side indistinct morainic forms suggest ice movement from the southeast. The evidence of such movement is doubtful, however.

At the cemetery a mile and a half above the mouth of the valley is a delta whose top stands at 1575 feet, or essentially the level of the Grand Gorge lake outlet. Another delta a little more than a mile farther up the stream has its top at 1750 feet. This level corresponds closely with that of a col half a mile south of Grand Gorge village, which shows evidence of having been water-swept and seems to have been the only available outlet for a lake at that level.

At the head of the valley is a large mass of thick drift of drumlin-like form.

MANOR KILL

The valley of Manor kill is remarkable for the variety and distinctness of its glacial phenomena.

Striae on the uplands indicate that the ice moved southwestward across the region in a direction almost parallel to the valley. The gaps in the range leading into the valley from the northeast were strongly scoured. In the pass east of High Knob the entire head of the valley has been left almost bare. The condition of much of its surface is well shown in figure 15. The head of the valley east-northeast of Manorkill suffered similar intense erosion.

The moraines in the valley show that as the ice withdrew from the region two opposing ice tongues met about a mile east of West Conesville, a mile and a half above the mouth of the valley. One of the tongues pushed eastward from the Schoharie valley up Manor kill to the point mentioned, the other descended the Manor Kill valley from the northeast. Meanwhile the Schoharie Valley ice lobe effectively blocked drainage to the north and impounded a lake in the Schoharie valley whose outlet was at Grand gorge. Consequently, while the ice was retreating up the Manor Kill valley it ended in this lake, a branch of which occupied that valley, and everywhere below lake level built its moraines under water. This condition apparently accounts for the gravelly nature of much of the moraine in the valley.

The easternmost moraine formed by the ice tongue that moved up the valley from the Schoharie starts on the south slope of the valley as a thick drift terrace, swings down the hillside toward the north, and changes into a distinct morainic loop leading toward a large mass of kames in the valley bottom.

Between this loop and the village of West Conesville, a large and rather complex mass of moraine chokes the valley. Its eastern part is veneered with lake clay, and its western part is gravelly. West of it, south of West Conesville, and leading into it is a very large winding S-shaped esker (figures 44 and 45)—the largest and most typical esker discovered in the Catskills. It is smallest at its western end, increases gradually in size toward the east and is believed to represent the course of a subglacial stream that traversed the ice tongue and discharged into the morainic mass—possibly a delta in part—east of West Conesville.

In the space between the eastward-facing morainic loop just mentioned and the westward-facing loop of kame-moraine a mile farther upstream, the valley bottom is floored with thick drift which, toward the valley center, is composed of gravelly lake clay.

The westward-facing loops above referred to are very massive kame-moraines. They are composed mainly of gravel, but have large boulders scattered through them. On the south side of the stream a very large kamelike mass stands detached from the valley side (figure 42). It may represent an accumulation of gravel at a point where a subglacial stream entered the lake.

At Conesville and for a mile upstream the valley is choked by massive gravelly moraines (figure 41). Associated with these moraines on both the north and south sides of the valley are small flat-topped masses of gravel at 1585 feet elevation that are probably small deltas built into the Grand Gorge lake while the moraines were being formed. Up-valley from these for two miles toward Manorkill the valley is almost entirely free of glacial débris other than the ever-present veneer of till. Its bottom, which is broad and flat and floored with alluvium, has the appearance of having been abandoned very quickly by the ice without recessional halts (figure 73). It strongly resembles the former bed of the Rhone glacier in Switzerland, which has been uncovered by rapid retreat of the glacier within the past 50 years.

At Manorkill another halt in the ice retreat is marked by a group of loop moraines, best developed northeast of the town. At this stage the ice tongue evidently ended in the shallow waters of Grand Gorge lake, and the large amounts of gravel and sand released by the melting ice quickly filled the valley to the water level, forming a large delta with a flat top at 1600 feet associated with the moraine at Manorkill. Kettle holes in the top of the delta indicate that ice was buried under parts of it and prove that the delta was formed while the ice ended in the immediate vicinity.

Aside from the moraines at Manorkill, no important moraines are found in the valley east of the Conesville loops. Patches of thick drift of drumlinoid form are scattered sparsely in the upper portions of the valley.

Search for evidences of local glaciation was made in the valleys on the north slope of Huntersfield mountain. At about 2050 feet in the valley northwest of the peak is a small moraine probably formed by a local glacier. The evidence of its local origin is not conclusive, however. No other moraines suggesting the former presence of local glaciers in that vicinity were noted.

North of Conesville another large delta, whose top stands at about 1610 feet (figure 74), appears to have been built into Grand Gorge lake while the moraine northeast of it was being formed. The delta top is flat except at the east end, where it is broken by a few small kettle holes. Part of the delta lies south of the present stream.

Near the head of Bear kill (a tributary entering Manor kill at Conesville) a considerable accumulation of moraine and thick drift appears to have been formed in an area between two ice tongues that encircled Leonard and Hubbard hills. Lateral moraines formed on the east side of an ice tongue that pushed through the gap west of Leonard hill mingle with lateral moraines formed at the northern edge of an ice tongue that moved southwestward from the passes in the neighborhood of High Knob. As might be expected, kames are found in this "interlobate" area. In the lee of the range, at the head of the valley, several well-defined drumlins are found in situations analogous to those in which the drumlins occur north of Windham.

PLATTER KILL

The outstanding glacial features of the valley of Platter kill are: a very large delta—the largest in the northern Catskills; a remarkable series of stony morainic ridges along the east side of the valley; and a number of large and typical drumlins on the plateau and in the tributary valleys west of the main valley.

As has already been indicated in the discussion of the Schoharie valley, the lower end of the valley of Platter kill is choked with a thick mass of glacial débris and glacial lake sediments, lacking in distinctive form, whose details have not been worked out. It is represented on the map as "thick drift." Much of this material is stratified sand and clay, and parts of it are covered with a thick veneer of lake clay. Owing to the weakness of its component materials, it has been deeply cut by postglacial streams.

A mile and a quarter upstream from the Schoharie is the first of the deltas, a small, isolated remnant on the east side of the valley. About an eighth of a mile north of it an isolated kame rises from a drift-covered hillside. Farther northeast, along the east side of the valley, is another small isolated patch of coarse gravelly delta. These isolated patches of delta material along the valley side, and the kame associated with them, are interpreted as having been formed in the earliest stages of the delta-building along the eastern margin of an ice tongue that then lay over the center of the valley where the main mass of the delta was later deposited.

The main body of the Platter Kill delta is about a mile long. It presents a steep front toward the south that has been modified considerably by slumping. A photograph (figure 75) taken from the hill west of the delta gives a good idea of its size. A portion of the delta extends about half a mile up the valley of a tributary stream entering Platter kill from the north between Darling hill and Mackey Rocks. Whether the material for the building of this part of the delta was supplied by an ice tongue ending at the pronounced morainic loop in that valley was not certainly determined, but it seems probable.

The main body of the Platter Kill delta merges upstream with a pitted outwash plain that can be traced upstream for nearly three miles. Its material evidently was supplied by outwash from the ice while the adjacent moraines were being built.

The moraines above referred to are long, rock-strewn ridges sloping diagonally southward into the valley from the west side of Leonard hill. Some of them are sharp and narrow, but most are rather broad. Hummocky morainic forms are noticeably absent, presumably because the moraines were not in any part deposited under water.

The fact that on the west side of the valley no series of moraines comparable with those on the east could be found is believed to indicate that ice covered the plateau west of the valley while the moraines east of it were being built. Thus, in a broad way, the moraines were lateral to a tongue of ice lying in Schoharie valley and covering the plateau between them and that valley.

Several large drumlins (figure 29) lie on this plateau and in the valleys draining it.

KEYSER KILL AND THE ADJACENT PLATEAUS (GILBOA AND SCHOHARIE QUADRANGLES)

The upper half of the valley of Keyser kill might fairly be called "The Valley of the Deltas." It displays the finest series of hanging deltas seen anywhere in the Catskills. Eleven deltas at levels ranging from 1615 to 1960 feet were mapped within an area not exceeding three square miles. Several of them are small, but others cover some hundreds of acres.

The setting for the formation of these deltas, as revealed by moraines, channels and deltas, was briefly as follows: A tongue of ice pushed southward from the continental glacier up Schoharie valley, blocking the lower valley of Keyser kill and impounding a lake in the upper end of that valley. Meanwhile another tongue of ice, pushing westward from the Hudson Valley lowland, lay on the plateau east of Keyser kill and discharged its débris-laden waters through half a dozen or more channels over the divide into the waters of the lake in Keyser Kill valley, which is here called Broome Center lake. When the first and highest delta was formed at Broome Center the ice appears to have covered all of the valley of Keyser kill except its extreme head. Into the small lake thus created, a stream from the east discharged, building the highest delta at 1960 feet. The lake discharged into the Platter Kill valley through the col south of Broome Center, where its channel may still be plainly seen (figure 76). Erosion of this col eventually lowered the lake level to about 1940 feet, as is indicated by the inner channel shown in the photograph. Meanwhile the ice had retreated northward about a mile and a large delta at the 1940-foot level was built.

Further retreat of the ice uncovered a lower outlet for the waters of the lake across a col on the plateau about a mile and a half west-northwest of Safford mountain, and it also made open water in the lake for at least a mile and a half north of Broome Center. At this stage a very small delta, the uppermost of a series of four on a single tributary of Keyser kill, was built at about 1875 feet a mile and a half north of Broome Center. This stage was short-lived, for a slight further retreat of the ice uncovered a col at 1820 feet a quarter of a mile west of the one just mentioned. In as much as considerable ice retreat was necessary before a lower col could be uncovered, the waters of the lake stood for a relatively long time at the 1820-foot level. Two large deltas were built at this level, one a mile and a half north of Broome Center, fed by the same channel that supplied the 1875-foot delta; the other half a mile north of Broome Center, fed by a channel from the moraine on the col east of Broome Center.

Further retreat of the ice on the plateau west of Safford mountain uncovered lower outlets, marked now by small channels at levels between 1780 and 1750 feet, around the hill north of the 1820-foot col. At this stage a good-sized delta was built at about 1765 feet by the stream from the channel a mile and a half north of Broome Center. The feeder channel from the moraine east of Broome Center may have been abandoned by this time, for no deltas at the 1765-foot level were noted which might have been supplied from it.

The next (and lowest) stage marked by conspicuous deltas in the valley, was the Grand Gorge Lake stage, whose deltas stand at 1615 and 1620 feet near the bottom of the valley two miles north of Broome Center. The northernmost of these deltas, at 1615 feet, was fed by a stream from the col northeast of it which lay at a lower level than those farther south, and which by this time was uncovered by the ice.

The existence of this delta at the Grand Gorge level fed by an ice-born stream from the divide to the northeast appears to show that the retreat of the ice in the Schoharie valley was considerably more rapid than that on the plateau to the northeast, for the ice in the former valley must have withdrawn almost to the mouth of Keyser kill to have permitted the Grand Gorge waters to flood the valley. The amount of recession involved in the withdrawal from Safford mountain to the 1620-foot level near the mouth of Keyser kill is about four times greater vertically than appears to have occurred on the plateau east of Broome Center in the same period of time.

On the plateau east of Broome Center morainic evidences point to a long halt of the ice margin. The moraines are partly in ridge form and partly hummocky. Two miles east of Broome Center a large mass of gravelly kame-moraine covers nearly a square mile. The highest parts of the knobs rise to about 2040 feet, which is very nearly the level of an extinct channel heading in the col west of them and leading down toward Broome Center. This mass of kame-moraine is interpreted as a delta or outwash plain built in a small lake formed between the margin of the ice and the col above mentioned. It is believed that the gravel buried part of the end of the ice tongue and that subsequent melting allowed the gravelly material to fall into the hummocky form now observed.

THE FRANKLINTON CHANNEL (SCHOHARIE QUADRANGLE)

At the head of Catskill creek, two and one-half miles north of Franklinton, is the beginning of a large glacial drainage channel that for a considerable time may have been the outlet of a lake held in the lower part of the Schoharie valley by an ice tongue blocking its lower end. At its head, at the northern end, the channel is 200 feet wide, and its banks attain a maximum height of about 50 feet. It holds about this width for nearly half a mile in traversing a mass of thick drift and moraine which there blocks the valley (figure 77). Below, it widens to 700 or 800 feet, which width it holds for about two miles of its course north of Franklinton (figure 78). The photograph shows clearly the flat, swampy bottom of the channel. The swampiness is due to partial obstruction of the channel by an alluvial fan built by a stream entering at Franklinton.

The elevation of the channel bottom at its head is 1168 feet, as determined by hand-level measurement from the road corner near-by.

The level of the water body that had its outlet through the channel was probably two to ten feet higher.

In his study of glacial water bodies in central New York Fairchild ('09, '12) failed to recognize this channel. Cook also ('24) states that the col is uncut.

LOCAL GLACIATION IN THE CATSKILLS

In preceding sections, particularly in those of local descriptions, reference has repeatedly been made to local, or mountain, glaciers that descended many of the valleys of the Catskills, in numerous instances moving in directions opposite to that of the movement of the continental ice sheet.

For detailed descriptions and for the evidences of the local nature of the glaciation in individual instances, the reader is referred to those sections, particularly to that describing the local glaciation in the valleys of Fly brook and Little West kill (Gilboa quadrangle) and West kill (Phoenicia quadrangle) (p. 86–90). In this section the broader aspects of the problem of local glaciation are sketched and its causes and date with reference to the continental glaciation are considered.

EVIDENCES OF LOCAL GLACIATION

Moraines. Of the fact of extensive local glaciation in the Catskills there can be no question. The evidences are conclusive and of several kinds. Most decisive is the presence of distinct morainic loops in such situations as to prove ice movement down mountain valleys in directions opposite to the direction of movement of the continental glacier. Such moraines were formed at many places, as has been pointed out on preceding pages.

Some of the moraines, notably those in the valleys of Fly brook, Little West kill, Woodland creek, Dry brook and Mill brook are especially clear and distinct. From moraines that are unmistakably due to local glaciers one finds all gradations to those so indistinct or so situated that their formation by local glaciers is probable, but can not be proved.

In general it is difficult, and in some instances impossible, to prove the local origin of moraines in valleys where the local glacier moved in the same general direction as the continental ice sheet. This applies to most of the south-facing valleys. Exceptions are found in a few instances where topographic conditions are such as to have made movement of the continental glacier into the valleys unlikely, as in the valleys on the south side of Hunter mountain.

Many of the moraines built by the local glaciers were of the pedestal type rather than loops (see p. 32–36). In fact, pedestals are considerably more common than distinct loop moraines in the valleys that were occupied by the local glaciers. In many instances the two are associated — pedestals making up the mass of the moraine, while small but distinct loops on its top prove its local origin. In as much as many of the local glaciers appear to have been comparatively sluggish and to have derived most of their rock load from the preexisting drift, they were undoubtedly overloaded in their lower parts, a condition believed to favor the formation of moraines of the pedestal type.

Pedestals, although commonly formed by the local glaciers, are by no means proof of local as contrasted with continental glaciation, and are not confined to valleys once occupied by local glaciers. They are common wherever sluggish tongues of the continental glacier spread out after pushing for short distances through narrow gaps.

CIRQUES, U-SHAPED VALLEYS AND OVERSTEEPENED VALLEY WALLS

Besides the moraines and pedestals deposited by the local glaciers, other evidences of their action are cirques. U-shaped valleys and oversteepened valley walls caused by the erosive action of these mountain glaciers. These are not so numerous as the moraines and pedestals because their formation required longer duration and more intensive action by the local glaciers than the formation of moraines. They are confined to the higher mountains, and are best developed around the Hunter, West Kill and Plateau Mountain group of peaks in the northern Catskills and the group of high mountains in the southern Catskills extending from Mill Brook ridge and Balsam Roundtop eastward to Slide mountain.

At the heads of many of the valleys in the areas just mentioned bare rock cliffs or masses of talus are found that are believed to have been caused by the disintegration of cirque walls formed by the local glaciers. Most of the valleys heading on Hunter and Plateau mountains appear from the topographic map to have cirque-like forms at their heads. Many of them also have a distinct U-shape, with oversteepened valley sides, which is a common characteristic of valleys scoured by local mountain glaciers. The valley on the south side of Hunter mountain entering that of Stony clove a mile and a half below Edgewood is an excellent example (figure 62). It has the typical U-shape; its sides have been widened until the ridges between it and the adjoining valleys have been made very narrow; and its head is approximately semicircular and very steep. Both the sides and the head of this and neighboring valleys must have been much steeper—in fact, almost vertical cliffs—at the time the glaciers melted out of them, for they are now almost entirely made up of talus formed by the crumbling and breaking down of these oversteepened walls. Similar talus slopes are found on the north side of Hunter mountain, on the north side of Slide mountain, and at other places where cirque action seems to have been strong.

In several of the valleys heading on the north side of West Kill mountain and other mountains in the same range, the valley walls of the tributaries at their lower ends, where they enter the main valleys, have been oversteepened in a manner entirely characteristic of mountain glaciers (figure 79). Vertical cliffs have been formed in situations where they could not have been developed by ordinary erosion or by the continental glaciers. The cliffs generally have talus slopes at their bases, and down-valley from them, where the ice spread out of the confines of the tributary valley into the main valley, scouring and other signs of strong glacial erosion are conspicuous.

Similar forms on a smaller scale were noted in some of the valleys on the north side of Mill Brook ridge in the southwestern Catskills. Distinct cirques at the valley heads are found along the south side of this ridge and eastward. Good examples are those at the head of Alder creek, Beecher Lake valley and Balsam Lake valley.

No attempt is made in this section to review all of the detailed evidences of the erosive action of local glaciers. Most of the more conspicuous instances are mentioned in the local descriptions.

DISTRIBUTION OF LOCAL GLACIATION

On the glacial maps (plate 1), the moraines that were interpreted as having been formed by local glaciers are shown by a separate color symbol. Likewise, on plate 2, extensive areas are shown around and outside of the borders of the outer belt of strong moraines, which are believed to have been occupied by local glaciers and their snowfields or by wind-drift snow of semiglacial character. These areas comprise the reentrant between the valley of the West branch and that of the East branch of the Delaware river, where the evidences of the presence of local glaciers are scattered and not entirely conclusive; and the reentrant formed by the ice front as it followed the general course of Esopus valley and the headwaters of Rondout creek, which includes the high southwestern Catskills, and in which clear evidence of extensive local glaciers is abundant.

In both these marginal areas the evidences of local glaciation, while unmistakable in parts of the last-named reentrant, are on the whole weak as compared with those found along the north slope of the Central escarpment, in spite of the fact that the southwestern Catskills are the higher. In the reentrant between the two branches of the Delaware river weak moraines pointing in directions suggesting local glaciation were found in several valleys, but nowhere strongly enough developed to furnish conclusive evidence of their local nature. The interpretation indicated on plate 2 is therefore partly conjectural and is based upon weak moraines, pedestals, the absence of moraines of the continental glacier in valleys where they should have been expected if those valleys were not occupied by local ice, and upon analogy with other valleys where similar relief and exposure resulted in the formation of local glaciers.

As may be seen from the map and from plate 2, local glaciers are believed to have descended the valley of Beaver kill (Margaretville quadrangle) nearly to Hardenburg; Mill brook to Grant Mills; Cold Spring hollow to its mouth; Dry brook to an elevation of 1500 feet a mile and a half above Arkville; Big Indian hollow to beyond Oliverea (and perhaps for its whole length); Woodland valley for its whole length; Traver hollow to an elevation of about 1200 feet; and probably Maltby and Mine hollows. On the south side of the range the fresh moraines in the West branch of Neversink creek near Branch, and in the East branch of Neversink creek at Ladleton, are believed to have been formed by local glaciers heading on the south side of the Slide Mountain group of peaks. At any rate there are no considerable moraines higher up those valleys, and those lower down appear to be much older.

In the northern Catskills the greatest center of local glaciation appears to have comprised Hunter mountain, Plateau mountain and West Kill mountain and the peaks to the west of it. On the south side of this group local glaciers or, in part, the continental glacier with reenforcement from local sources, are believed to have descended the Stony Clove valley for its whole length, and to have descended for considerable distances in the valleys west of Stony clove and south of the West Kill Mountain-Deep Notch range. A small local glacier descended the north side of Halcott mountain, but no evidences of local glaciers were recognized on the south side of the range between Deep notch and Grand gorge, although the distribution of moraines in relation to gaps in the Central escarpment indicates local reenforcement of the continental glacier in that locality.

On the north side of the range, between Grand gorge and Vly mountain, local glaciers occupied nearly all of the valleys, increasing in size southeastward. The moraines in the valley of Fly brook have already been described, p. 88–90. (See also earlier descriptions by Rich, '06 and Johnson, '17.) A local glacier descended the valley of Little West kill nearly to its junction with Schoharie kill, and another appears to have descended the valley of West kill to within a mile or less of its mouth. Little if any evidence of local glaciation was found on the north side of the range between Vly mountain and Deep notch. Although the mountains are high and have favorable northern exposure, comparatively little evidence of local glaciation was found along the north side of the range bordering the south side of Schoharie valley from the mouth of West kill to the eastern end of the Central escarpment. Local glaciers were present but they were not on a scale such as would be expected from the location. An explanation of this condition is suggested in a following paragraph. Small but unmistakable moraines testify to the presence of local glaciers on the north slope of the Blackhead mountains, but considering the favorable elevation and the exposure, the glaciers appear to have been much less extensive than those in similar situations farther southwest. No evidences of local glaciation were found on the south side of those mountains.

No evidences of local glaciation were noted along the Northeastern escarpment except small moraines in Winter cove and indistinct and doubtful moraines in a valley on the north slope of Huntersfield mountain. In general, evidences of comparatively vigorous local glaciation are found along the north side of the Central escarpment from the head of Fly brook to Plateau mountain; less evidence of local glaciation than might be expected from the exposure and elevation is found along the mountains south of Schoharie valley from the mouth of West kill eastward; and the same is true of the north side of the Blackhead mountains and of the northern slopes of the Northeastern escarpment.

The distribution of evidences of extensive, but comparatively weak local glaciation in the southern and southwestern Catskills has already been described.

POSSIBLE RÔLE OF GLACIAL ANTICYCLONE IN INFLUENCING LOCAL GLACIATION

In seeking an explanation for these facts and peculiarities of distribution of the local glaciation, it appeared that they were to be explained only in part by topography and exposure. Several features indicated that snow supply might be the other controlling factor. This led to a consideration of the possible rôle played by the "glacial anticyclone," described by Hobbs ('26), in the local glaciation of the Catskills.

Hobbs has shown that on the continental glaciers of Greenland and Antarctica, winds blow prevailingly down the slopes of the dome-shaped ice masses on account of the cooling of the air over the ice and its gravitational sliding down the slopes. It does not, however, blow steadily. It blows, rather, in a repeating cycle of raging blizzards and calms. During the blizzard stages of the cycle the wind picks up enormous quantities of snow from the surface of the ice and sweeps it down to lodge about the margins (see Chamberlin '95, p. 579).

The situation of the Catskills in a great reentrant between the Hudson and Mohawk lobes of the continental glacier, and the development of smaller reentrants within the mountains themselves as the ice withdrew, seem to have been particularly favorable to the concentration of wind-drifted snow by the glacial anticyclone. In view of that condition, the following interpretation of the local glaciation of the Catskills is made:

At the Late Wisconsin terminal (?) moraine stage as shown on plate 2, the group of high southwestern Catskills lay in a deep reentrant of the ice front, in such a situation that snow would have been drifted into them from three sides by the glacial anticyclone. It is at this stage that the local glaciers in the southern Catskills are believed to have been formed. To what extent they merged with the continental glacier along the Esopus and upper Rondout valleys could not be certainly determined.

At this stage also, the area between the West branch and the East branch of the Delaware river appears to have been in a pronounced reentrant where drifted snow would have been concentrated.

Meanwhile, the higher peaks of the Central escarpment and of the northern Catskills may have protruded above the continental ice sheet, but the valleys must have been buried.

During the stage when the margin of the continental glacier lay along the north side of the Central escarpment, the valleys leading south from the escarpment were in a position to receive large quantities of wind-driven snow from the continental glacier. To this is attributed the vigor of the ice tongues that occupied some of those south-facing valleys; the extensive moraines in the valleys of Batavia kill and Vly creek; and the strong development of cirques and other evidences of glacial erosion on the south side of Hunter mountain.

At a later stage, when the continental glacier had withdrawn to the position marked by spreading lobes in Schoharie valley (Schoharie valley stage, plate 2), the valleys of West kill and Little West kill and the northern slopes of the Central escarpment were favorably situated to receive large quantities of wind-driven snow that is thought to have caused the strong local glaciation of which moraines and other indications were observed in those valleys.

Meanwhile the ice lay over the valleys farther north so that local glaciers could not be formed there, and lay in the Schoharie valley so that local glaciers that were formed on the northern slopes of the range south of that valley and east of the mouth of West kill merged with the ice of the continental glacier and were unable to build up independent local moraines until after the continental glacier had withdrawn.

As the ice withdrew still farther northward, small local glaciers were formed on the north side of the Blackhead mountains, but for some reason, perhaps higher general temperature and more rapid ice retreat, they were not so extensive as in similar topographic situations farther south.

To summarize: It is believed that the local glaciation of the Catskills was essentially a phenomenon associated with the margin of the continental glacier and dependent to an important degree upon excess snow supply contributed by the winds of the glacial anticyclone. Further, it is believed that the belt favorable to the development of local glaciers migrated northward across the area as the continental glaciers withdrew.

Considerable evidence, however, suggests that the local glaciers lingered in the higher valleys along the Central escarpment until the continental glacier had melted back a considerable distance, and it may be that the record is complicated by readvance of the local glaciers during a stage of cooler climate and readvance of the continental glacier.

A delta at Grand Gorge lake level a short distance below the Fly Brook local glacial moraines indicates that those moraines were being built during the Grand Gorge lake stage. In Little West kill, however, the local glacier seems to have descended below the lake level and may have overridden a delta at the Grand Gorge level, for at that level a thick mass of lake clay is found which apparently has been overridden and is covered with a veneer of till. This suggests an advance of the Little West Kill glacier during the life of the lake.

On the south side of the range, in the valley of Stony clove, the sharpness of the moraines and the failure to find evidences that those in the lower valley were built into a lake suggests that the ice may have lingered in this valley until after it had melted out in the Hudson valley to a position low enough so that a lake was not impounded in Stony Clove valley. This interpretation, however, is not entirely consistent with the evidence from the deltas at Edgewood (p. 81).

Another puzzling condition that suggests possible readvance or an independent later existence of some of the local glaciers, is the blocking by later drift of the stream channels that were responsible for the cutting of Deep notch and Stony clove, unless, perhaps, those notches were made during the advance and not during the retreat of the continental glacier. The solution of these problems must await further study.

DURATION OF LOCAL GLACIATION

On the whole, it is clear that the local glaciers were relatively feeble and short-lived. In most places they did little more than pick up and rearrange some of the drift that had been left by the continental glacier as it retreated. In many places they overrode moraines and other deposits of the continental glacier, smoothing and modifying, but not obliterating them. In places the moraines of the continental glacier can still be found pointing in one direction while the fresher, sharper, local glacier moraines near-by point in the opposite direction.

In only a few places did the local glaciers persist long enough or become active enough to remove the preexisting drift from their beds and scour down into live rock. Some of the glaciers descending the north side of West Kill mountain were the only ones where such effects were noted. Cirque action, also, was confined to relatively few places. Strangely enough, on first thought, the most clearly defined cirques face south, both on Hunter mountain and on the mountains near Balsam Roundtop. This is believed to be due to the effects of drifting snow as already outlined. It may be also that, because ice flows more readily at higher temperatures, local glaciers facing southward would be more active than those facing northward, and would form extensive cirques, provided an adequate supply of snow were furnished by the glacial anticyclone.

RELATION OF LOCAL GLACIATION IN THE CATSKILLS TO THAT IN THE ADIRONDACKS AND THE WHITE AND GREEN MOUNTAINS

If the interpretation here presented of the local glaciation of the Catskills is correct, namely, that they were developed at times when the outer margin of the continental glacier lay against the Catskills, and were nourished in considerable degree by drifted snow contributed by the glacial anticyclone, it is not surprising that local glaciers should have been better developed in the Catskills than in the mountains farther north, for at the time of the local glaciation of the Catskills the more northern mountains must have been completely buried under the continental glacier. In that case, any local glaciation in the northern mountains would have been later than that in the Catskills, and might well have occurred under conditions of much warmer climate and more rapid ice retreat which were unfavorable for the development of extensive local glaciers.

Such an interpretation seems to harmonize the observations in the White and Green mountains (Goldthwait '16; '17; Johnson '17) with those in the Catskills.

HISTORY OF THE GLACIAL RETREAT

GENERAL STATEMENT

By means of the moraines, glacial drainage channels and deltas built into glacial lakes by débris-laden streams from the ice, it has been possible to reconstruct, in part, the history of the glacial retreat across the Catskills and to show the positions of the ice front, the marginal drainage and the glacial lakes at several different stages of the retreat (plate 2).

It has not been possible to make positive correlations of the positions of the ice front in all stages or over the entire Catskill area, because the morainic record is commonly lacking except near the ends of the ice lobes, and corroborative evidence from channels and glacial lake deltas is not everywhere available. Nevertheless, enough evidence remains to permit the deciphering of the broader features of the retreat, and even some of the details.

By study of the finely laminated clays deposited in the glacial lakes, future investigators, using the methods developed in Scandinavia by Baron De Geer and applied to eastern North America by Antevs ('22; '28), may be able to make exact correlation of many of these stages, even in widely separated valleys. Such a study is likely also to show that there were important readvances of the ice that could not be detected by the methods heretofore used.

De Geer's method is based on the fact that the sediment deposited in a lake into which glacial waters are being discharged shows a seasonal banding caused by differences in the amount of sediment deposited in summer and in winter. On account of the summer melting of the ice, sediment is supplied to the glacial lakes mostly during the summer, when the coarsest of it settles out, leaving the finer material to settle during the winter while the glaciers are frozen. Thus there comes about a distinct seasonal banding or variation in the texture of the lake clays.

During an exceptionally warm summer the ice melts more rapidly; more sediment is supplied to the glacial waters; and, consequently, the resulting clay bands are thicker than ordinary. Such seasonal changes of temperature affect areas of considerable size, so that during a warm summer, thicker clay layers would generally be deposited in all of the glacial lakes of an area considerably larger than the Catskills. These records of the seasonal fluctuations furnish the means of correlating from one lake to another.

By carefully measuring and platting the thicknesses of these clay layers, or "varves," De Geer and his followers have been able to build up a remarkably exact chronological system.

By the use of various lines of evidence other than the lake clays, it has been possible, however, to outline in a general way several stages in the retreat of the ice across the Catskill area (plate 2). This has been done by tracing the more conspicuous belts of moraines, by correlating moraines with lake deposits and lake outflow channels and by projecting the position of the ice margin from one valley to another on the basis of its known direction of movement and probable slope. When the evidence that was used can be checked and amplified by study of the varved clays in the numerous glacial lake deposits, the correlation can be made much more accurate and detailed than that here attempted.

LATE WISCONSIN TERMINAL (?) MORAINE STAGE

The earliest stage of ice retreat that can be traced with any degree of certainty is that marked by the most southerly—and highest—series of distinct moraines. This belt of moraines is conspicuous in that it marks the boundary between a region of prevailingly fresh loop-moraines, strong glacial scouring and fresh, little eroded drift north and east of the belt, and a region south and west of this belt of moraines where the characteristic features are smooth till or thick drift of subdued form, few distinct loop moraines, noticeably greater erosion of the drift by postglacial streams, large postglacial alluvial fans and in places weathered boulders in the drift.

The significance of the contrast on the two sides of the morainic belt is discussed in a following section.

The ice margin marked by this outer belt of moraines (plate 2) appears to have had, roughly, the following course: From Delhi (Delhi quadrangle) northeastward along the northern base of the range of mountains south of the valley of the West branch of the Delaware river to Mount Utsayantha, south of Stamford, where the moraines reach a height of at least 2250 feet above sea level; thence southeastward along the north slope of Moresville range at about the same elevation to the Grand Gorge gap; thence southward along the west side of the valley of the East branch of the Delaware river to Halcottsville and Kelly Corners, and possibly as far as Margaretville; thence in an easterly and southeasterly direction along the general course of the valleys of Bush kill and Esopus creek to the southeastern end of the higher Catskills at the head of Rondout valley (south slopes of Balsam Gap); thence (possibly leaving High Point, Mombaccus and Samson mountains as nunataks) turning southwesterly along the west side of the upper Rondout valley to the south slopes of Denman mountain; thence westward to the large terminal moraine at Curry, three miles west of Grahamsville.

From Curry the course of the ice margin at this stage has not been traced. It evidently lies west of the plateau west of Ellenville, which has been strongly scoured and bears several drumlins but very little moraine. The massive moraine at Phillipsport may correlate with that at Curry and represent in that locality the terminal moraine of this glacial stage. If such a correlation is correct the moraine will probably be found extending from Phillipsport northwestward along the valley of Sandburg creek, thence northward to Curry.

A possible alternative for that part of the above course extending from Delhi to the headwaters of Esopus creek is that the margin may have lain a little farther south and west, following along the south side of the valley of Little Delaware river from its mouth to the mountains at its head, thence southward down the west side of the valley of Platte kill, thence westward down the valley of the East branch of the Delaware river to some point below Arena and beyond the area examined.

Favoring this view are the facts that some of the moraines in the valley of the Little Delaware appear fresh and all point down the valley; rather strong moraines point up the valley of Platte kill north of Dunraven; and the lower slopes of the valley of the East branch of the Delaware river between Margaretville and Arena have been rather strongly scoured.

Opposed to the view is the old appearance of the drift in the upper valley of the Little Delaware, and the general smoothed and subdued appearance of the moraines in all of this area except the lower course of the Little Delaware, as compared with the sharp, fresh appearance of the moraines and the large amounts of outwash and kame materials found all along the course first sketched.

If the more southerly course is the correct one it is believed that the ice in this outer belt had somewhat the nature of a local ice cap and was largely a product of wind drift off the continental glacier, so that it was inactive in forming moraines except in the lower courses of valleys like that of Little Delaware, extending in the general direction of continental ice movement.

It is believed, as has already been suggested, that at this stage a local ice cap occupied parts of the high southern Catskills and joined its ice with that of the continental glacier, so that in the section of the above-described course extending from Halcottsville to Balsam gap and thence southwestward down the upper Rondout valley, probably at least as far as Sundown, the continental glacier did not rest against the mountains with a distinct contact which could be marked by moraines like those along other parts of its course but, instead, that it merged with ice of local wind-drift origin which filled the valleys and caused a general condition of stagnation where the local and the continental ice flows were in opposition, and an accelerated movement where they reenforced each other. The higher mountains probably stood out as nunataks.

Such a condition would have prevented the deposition of lateral moraines in many of the valleys as, for example, the upper Rondout valley, where they are not now found, but where they would otherwise have been formed.

As the ice began to retreat at the close of this glacial stage, it seems that the local ice lingered in the higher valleys, where, depending upon the topography, it either reenforced the ice of the continental glacier, causing it to linger longer and build more massive moraines than it otherwise would have done (as seems to have been the case in the valley of Batavia kill which enters the Delaware river at Kelly Corners); or it flowed in a direction opposing that of the continental glacier and thereby caused a stagnant condition unfavorable to the deposition of moraines. Such is believed to have been the case in Maltby hollow, along most of the course of the valley of Esopus creek and its southern tributaries, and along the upper course of Rondout creek (Slide Mountain quadrangle) where one finds neither the marginal moraines of the continental glacier nor clear moraines of local glaciers. By analogy with conditions in other valleys similarly situated, such moraines should have been present had the local glaciers not flowed out against and joined with the ice of the continental glacier.

The observed distribution of moraines and other glacial deposits in the valleys leading southward from the Central escarpment and in the valley of Esopus creek and its southern tributaries seems explicable on the hypothesis sketched above, but not on any other that has come to the writer's attention.

While the margin of the continental glacier lay along the course of the outer moraine as just described, a group of large, independent local glaciers seems to have radiated out from the southwestern group of the high Catskills. A local glacier appears to have descended Dry brook to near its mouth; others descended Cold Spring hollow, Mill brook to Grant Mills, Beaver kill to Hardenburg, West branch of Neversink creek to a point below Branch, and East branch of Neversink creek to Ladleton. As already suggested, the local glaciers in Big Indian hollow, Woodland valley and Maltby hollow probably merged with the continental glacier.

Meanwhile it is probable that most of the high peaks in the southern Catskills and the higher ones of those along the Central escarpment stood out above the ice as nunataks.

As the ice retreated from the position marked by the outer belt of moraines, its later stands are well marked by moraines and other indications except in the localities just mentioned, where continental and local ice are believed to have merged. There the moraines are complex and the glacial history is difficult to decipher. The key to the interpretation of the moraines in those localities seems to lie in the concept of general stagnation of the ice in the Esopus valley and its gradual melting out; retreat of the local glaciers up the valleys of the tributaries entering Esopus creek from the south; and strong ice flow in the valleys leading southward from the Central escarpment supplied not only by ice pushing through the gaps in that escarpment, but also by local glaciers from the higher mountains rendered exceptionally active by contributions of wind-drift snow from the continental ice sheet. On account of this local reenforcement of the continental ice in these valleys, they are believed to have been occupied by ice longer than they otherwise would have been.

PEEKAMOOSE GORGE—SUMMITVILLE LAKE STAGE

As the ice front retreated from its position along the outer belt of conspicuous moraines (Late Wisconsin Terminal (?) Moraine stage), it made several halts, and built moraines at Grahamsville and at Ellenville, which could not be definitely correlated with each other. Meanwhile glacial drainage apparently escaped westward into the Neversink river through a series of cols previously mentioned (p. 71).

As the ice withdrew from the Phillipsport moraine, a lake was formed in the valleys of Homowack kill and Sandburg creek, which, from its outlet at Summitville, may be called Summitville lake. This lake was destined to endure until the ice had melted back many miles to the neighborhood of High Falls, where the next lower outlet across the north end of the Shawangunk mountains was uncovered. (W. B. Heroy, personal communication.) The level of the lake dropped gradually as its outlet at Summitville was cut down from about 640 feet at the beginning to about 540 feet at the end.

A remarkable series of deltas was built into Summitville lake at points where glacial drainage emptied into it. These deltas, together with an equally remarkable series of glacial drainage channels, enable us to reconstruct a second stage of the ice retreat that is here called the Peekamoose Gorge-Summitville Lake stage.

At that stage the ice had uncovered the Peekamoose gap at the head of Rondout creek and the whole of the Rondout valley as far as Honk lake. The ice margin extended from Wawarsing northward along the mountain front to High Point at an elevation of more than 1800 feet, its course being marked by a series of moraines and marginal drainage channels.

All the marginal drainage following the west side of the glacier north of High Point, together with the local drainage of Esopus valley, was diverted through Peekamoose gap, whence it followed Rondout creek to Summitville lake, where it built a huge delta at Honk lake near Wawarsing.

Discharge through the Peekamoose channel continued while the ice melted back from Wawarsing to the neighborhood of Liebhardt. Between Liebhardt and High Point the ice retreat was accompanied by a shifting of the marginal drainage channels along the eastern base of the mountains and by the building of a series of small deltas progressively farther and farther north in Summitville lake.

Meanwhile, with the ice standing at about 1800 feet on High Point, and Peekamoose gorge being lowered by erosion from an original height, which is unknown but which was less than 1890 feet, to its present bottom at 1640 feet, the ice north of High Point projected into Esopus valley as a lobe, ending apparently about two miles below Phoenicia and impounding a lake that may be called Peekamoose lake at levels progressively lowering from about 1835 feet to 1640 feet. (At an earlier stage before the Peekamoose outlet was uncovered, a similar lake discharged for a time westward into the Delaware river drainage at Highmount, where its channel at 1890 feet is clearly visible.)

Deltas built into Peekamoose lake give a clue to the position of the ice on the north side of the lake at this stage. The gravelly flat top of the moraine at about 1835 feet in Broadstreet hollow three miles northeast of Allaben; a marginal kame-delta at 1820 feet at the mouth of Angle creek; the large gravelly moraine at about 1800 feet two miles north of Lanesville; and the deltas at 1830 feet to 1800 feet near Edgemont; all lie within this range of elevation. But after a consideration of all the known facts the writer believes that, of these, only the delta at Broadstreet hollow was surely built in the waters of Peekamoose lake.

The Angle Creek delta may have been built into a small local lake in Angle Creek valley, and the deltas at Edgemont may possibly have been formed later, during the retreat of local glaciers in that valley.

On Warner creek, however, at the Greene-Ulster county line, is a large delta at about 1740 feet which almost certainly was built into Peekamoose lake while the ice was building a moraine at 2000 feet in the low gap east of it. From the latter point the ice margin at this stage is believed to have extended eastward along the south slopes of the Plateau Mountain-Indian Head group of mountains to their eastern end, whence it turned westward along their northern side, lying at a probable elevation of about 2500 feet. Westward the ice appears to have lain banked against the north slopes of the Central escarpment at about the same elevation, projecting southward through the lower gaps in the range at Broadstreet hollow and Deep notch, but leaving the higher mountains standing out as nunataks entirely surrounded by ice. At this stage it is conceived that the local glaciers occupying the higher mountain valleys merged with the continental glacier, making the Central escarpment a minor center of ice dispersion.

The persistence of the local glaciers as the continental ice retreated farther is believed to be responsible for much of the complexity of the morainic phenomena in the valleys of Stony clove and Bushnellsville creek.

Meanwhile it is believed that the continental ice lay banked against the Central escarpment at least as far west as Stamford, and sent protruding ice tongues southward through gaps in the range at Grand gorge and elsewhere, but no means is at hand of correlating closely the ice position near Stamford with that at the same stage farther east.

WAGON WHEEL GAP STAGE

Further shrinkage of the ice lobe in Hudson valley eventually uncovered an outlet for the waters of Peekamoose lake around the eastern end of High Point at a level lower than that of the Peekamoose gorge (plate 2). The ice evidently halted here for a long time, for a rock gorge over 200 feet in depth was cut by the lake outlet waters at Wagon Wheel gap (figure 58).

At the Wagon Wheel Gap stage the position of the ice margin south of High Point is marked by a series of remarkably distinct fossil stream channels, and by deltas where these streams emptied into Summitville lake and into smaller lakes at higher levels along the ice margin. A number of extinct waterfalls and cataract plunge basins add interest to these channels.

At the beginning of the Wagon Wheel Gap stage the ice in the Rondout valley ended in the neighborhood of Fantinekill and Pataukunk, whence its western margin passed through Liebhardt and thence to Wagon Wheel gap along the hills west of Beaverdam creek. At a later stage a lower channel leading through the west branch of Beaverdam creek was uncovered.

North of High Point the position of the ice margin at this stage is marked by a series of deltas built into the lake in the Esopus valley, whose outlet was at Wagon Wheel gap. That lake is here referred to as Shandaken lake, from the large delta at that place.

The western margin of the Hudson Valley lobe, as determined by moraines and by the deltas, extended from Wagon Wheel gap up the Esopus valley to the neighborhood of Boiceville; thence eastward round Ticetonyk mountain; westward in a lobe down Little Beaver kill almost to its mouth; eastward round Mount Tobias; westward in a lobe down Beaver Kill valley to Silver hollow; thence northeastward along the south side of the Central escarpment to its end at Plattekill mountain.

At the same time ice from the Schoharie Valley lobe of the continental glacier appears to have pushed through the gap in the Central escarpment at Deep notch and ended in the Bushnellsville Creek valley a short distance above Shandaken, where a large delta was built at 1320 feet in Shandaken lake.

Between Deep notch and the east end of the Central escarpment at Plattekill mountain, the course of the glacier margin on the north side of the range is not definitely known, but it presumably followed the northern side of the range at somewhat less than 2500 feet.

LATER STAGES OF HUDSON VALLEY LOBE

After shrinkage of the Hudson Valley lobe had caused the abandonment of the lake outlet at Wagon Wheel gap, the ice margin appears to have been lowered gradually on the spur east of Wagon Wheel gap, without halting long enough for the cutting of a distinct channel until the col at 780 feet about a mile east of the gap had been uncovered. This col carried a good-sized stream, apparently for a considerable time.

The course of the ice margin south of the col during its occupation by a glacial stream can not be stated definitely because it is outside the area surveyed, but it is believed to have been southward to the Rondout valley near Port Jackson.

During the period between the abandonment of Wagon Wheel gap and the establishment of drainage through the col above mentioned, the ice melted out of the valleys of Little Beaver kill and of Beaver kill, leaving a delta at an intermediate level—about 870 feet—associated with one of the moraines in the valley of Little Beaver kill. At about this time the moraines appear to have been built at Cooper Lake and Meads. Thence, on the basis of assumed slope of the ice front, tentative correlation is made with the moraines of the upper Schoharie valley three miles west of Plaat Clove.

SCHOHARIE VALLEY STAGE

Correlating on the basis of moraines and deltas, the ice north of the Central escarpment at the stage referred to in the preceding paragraphs appears to have lain in the Schoharie valley in the form of several spreading lobes that entered the valley through gaps in its north side, from which it spread out both up and down the valley. One such lobe pushed about three miles down Schoharie creek from the Hudson Valley lobe at Plaat Clove as already described. Another lobe entered the valley through the gaps north and east of Tannersville, spreading both east and west, and a third entered the valley through the low area between East Jewett range and Patterson ridge, spreading eastward until it joined or nearly joined the lobe from Tannersville, and westward to the mouth of Little West kill.

Between these various lobes bodies of water were impounded, as is shown by the presence of deltas and kames at various levels, some of them apparently corresponding closely with the levels of the gaps at Deep notch and Stony clove, although any channels in these notches have been obscured by later drift.

From the mouth of Little West kill the ice margin at this stage appears to have swung eastward round the east end of the range at Tower mountain; thence westward down Batavia kill to a point a short distance east of Red Falls; thence northeastward round the east end of the Huntersfield Mountain group; thence westward and southward round Huntersfield mountain past Richmond Corners to Red Falls; thence southwestward, pushing a short way up Schoharie creek; and thence westward along the base of the Central escarpment at an elevation of 1800 to 2000 feet to Grand Gorge and probably to the large moraines near South Gilboa. Meanwhile, local glaciers probably occupied the valleys of West kill and Little West kill.

Owing to the irregular shape of the ice front, lakes, whose former presence is witnessed by a series of deltas at various levels, were impounded in the valleys between the ice lobes, notably in the valley of Lewis creek, northeast of Red Falls.

The several outlets of these water bodies are not definitely known. Grand gorge was the ultimate outlet, and it is believed that the lakes discharged through this outlet by means of channels held at various levels by the ice between its margin and the base of the Central escarpment east of Grand Gorge. As further evidence of such marginal drainage, several small channels across the hill spurs east of Grand Gorge were noted.

Deltas at 1865, 1770 and 1650 feet in the region between Beaches Corner and Kaaterskill Junction are believed to mark water bodies having a similar mode of discharge.

GRAND GORGE LAKE STAGE

The Grand Gorge Lake stage became established when the retreat of the Schoharie Valley lobe had progressed far enough to permit unobstructed outlet of all lake waters held in the upper Schoharie valley through the gap in the Central escarpment at Grand gorge.

Grand Gorge lake was relatively long-lived, for it was necessary for the ice to melt back a distance of about 18 miles to the spur two miles south of Middleburg before a lower outlet—that through the Franklinton channel at the head of Catskill creek—was uncovered.

During the life of the lake its outlet appears to have been lowered about 40 feet by the cutting down of its channel; for the earlier deltas, north of Grand Gorge, stand at about 1640 feet, while the later deltas in Manor Kill and Batavia Kill valleys have elevations of only about 1600 feet. The present level of the bottom of the Grand Gorge channel is a trifle under 1560 feet. This lower level of the bottom of the channel may be accounted for in part by further channel cutting between the time the 1600-foot deltas were formed and the opening of the Franklinton channel, and in part by the depth of water of the outlet stream. No clear evidences of postglacial tilting of the land were found.

During the comparatively long life of Grand Gorge lake the ice margin shifted considerably. For that reason the exact position of the ice front at any one time could not be determined by the methods used. At many places, however, lake clays were deposited whose laminae or "varves" when studied, may reveal the exact chronology of the glacial retreat during the life of the lake.

Although the Grand Gorge deltas were not all formed at the same time, and consequently the position of the ice front in all parts of the lake at any one stage can not be determined, nevertheless the limits between which the ice retreated during the life of the lake are reasonably clear. For example, the absence of deltas at Grand Gorge Lake level in the upper valley of Schoharie creek, except for a probably secondary one at about 1650 feet two and a half miles west of Hunter, indicates that at that stage the Schoharie valley above Hunter had been abandoned by the ice.

The retreat of the glacier up the Batavia Kill valley is recorded by the deltas at Ashland, East Ashland and Windham. At about the same time the ice front was retreating up the Manor Kill valley and building deltas north of Conesville and at Manorkill.

The large Platter Kill delta northwest of Gilboa appears to be earlier than the deltas at Manorkill and Windham. This is indicated by the correlation of moraines and by the fact that it stands at a higher level than the others.

A later stage in the history of the ice retreat during the life of Grand Gorge lake is recorded by the moraines, deltas and channels in the neighborhood of Broome Center (see p. 108–10).

At this later stage all of the gaps in the Northeast escarpment from Broome Center to East Windham, except possibly some of the lower ones at the eastern end, were free of ice, but ice moving from the northeast terminated on the plateau east of Broome Center north of the Northeastern escarpment. The Schoharie Valley ice lobe lay over the lower valley of Keyser kill and against the northern slopes of Mount Safford at about 2000 feet, whence a tongue pushed up Schoharie valley to a point between North Blenheim and Gilboa.

Under these conditions a remarkable series of deltas, already fully described (p. 109), was built in a small lake at the head of Keyser kill by outwash streams from the ice on the plateau to the east. As the ice level on Mount Safford was lowered, a series of drainage channels was cut on the plateau west of the latter mountain, progressively lowering the level of the lake in the upper Keyser kill, and discharging into Grand Gorge lake a mile northeast of North Blenheim, where a delta was built.

FRANKLINTON CHANNEL STAGE

The latest stage, which may be called the Franklinton Channel stage, of the ice retreat recorded in the area under investigation, is that shown by the lake outlet channel at 1168 feet at the head of Catskill creek two miles north of Franklinton.

At the beginning of this stage the ice in Schoharie valley must have reached a level on the hill spur two miles south of Middleburg lower than that of the Grand Gorge lake outlet, permitting the waters of that lake to drain out through the Franklinton channel. Meanwhile the retreat of the ice of the Hudson Valley lobe must have progressed far enough to permit the escape of the waters from this channel along the northern base of the Catskills at elevations below 1150 feet.

DATE AND CORRELATION OF CATSKILL GLACIATION—MULTIPLE GLACIATION

Attention has already been called to an outer belt of moraines, (see p. 120–21 and plate 2) that seems to separate two unlike areas—one to the north and east, in which moraine loops are abundant, sharp and fresh; and the other to the south and west where few moraines are found, where smooth, thick drift is the prevailing form of glacial deposit, where evidences of the erosive action of the ice are few, and where the topography and the weathering of boulders suggest noticeably greater age of the drift.

These differences appear to be of the same order as those observed by Tarr ('09) outside of the belt of "valley head" moraines in the Finger Lakes region. It is, therefore, suggested as a working hypothesis that the outer belt of moraines in the Catskills corresponds with the "valley head" moraines of the Finger Lakes region.

Taylor ('25) has correlated the "valley head" moraines with the Alden and Marilla moraines of the Buffalo region, which, in turn, he correlates with the Port Huron moraine of Michigan (Taylor '25 a). The latter, he states, is the front of the Late Wisconsin.

Chamberlin ('81–'82) long ago, as the first of three possible correlations, made the suggestion quoted below:

> The ice of the second glacial epoch, according to this view, passed westerly and southwesterly across the northwestern spur of the Catskills, forming the moraines below Schuyler and Otsego lakes, those along the upper 20 miles of the Susquehanna valley, and in the Charlotte valley, those that lie opposite the gaps in the range at Stamford, and at Grand Gorge and in the valleys below those points. It is believed also that the sheet passed over the northeastern and eastern portions of the main Catskills, but that it did not override with appreciable force, if indeed it surmounted at all, the higher southerly and southwesterly Catskills, the ice there being broken up into valley currents and practically arrested in its progress. To these local currents are referred the minor moraines scattered through the mountain valleys, though some of them may be due to independent local glaciers of later date.

Chamberlin states that south of the Catskills a considerable glacial stream entered the gap between the Catskills and Shawangunk Mountains and moved west and southwest.

> The margin thus outlined divides the territory that shows unmistakable evidence of glacial subjugation from that in which the modifying effects of ice action are far less marked and quite subordinate to the pre-glacial configuration of the surface, the drift being little more than a thin, discontinuous blanket spread over the hills and valleys only slightly modified by ice action. This distinction between the two areas obtains throughout the entire glaciated territory traversed by the moraine, and possesses considerable value in discriminating between the earlier and later glacial provinces, but in its application to a region originally so rough as this more or less doubt attaches to a correlation based upon it.

From the above it will be seen that Chamberlin in his "first correlation" has anticipated very closely the interpretation that has resulted from the later, more detailed work.

Study of the area between the Catskills and the Finger lakes will be necessary before the correlation can be finally settled, and further critical study of the evidences of the relative age of the drift on the two sides of the moraines will have to be made before a long time interval between them can be certainly proven.

According to the interpretation here made, the higher Catskills, especially in the southern part, were not covered by ice during the Late Wisconsin stage. This interpretation harmonizes with the failure to find striae on any of the higher parts of the mountains, except those reported by Chadwick on Slide mountain, and with the conspicuous weathering that is shown by the rock ledges near the summits of the higher mountains.[1]

No certain evidences of pre-Wisconsin glaciation were found, though they may well exist in many places. Till sheets separated by gravel and clay beds were noted near Boiceville (Slide Mountain quadrangle) (see page 75) and at a number of places near Gilboa (see pages 93–94). Critical study of these localities might reveal definite evidences of earlier glacial or interglacial deposits. Unfortunately, the water of Gilboa reservoir has covered some of the best exposures in that vicinity.

Drift-filled gorges are found at a number of places. Careful study of these might reveal evidences of multiple glaciation.

ECONOMIC EFFECTS OF GLACIATION IN THE CATSKILLS

The glaciers greatly affected the economic possibilities of the Catskill region in many ways. They completely reworked the soils; made workable deposits of sand, gravel and clay in many places; and interfered with the normal stream drainage, causing lakes, swamps and waterfalls.

SOILS

By modifying the soils the glaciers controlled in large measure the agricultural possibilities of the region. The various types of glacial deposits that have been described on preceding pages each produce characteristic types of soil and subsurface drainage, so that the glacial map could be used with considerable success in predicting the agricultural possibilities of any particular area.

One of the most important detrimental effects of the glaciers was to scatter stones of all shapes and sizes through the soil. Slabs of the shelly Catskill sandstone (figure 9) were plucked off the ledges in great quantities and scattered widely. Clearing away these stones so that the land could be cultivated was one of the hardest tasks of the early settlers and one that is not yet completed, for the frost

[1] It is believed that the striae found by Chadwick ('28) on Slide mountain were made during the Early Wisconsin glaciation that built the moraines on Long Island and that undoubtedly overrode the Catskills.

continually brings new crops of stones to the surface. The stone walls so abundant in many parts of the Catskills testify to the task that has been imposed on the settlers by the glacially transported stones.

The stoniness of the glacial soils depends upon the nature of the drift, on the locality and on various special conditions. Most of the till is stony. The thick drift, as a rule, is less so; kame, esker and delta deposits are gravelly; and moraines may be either gravelly or stony, ranging in stoniness to the "bear-den" type, which is composed entirely of stones and boulders with little or no soil.

On the whole, the best agricultural land, except some of the alluvial land in the stream valleys, is found in the areas mapped as "thick drift." These areas are generally relatively smooth; not too stony and generally not too steep for cultivation. The "thick drift" holds moisture well, yet is not likely to be too wet.

The till, which is the thin glacial soil covering most of the mountain sides, is generally used for pasture or woodland. As a rule it is too thin or too stony or on land too steep for profitable cultivation.

Along some of the larger streams, postglacial alluvial deposits make fertile farms, but along the smaller and steeper streams they are commonly too gravelly and too much subject to overflow and erosion to make desirable agricultural land.

In some places outwash terraces are composed of material fine enough to make good farm land, but generally the gravel is too coarse, or so porous that the soil becomes too dry for successful cultivation.

Many areas in the valley of Schoharie creek and its tributaries and of Esopus creek are underlain by lake clay that slumps and landslides so badly as to render the land worthless for anything except pasturage or forest.

SAND, GRAVEL AND CLAY

Sand and gravel in the Catskills are moderately abundant, but their occurrence is limited almost entirely to certain types of glacial deposits whose distribution can be ascertained from the accompanying maps, since each type of deposit containing sand and gravel has been distinguished by its appropriate color on the map.

The deposits that have yielded or may yield sand and gravel are: deltas, kames and kame-moraines, eskers and outwash plains.

The largest gravel and sand deposits are in the deltas that were formed in the numerous glacial lakes, especially in the Schoharie and Esopus valleys. Any delta shown on the map is a potential sand and gravel bank, whether or not it has yet been opened. Some, of course, have sand and gravel of much better quality than others.

All kames also are made of sand and gravel, although in some of them it may not be apparent at the surface because of a veneer of till. Kame-moraines are made up of irregular mixtures of sand, gravel, till and clay.

Outwash plains and terraces may be expected to yield coarse gravel, but little high-grade sand.

The glacial sand and gravel in the Catskill region is rather inferior in its qualities because it is made up of mixtures of shale and sandstone pebbles, instead of pure quartz sand. Shale pebbles in the gravel, on account of their weakness, make it unsuitable for some purposes such as high-grade concrete or road surfacing.

Clays in great abundance and of great purity are found in many parts of the Catskills. They were deposited in the many glacial lakes that were impounded in valleys blocked by the ice. They are prevailingly red in color, being derived mainly by glacial reworking of the Catskill red shales. Many of the deposits are practically free from stones. Some have small and large stones scattered through them.

Whether or not these clays have any particularly valuable characteristics is not known to the writer. Unfortunately their distribution is only very inadequately shown on the map because in most places they are veneered by glacial deposits of other types. They are very abundant in Schoharie valley; in the valley of Esopus creek; and in the area once covered by the Summitville lake, especially in the neighborhood of Kerhonkson and Ellenville. For their distribution in any particular valley the reader is referred to the local descriptions, where most of the more conspicuous deposits are mentioned.

DRAINAGE CHANGES

In the Catskills the economic effects of glacial interference with normal drainage were of little consequence. A few lakes were formed that have been important in connection with the summer tourist and resort industries, but on the whole the number of lakes is remarkably small. The same is true of swamps. Very little of the land is swampy.

By diverting streams out of their normal courses and causing waterfalls and rapids, a number of water power sites of moderate importance have been formed. It happens, however, that except for the falls in the Schoharie at Gilboa and Devasego, both of which are within the area covered by the new Gilboa reservoir, and a fall in Batavia kill at Red Falls, none of the larger streams in the Catskills proper has been diverted so as to form important falls.

South of the Catskills the diversion of Rondout creek at Napanoch has given rise to an important water power site with a drop of 272 feet (from 572 feet to 300 feet altitude).

Throughout the Catskills many small waterfalls and cascades occur where tributary streams have been shifted to one side, as they enter the main valleys, by deposits of thick drift plastered across the mouths of their valleys. These streams are generally too small to constitute important water power resources.

On account of the abundance of spring water to be had everywhere in the Catskills, the glacial drift has little importance in connection with local water supplies.

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Figure 8 Looking across the upper part of Big Indian hollow toward Slide mountain, a typical scene in the higher Catskills. All is forest except in the larger valleys where a few small clearings have been made. Many of these are now being allowed to return to forest.

Figure 9 Typical slabby cross-bedded sandstone—the commonest rock in the Catskills. Elevation, about 2400 feet two miles south of Hobart. Note pronounced weathering of the ledge.

Figure 10 Physiography of upper valley of Esopus creek, showing remnants of 2000-foot peneplain on shoulders and spurs; sharply cut valleys below them; and, in the distance, monadnocks like Panther mountain which rose high above the peneplain. Looking southeast from a mile east of Pine Hill.

Figure 11 The 2000-foot peneplain sharply trenched by the valley of Schoharie creek, as seen from the hill a mile west of Prattsville, looking northwest. Devasego morainic loop (p. 95) and the lake clay deposits south and west of it appear in the middle distance.

Figure 12 Bench in the Schoharie valley about 300 feet above the stream and 700 feet below 2000-foot peneplain which forms the nearer skyline. Peaks of the Central escarpment rising over 1000 feet above the peneplain appear on the distant skyline. The bench is partly drift, especially at the left. Looking southwest from slopes of Red hill, two miles north of Gilboa.

Figure 13 Looking south-southwest from Mount Utsayantha across head of the Town Brook valley. Shows broad, open character of the valley head—a condition typical of many of the valleys near or above the level of the 2000-foot peneplain. "Narrow Notch" (fig. 23) appears in center.

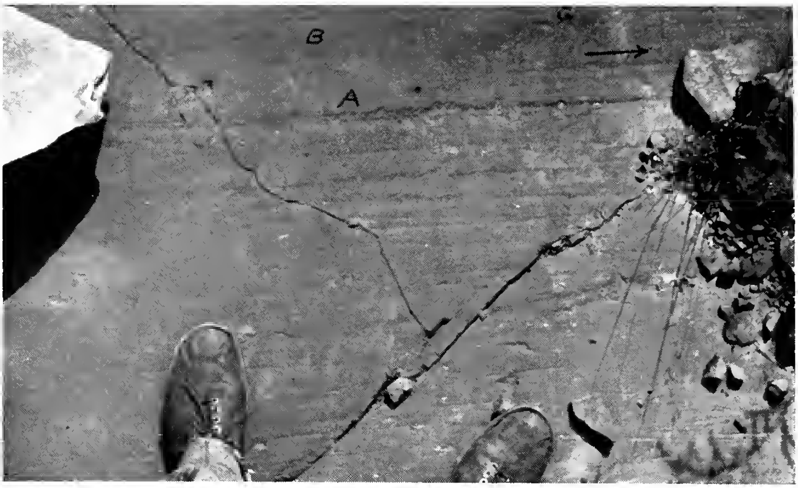


Figure 14 Glacial markings on sandstone. Direction of ice movement indicated by arrow. Note "fern-leaf" flaking (A), a relatively rare marking; numerous striae and gouges; and abrupt termination of gouges (B and C) in direction of ice movement. On road half a mile southeast of Kaaterskill falls, looking southwest. The ice here moved north-northwest.

Figure 15 Glacial striae, chatter marks, and fluting in gap through Northeastern escarpment two and three-quarters miles east-northeast of Manorkill. Chatter marks may be seen toward the observer from wheel of automobile. Note curving of striae. Looking westward in the direction of ice movement. Shows intense glacial scouring characteristic of all passes through the Northeastern escarpment.

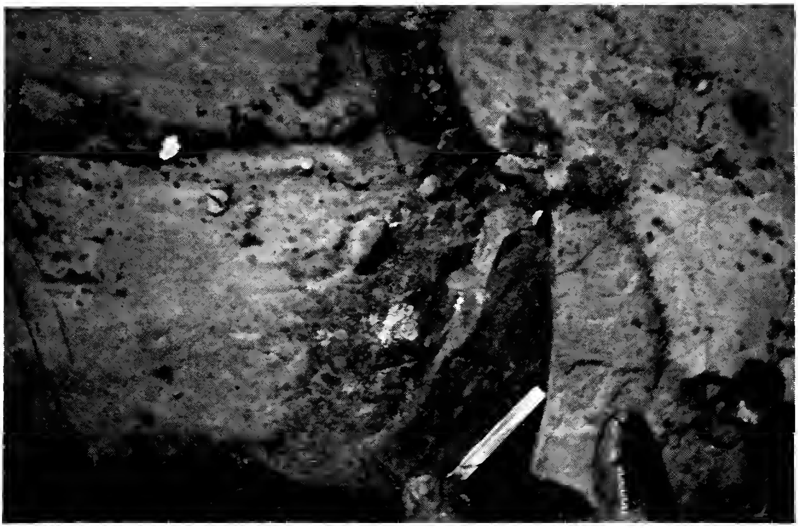


Figure 16 Glaciated surface of Catskill conglomerate showing "crag and tail" effect caused by resistant quartz pebbles. The ice moved toward the left, gouging hollows in front and at the sides of the pebbles and leaving elongated "tails" behind. Summit of Overlook mountain.

Figure 17 Ascending glacial striae on vertical ledge, showing ice movement to the right, which in this instance was down-valley and northward, indicating that the striae were made by a local glacier. One mile east-southeast of Spruceton (Phoenicia quadrangle).

Figure 18 Mount Pisgah from the east, showing rock ledges stripped by powerful glacial erosion. Note southward dip of the rocks.

Figure 19 Morainic ridge swinging diagonally down and away from a steep hillside. It grades upward into an embankment (fig. 20) where it ties onto the hillside. Looking toward Stony clove from a mile southwest of Kaaterskill Junction.

Figure 20 Looking down along top and back side of moraine shown in figure 19 from the point where it ties onto the hill. In background is east wall of Stony clove. Note its steepness and the large amount of bare rock and talus.

Figure 21 Smooth moraine in Rider hollow, half a mile east of Dry Brook. Looking up the hollow from near its lower end.

Figure 22 Hummocky kame-moraine a mile and three-quarters south-southwest of Bloomville. Looking north-northeast.

Figure 23 Wavy moraine on north side of notch ("Narrow Notch") between Town Brook and Rose Brook valleys three miles east-southeast of Hobart. The north end of the rock gorge cut by a glacial stream through the notch may be seen. The gorge is followed by the road.

Figure 24 Typical boulder or "bear-den" moraine. One mile southeast of Jewett.

Figure 25 Wall-like morainic embankment with pavement of washed boulders between it and the hillside. Looking west two miles northwest of Plaat Clove.

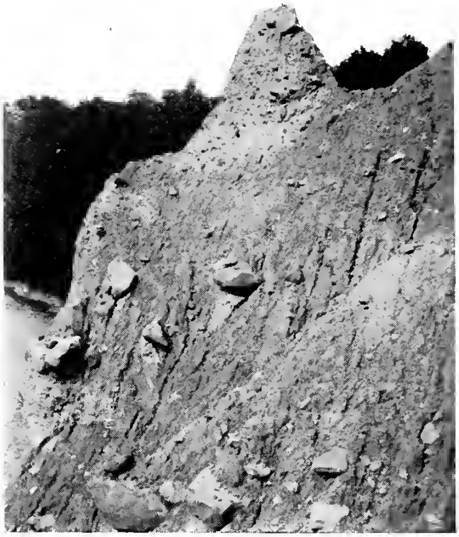


Figure 26 Till, an unassorted mixture of boulders, sand and clay. In railroad cut three-quarters of a mile south-southeast of Boiceville.

Figure 27 Smooth thick drift in valley bottom (in clearing behind house and to the left), possibly overridden moraine. Upper valley of Batavia kill two and a quarter miles above Big Hollow. Looking southeast toward Black Dome and Blackhead.

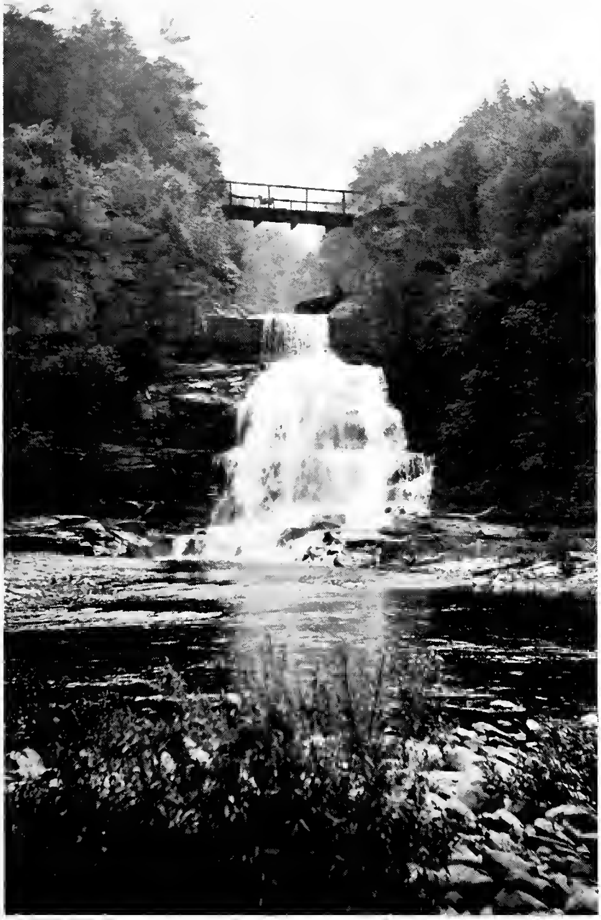


Figure 28 Manorkill falls from south side of Schoharie creek (1917). Many such falls and gorges have been caused by glacial diversion of streams. The falls are now partly buried under the waters of Gilboa Reservoir.

Figure 29 Drumlin three-quarters of a mile north of Mackey (Gilboa quadrangle), as seen from the northwest. Note smooth contour and rounded form.

Figure 30 Group of drumlins two miles northeast of Windham, as seen from the east.

Figure 31 A pedestal moraine in process of formation, McCormick bay, North Greenland. (Salisbury, R. D. Physiography, 1909, p. 256. Courtesy of Henry Holt & Co.)

Figure 32 A pedestal similar to that shown in figure 31 after the ice has melted away; same locality. (Salisbury, R. D. Physiography, 1909, p. 256. Courtesy of Henry Holt & Co.)

Figure 33 Pedestal three-quarters of a mile south of Belle Ayr as seen from below. Note that it has a steep front and a relatively flat "tread," and that it is highest in the middle and its front is convex down-valley. Concentration of boulders on the front slope may also be seen. Note over-steepened sides of mountain spur in center background. Balsam Roundtop in distance.

Figure 34 Profile of small pedestal on northeast slope of Irish mountain (Hobart quadrangle) built by a local glacier descending from the left and moving northward.

Figure 35 Looking northwestward at crescentic pond behind small morainic loop on top of pedestal shown in figure 34. Note that crescent is convex down-valley (northward). The height of the morainic loops is very small compared with the height of the front of the pedestal.

Figure 36 Marginal terrace of gravel on west side of valley three and a quarter miles above Halcottsville, looking south.

Figure 37 Flat-topped delta at about 1770 feet, three-quarters of a mile south of Beaches Corner, as seen from the southwest. Note lobate front.

Figure 38 Looking southwest at upstream side of delta three-quarters of a mile northeast of East Ashland. To the right (up stream) from the flat-topped part of the delta is a hollow which could not have been there when the delta was being formed. It is believed to have been occupied by ice at that time.

Figure 39 A typical lone kame. Two miles north-northwest of Halcott Center.

Figure 40 Section of kame showing veneer of till (upper 2 or 3 feet) containing large boulders. Below the till veneer the kame is composed of sand and gravel. West of road a mile and a half south-southwest of Tannersville.

Figure 41 The moraine loop at Conesville, as seen from the south side of the valley. Hummocky kame-moraine of the type which was built under water.

Figure 42 Large mass of kame-moraine a mile below Conesville, as seen from the northwest. It is mainly gravel and is believed to have been formed at the end of an ice tongue and under the waters of a lake at a point where a subglacial stream discharged from the ice.

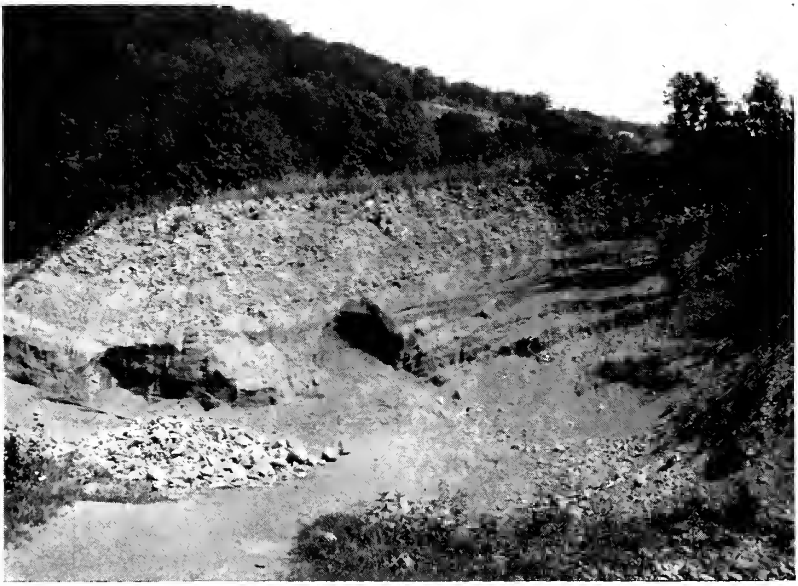


Figure 43 Section of kame-moraine half a mile northeast of Delhi showing coarse gravel of outwash type resting on sand and finer gravel.

Figure 44 Looking along the top of the large esker southeast of West Conesville. Note winding course and steep slopes.

Figure 45 The esker at West Conesville as seen from the northwest. Shows more of the esker than figure 44 and its relation to its surroundings.

Figure 46 Kames on the south slope of Mount Royal a mile and a half south of West Conesville. Looking south from the top of an esker which leads diagonally down the hillside into the kames.

Figure 47 Esker in middle of valley two and a half miles below Roxbury.

Figure 48 Stratified lake clay at about 1072 feet a quarter of a mile southwest of Gilboa. Thick beds of till are found above the clay. (Locality since buried by waters of Gilboa Reservoir.)

Figure 49 Characteristic topography developed on thick lake clay in the Schoharie valley, about two miles north-northwest of Gilboa.

Figure 50 Lower end of Alder lake from the northeast, showing the moraine by which it is impounded.

Figure 51 Grand Gorge Lake outlet channel. View down stream from about half a mile above More Settlement. The inner channel is cut in rock. Note "underfit" character of present stream. This channel was the outlet of a glacial lake in the Schoharie valley.

Figure 52 Grand gorge and Grand Gorge Lake outlet channel. On the skyline to left of knob is older (preglacial ?) notch. Looking up stream from about a mile above More Settlement.

Figure 53 Looking down on a typical small pedestal (center of picture) in Meeker hollow (Hobart quadrangle), a mile north of top of Plattekill mountain. Note steep convex front and flatter top sloping gently down-valley. The pedestal lies at the mouth of a valley (to the left) opening northeastward off the high range to the south.

Figure 54 Nearer view of pedestal of figure 53 from below, showing its down-valley convexity and the deceptive appearance of having a depression behind it.

Figure 55 Looking south at pedestal of figure 53 from below, showing where it is breached by the stream. Note that it is highest in the middle. The pedestal is believed to have been built by a local glacier which descended the valley from the mountain shown in the background.

Figure 56 Looking southwest across lower end of valley of Town brook, which flows left to right through the pines. Large gravelly morainic ridge ties onto the south wall of the valley at *A* at the left side of the picture, leaving a pronounced hollow behind it (woods in middle distance) and suggesting its formation by a glacier flowing down Town Brook valley. Rolling moraine on northeast side of the valley shows in foreground.

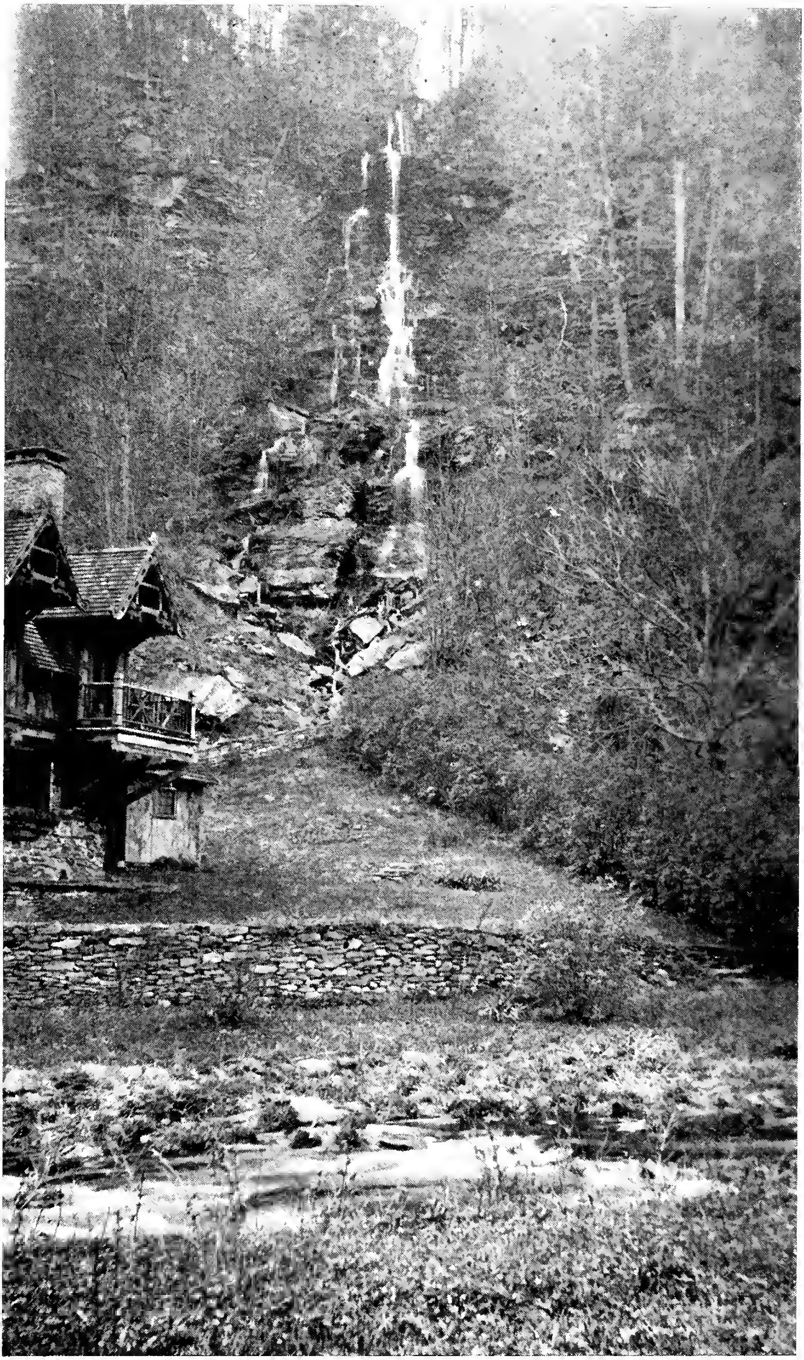


Figure 57 Small tributary stream cascading over the walls of Peekamoose gorge at Peekamoose Lodge

Figure 58 Looking south at High Point and Wagon Wheel gap from north side of Ashokan Reservoir. The 780-foot col is in the low gap at left of picture.

Figure 59 Farming under difficulties on the boundery outwash plain at the foot of Maltby hollow.

Figure 60 Deep notch from the north. Note steep-walled gorge in the bottom.

Figure 61 Stony clove from the south. Note lack of evidence of a stream channel south of the pass. Compare Grand gorge (figs. 51 and 52) where a glacial lake outlet channel is clearly shown. Steep western side of the "clove" rises 1400 feet above its bottom.

Figure 62 Looking up the valley a mile west of Wedgewood toward Hunter mountain. Note U-shape, oversteepened valley sides, talus near the head of the valley, and lack of morainic accumulations in the valley.

Figure 63 Looking eastward across the western moraine at the head of Fly brook. The moraine was built by a local glacier which descended the valley from the right. Note northward convexity of moraine front, also small lake impounded by the moraine.

Figure 64 Looking southward from the moraine of figure 63 toward the mountain from which the local glacier descended. Prominent recessional moraines appear in the middle distance. Note lack of cirques or other evidences of strong glacial erosion at the head of the valley.

Figure 65 Moraine of the central glacier at head of Fly Brook valley as seen from below. The front of the moraine is about 40 feet high where the stream cuts through it. At the right is Bloomberg Roundtop, from which the moraine-building local glacier descended.

Figure 66 Looking eastward across the top of the moraine shown in figure 65. Note considerable back-slope on the up-stream (right) side of the loop. The house stands on the pedestal-like moraine of the eastern of the three glaciers which descended from the mountains at the head of Fly brook.

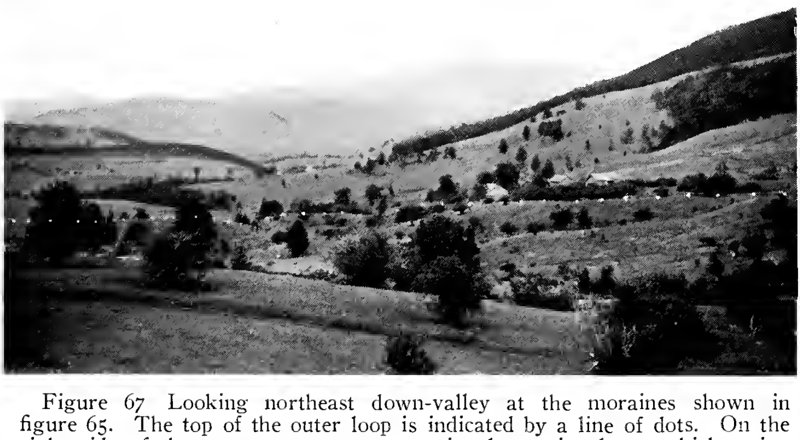


Figure 67 Looking northeast down-valley at the moraines shown in figure 65. The top of the outer loop is indicated by a line of dots. On the right side of the stream, note two recessional moraine loops which swing down toward the stream from the outer loop. Huntersfield mountain in background rising above the 2000-foot peneplain.

Figure 68 Moraine of local glacier a mile south of Jewett Center, looking west. Note that the moraine swings out away from the hill northward. This is the middle one of three morainic loops of local glaciers in this valley.

Figure 69 Looking down-valley (northwestward) at the lower of three moraines of local glaciers in the valley a mile south of Jewett Center. Note the pronounced backslope, and how the moraine ties onto the hill on the west side of the valley.

Figure 70 Looking northeastward at morainic loop a mile south of Elka Park. The moraine is convex down-valley, and is believed to have been formed by a local glacier.

Figure 71 Looking south at the moraine of a local glacier which descended the north slope of Blackhead at the source of Batavia kill, moving down the valley from left to right of the picture and ending a short distance to the right of the area shown, where the moraines cross the valley. The buildings stand in a natural amphitheater formed by the moraines. Beyond the house is the moraine which was built at the southwestern side of the glacier. Its counterpart is in the foreground. In the background is the saddle between Blackhead and Black Dome. Between the saddle and the moraine appears to be a large drift pedestal.

Figure 72 Looking south along the top of the morainic ridge shown behind the house in figure 71. The ice contact slope is to the left. In the background is the saddle between Blackhead and Black Dome.

Figure 73 Looking up the valley of Manor kill toward Manorkill from the top of the moraine a mile east of Conesville. Note the broad flat valley-bottom notably free of glacial débris. The valley appears to have been left in this condition by a rapid retreat of the glacier without recessional halts, or possibly by stagnation of the ice and melting out *in situ*.

Figure 74 Front of delta a mile and a half northeast of Conesville as seen from below. The top of the delta is on the skyline.

Figure 75 Looking down on Platter Kill delta from the west. Shows considerable slumping along the front.

Figure 76 Looking down a channel three-quarters of a mile southwest of Broome Center cut by the outlet of a lake which was held in the valley of Keyser kill by a glacial dam. The lake for a time discharged southward through this channel into Platter kill. Elevation of channel 1931 feet.

Figure 77 Looking down Franklinton channel from near its head two and a quarter miles north of Franklinton. Width of channel here about 300 feet.

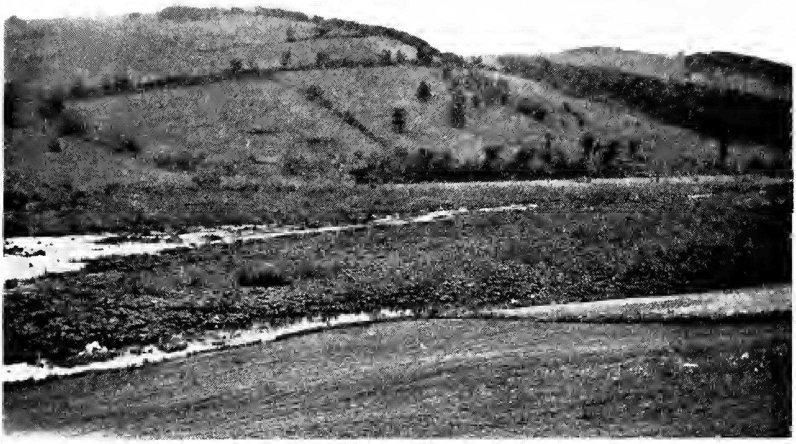


Figure 78 Looking northwest across Franklinton channel from half a mile above Franklinton. Swampiness is due to blocking of the channel lower down by an alluvial fan.

Figure 79 Looking southwest at oversteepened valley wall on north side of West Kill mountain two miles east of Spruceton. Near the top of the picture the valley wall may be seen to be a vertical cliff with talus at its base. The oversteepening is believed to have been produced by a local glacier.

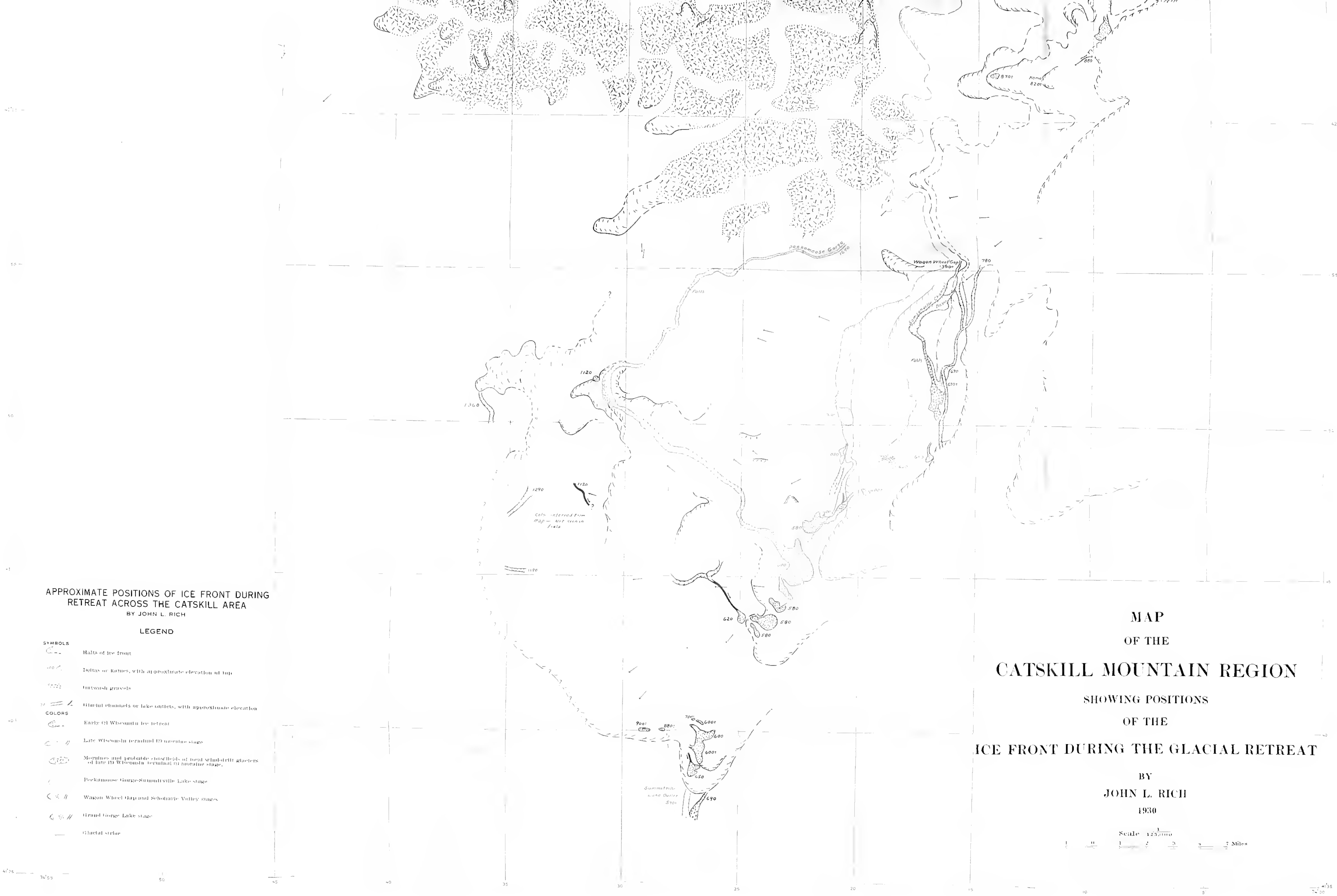
INDEX

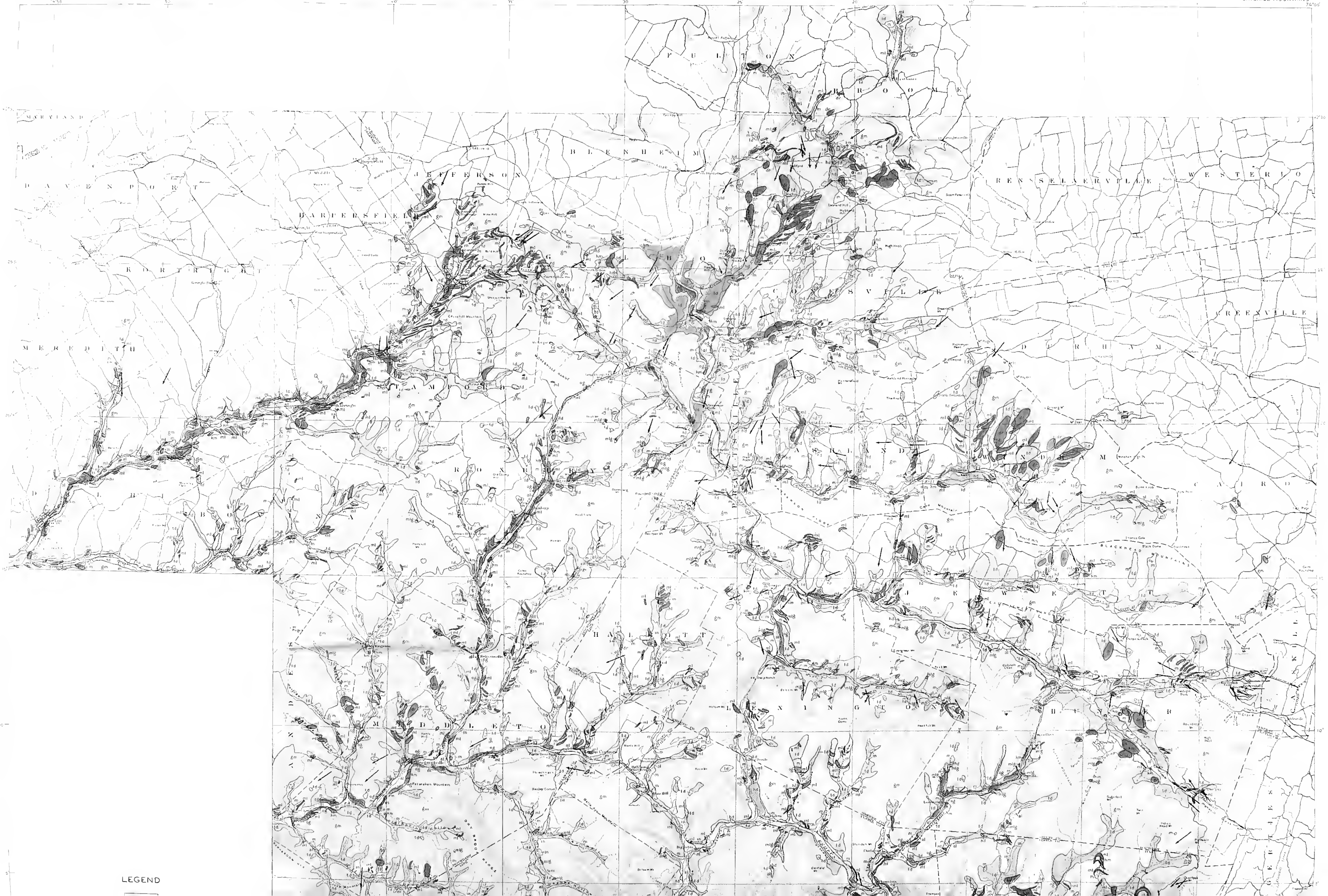
Map 1 The Catskill Mountains, showing glacial geology.

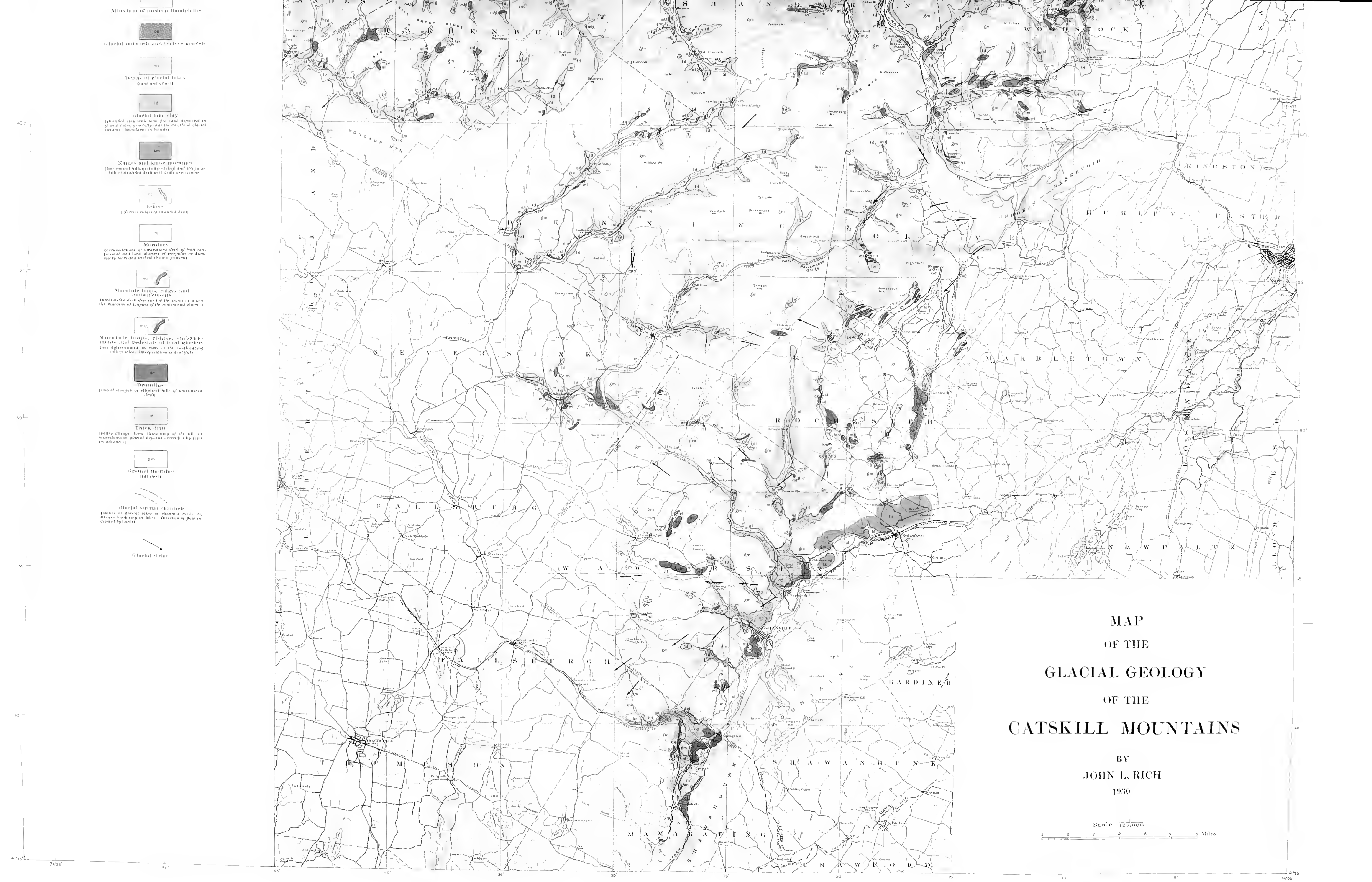
Map 2 The Catskill Mountains region, showing positions of the ice front during the glacial retreat

NOTE. These maps are reduced one-half from the standard U. S. Geological Survey topographic quadrangle maps. It will therefore be desirable to use a reading glass for examining the physical and cultural features.


Grand Gorge Outlet Channel
Possibly local snowdrift glacier
Combined continental and local?
Local Glacier
Kames
Kame
Lake at 1840 to 1800
Nunatak?
Kame or Delta


MAP
OF THE
CATSKILL MOUNTAIN REGION
SHOWING POSITIONS
OF THE
ICE FRONT DURING THE GLACIAL RETREAT
BY
JOHN L. RICH
1930
Scale
Miles
APPROXIMATE POSITIONS OF ICE FRONT DURING RETREAT ACROSS THE CATSKILL AREA
BY JOHN L. RICH
LEGEND
SYMBOLS
Halts of ice front
Deltas or kames, with approximate elevation of top
Outwash gravels
Glacial channels or lake outlets, with approximate elevation
COLORS
Early (?) Wisconsin ice retreat
Late Wisconsin terminal (?) moraine stage
Moraines and probable snowfields of local subdued glaciers of late (?) Wisconsin terminal (?) moraine stage.
Peekamoose Gorge-Summitville Lake stage
Wagon Wheel Gap and Schoharie Valley stages
Grand Gorge Lake stage
Glacial striae
Wagon Wheel Gap 1360
Peekamoose Gorge 1630
Summitville Lake Outlet 570


FULTON
BROOME
BLENHEIM
JEFFERSON
DAVENPORT
HARPERSFIELD
KORTRIGHT
GILBOA
CONESVILLE
RENSSELAERVILLE
WESTERLO
GREENVILLE
DURHAM
MEREDITH
STAMFORD
ROXBURY
ASHLAND
WINDHAM
CAIRO
JEWETT
HALCOTT
LEXINGTON
HUNTER
MIDDLETOWN
LEGEND



Glacial outwash and terrace gravels
Deltas of glacial lakes
Glacial lake clay
Kames and kame moraines
Eskers
Moraines
Morainic loops, ridges and embankments
Morainic loops, ridges, embankments and pedestals of local glaciers
Drumlins
Thick drift
Ground moraine
Glacial stream channels
Glacial striae
MAP
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