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BY

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PART IV.—THE INFLUENCE OF THE GLACIAL PERIOD UPON TOPOGRAPHY.

INTRODUCTION.—When the Geological Survey of New York was undertaken, considerably more than half a century ago, the belief was current that the State had been overrun by great floods of water which had strewn the surface with the various deposits of boulders, gravel and clay which are so noticeable throughout the State.* Then came the glacial theory of Agassiz, at first vigorously opposed, but gradually accepted, until at present it is all but universally adopted as the real explanation of the phenomena formerly ascribed to the flood.

The farmers of the State till a soil brought to their land by an ice sheet of vast proportions, greater by several times than that now covering the great continental island of Greenland with 500,000 square miles of ice. They remove from their fields the boulders brought by the ice from the north, perhaps from even beyond the confines of the country, and they look upon a landscape modified, or perhaps even moulded, or entirely made, by this ice sheet. The lakes, the swamps, the gorges and the waterfalls have come to be what they are because of this glaciation; and the economic development of the State has depended in very large measure upon the

* See Eaton, Am. Journ. Sci., XII, 1827, 17–20; Dewey, Am. Journ. Sci. XXXVII, 1839, 240–242; Same, XLIV, 1843, 146–50; Emmons, Geol. of N. Y., Second Dist., 1842, 422–427; Hall, Same, Fourth Dist., 1843, 318–341; Mather, Same, First Dist., 1843, 158–228; Vanuxem, Same, 3d Dist., 1842, 212–224, 244–247; Lloyd, Quart. Journ. Geol. Soc., XXXII, 1876, 76–79.

visit of this ice sheet. Without this visit the industries, cities and people would have been very different.

Much interest has been aroused in the problems presented for solution by this latest great physiographic factor in the development of topography. Upon these problems much work has been done; but much remains still undone. New York State, though supporting a geological survey with some continuity for more than half a century, the results of which in a single direction have been of the best, has almost totally neglected this important subject. Hence, barring a few scattered individual efforts, and a single Government publication, almost nothing has been done to put before the people of the State the facts concerning their own environment. The farmer who would know the cause for his soils, or the teacher who would learn the meaning of the hills surrounding the school, or of the gorge or lake near by, can find no place in which to look for an answer to his queries. This stands to the discredit of New York State.* This discussion is bound therefore to be very inadequate because little is known.†

BEFORE THE GLACIAL PERIOD.—Without careful and wide-extended study it would be impossible to tell in detail what the condition of New York was before the glacial period. This much is certain, however, that most of the larger features of land-form were then much as they are now. There was then an Adirondack Mountain mass, a Catskill Mountain group, and a dissected plateau in western and central New York; and each of these sections was then cut into hills and valleys, very much as they are now. The larger stream valleys, such as the Hudson, the Mohawk, and the Susquehanna, and also most of the smaller tributaries of these, then existed, although the details of stream course were in many instances very different from the present. Some rivers now flow into different valleys from those which they formerly entered, and still more flow in different parts of the old valleys, perhaps upon one side of the former course. The ice has planed down some of

* What is said of glacial geology applies equally to physiography in general, and also almost as fully to economic geology. The paleontology and stratigraphy are well known in some parts, but there is no adequate discussion of the salt, the iron, the oil and gas and the several mining industries of the State. In an intelligent and wealthy community such a condition should not exist.

† For statement of some of the principles of glacial geology reference may be made to Wright's Ice Age in North America; Wright's Man and the Glacial Period; Geikie's The Great Ice Age; and Salisbury's discussion in the Ann. Rept. of the State Geologists of New Jersey, for 1891, 35–108.

these hills to slightly lower levels than formerly, and rounded off still others, while the valleys have in many places been clogged, or in some cases even entirely filled, with glacial deposits.

But the most marked difference between the New York of to-day and the preglacial New York is in the introduction of numerous lakes. One could not safely assert that there were then *no* lakes in the State; but upon every physiographic argument that can be made, the existence of any but the smallest lakes seems highly improbable. Lakes must have a cause, and lake-making causes had apparently not been in operation extensively immediately before the glacial period. Therefore, the lakes, Champlain, Ontario, Erie, Chautauqua, the Finger Lakes, and the thousands of smaller ones, were probably not present. Of the larger number of these it may be stated positively that they did not then exist, for their cause is certainly glacial action.

At some time before the glacial period, the general altitude of the State was very different, being considerably higher above sea-level. Whether this was true at the very time when the ice encroached upon this region cannot be so certainly stated, though there is much reason for believing that, even as the ice gradually advanced, the land was standing higher above the sea than now.

Notwithstanding these differences between the present and past, could we have an accurate model of New York State upon a large scale, representing the conditions of preglacial times, one would have no difficulty in recognizing the *general* topography of the region in which he dwells. The general elevation might be higher than at present, and some of the hills higher above the valley bottoms. Some valleys may now be deeper than formerly; and, as a result of the glacial deposits, some now absent would then be present, and some now existing would not appear upon the model. The course of some of the rivers would be different, and most of the gorges, waterfalls and lakes would not be found, the site of the lakes being then valleys occupied by running water. Probably, also, the coast line was different in an important way. If the land were then higher, the coast line must have been somewhere to the eastward of its present position. So it follows that there were many differences, some of them of a very striking kind, but not so many as to make the general topography of the land unrecognizable.

THE ADVANCE OF THE ICE SHEET.—Over this land the ice front slowly advanced, coming on irresistibly, and fed from some centre in the far north, evidently in the vicinity of the Labrador Peninsula, from which the ice radiated outward in all directions, as the Greenland ice sheet of to-day radiates from a centre somewhere within that great ice-covered land area. Why it came cannot now be stated; nor can we say when it began, nor how long it stayed, nor when, nor why it went. Speculations upon this point are abundant, but they have been of little value in reaching definite and well-proved conclusions. The *fact* of the coming and going is all that can be stated with positiveness in this connection.

FIG. I.—TO SHOW PROBABLE EXTENT OF AMERICAN ICE SHEETS (CHAMBERLIN IN GEIKIE'S GREAT ICE AGE).

As the wall of ice gradually moved southward, involving States at present temperate in climate, and before that even warmer than now, there must have been a refrigeration of climate, partly due to the *presence* of the ice, and partly to the causes upon which the formation of the great continental glacier depended. Then, upon the high mountains, the winter snows must have lasted longer and longer into the summer, until the protected valleys held some of the snow throughout the entire season. At this time valley glaciers, somewhat like those of the Alps, probably appeared in the Adirondacks and Catskills, growing larger as time passed, and finally adding their supply to that of the great glacier from the north. This rose higher and higher upon the mountain sides, until, finally, the highest peaks of the Adirondacks and Catskills were submerged in the onmoving flood of ice, and all of New York State, with the possible exception of a small tract in the extreme western part, was transformed to a great ice plateau like that of Greenland to-day. From Labrador to Pennsylvania no land appeared above the ice covering, whose depth was certainly greater than a mile in some places. At present no similar ice sheet exists, unless possibly the one in the South Polar regions.

With the advance of the ice, plants were exterminated, and animals either exterminated or driven out to the southward. For a long time these conditions lasted, though how long, no one can now say; and year by year the ice advanced through the valleys and over the hills and even the mountain tops. At first it swept

FIG. 2.—TO SHOW APPROXIMATE EXTENT OF ICE SHEET IN EASTERN UNITED STATES. "MORAINE OF SECOND GLACIAL EPOCH" SHOWN BY HEAVY SHADING (CHAMBERLIN).

off the soil and rock, dragging it southward, and grinding it by rubbing particle against particle, or against the rock over which the glacier was slowly gliding. Valleys were deepened somewhat and

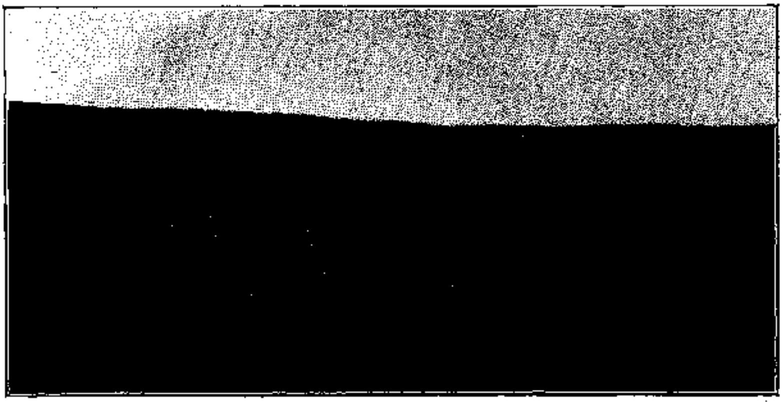

FIG. 3.—SURFACE OF THE GREENLAND ICE PLATEAU (PHOTOGRAPH BY J. O. MARTIN).

hills scoured by this great force of erosion, the hills losing some of their height and being rounded. The pebbles that the ice held, and the bed rock over which they were dragged were both grooved,

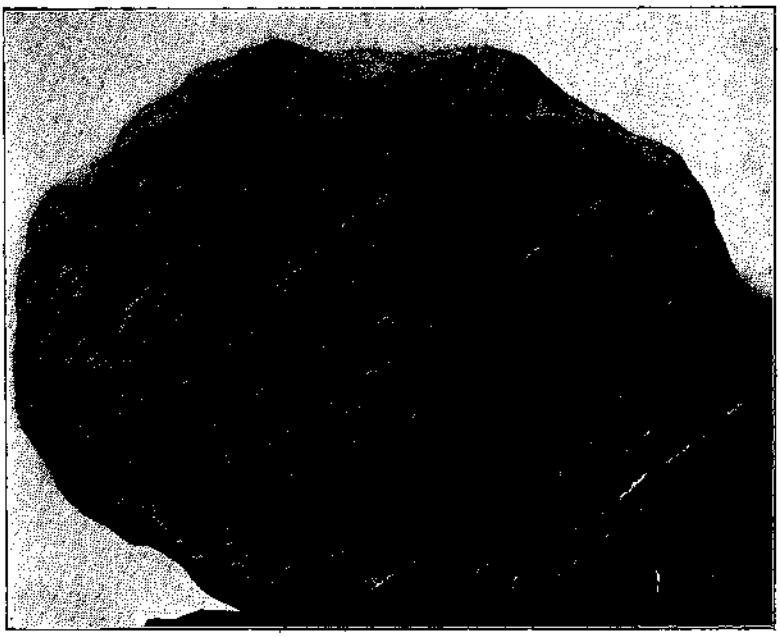

FIG. 4.—A GLACIALLY SCRATCHED PEBBLE (PHOTOGRAPH BY U. S. GEOL. SURVEY).

or scratched, and polished; and at all times during the stay of the ice, the glacier contained in its mass a load of rock fragments,

FIG. 5.—GLACIAL SCRATCHES ON BED ROCK (CALVIN, IOWA GEOL. SURVEY).

varying in size from boulders to clay particles, all slowly journeying southward with the ice, and being ground as they went.

At the margin, land appeared above the ice, at first as isolated hills, reaching above the ice surface, as the mountain peaks of Greenland project above this great glacier, forming the nunataks of that region; then, nearer the margin, as ranges of hills separat-

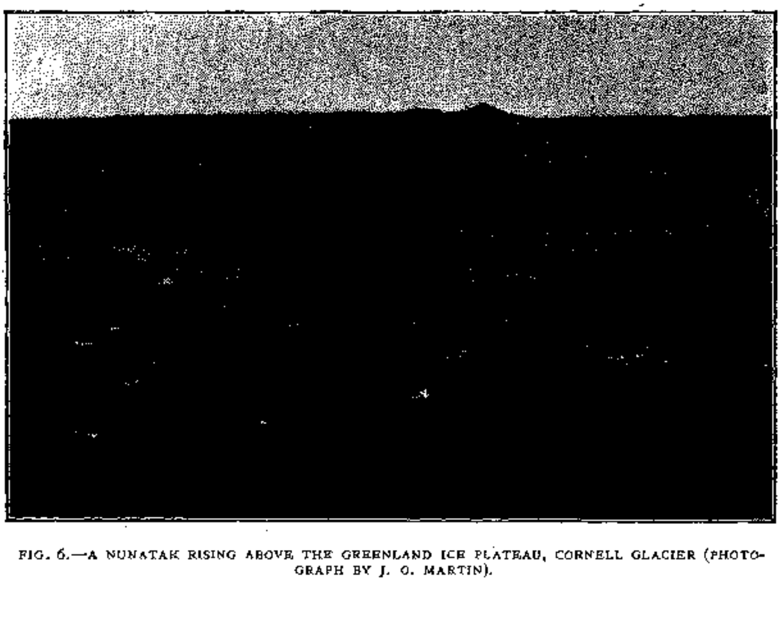

FIG. 6.—A NUNATAK RISING ABOVE THE GREENLAND ICE PLATEAU, CORNELL GLACIER (PHOTOGRAPH BY J. O. MARTIN).

ing projecting tongues of the glacier front,—small valley lobes projecting further southward along the valleys. The margin was evidently serrated or lobate, and the reason for the margin was that there the ice supply just equalled the ability of the sun to melt it.

So, along this margin, as along the margin of all glaciers on the land, there were vast floods of water poured upon the hill sides and gathered into the valleys. Here was supplied to river valleys the rainfall of other drainage systems far to the north. Some, falling where it now escapes into the Arctic waters or the St. Lawrence system, then passed on and entered the Susquehanna, or further west, the Upper Allegany, whence it was led to the Gulf of Mexico. As a result, many small stream valleys then carried large volumes of water. Sometimes the front of the ice was not in a valley sloping away from it, but toward it, and then, in such north-sloping valleys, glacial lakes were ponded back in places where now no lakes exist. The records of these are abundant.* In the north-sloping valleys this water was iceberg laden, and everywhere, where

FIG. 7.—LAND MARGIN, CORNELL GLACIER, GREENLAND, SHOWING DEBRIS-LADEN ICE LAYERS NEAR BASE, AND TERMINAL MORAINE IN FOREGROUND (PHOTOGRAPH BY J. O. MARTIN).

it started from the ice, was ice-cold, so that, flowing into more temperate latitudes, it must have produced a very important influence upon the climate of parts of the South, especially along the Mississippi Valley, nearly all of the headwaters of which were supplying this ice-derived water.

* See Tarr (Part III of this series), Bull. Am. Geog. Soc., XXX, 1898, 44.

Not merely was *water* supplied to the streams, but much rock material also; for this too was constantly moving on with the ice to the place of melting. Some of this entered marginal lakes, forming lake deposits in places where now no lakes exist and some passed

FIG. 8.—BOULDERY TERMINAL MORAINE AT MARGIN OF CORNELL GLACIER, GREENLAND (PHOTOGRAPH BY J. O. MARTIN).

off in rivers, forming various types of river deposits,* often in valleys in which now the rivers are not depositing sediment. Not all of this rock load could go off in the streams, but much fell to the base of the ice, or remained in its place beneath the glacier. If the front of the glacier remained for a long time in approximately one

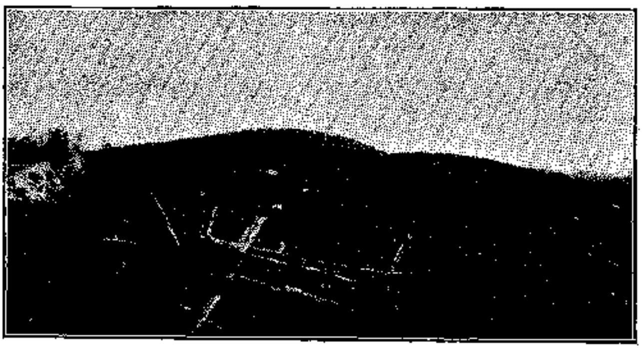

FIG. 9.—NEARLY BOULDER-FREE MORAINE IN PENNSYLVANIA (LEWIS).

place, as it did year by year, this dumping of rock fragments continued until perhaps a very considerable accumulation was made,

*See Tarr (Part III of this series), Bull. Am. Geog. Soc., XXX, 1898, 43 and 45.

forming a moraine. The former position of the ice front is now traced by these moraine hills and ridges, which extend across the country as indicated in the accompanying maps. The moraine formed upon the land is quite like that now being made at the margins of existing glaciers.

While throughout most of New York State the southernmost stand of the glacier front was upon the land, it is quite possible that the front in the Long Island region was at one time in the sea, as it certainly was farther east. In this case the glacial deposits were then dumped in the ocean near the ice margin, or such fine parts as could be floated away were removed by currents, to which transportation was added that done by the numerous icebergs which must have broken from the glacier front.

FIG. 10.—TO SHOW GENERAL EXTENT OF ICE IN NEW YORK. SOUTHERN LIMIT OF SHADING MARKS THE POSITION OF THE OUTERMOST TERMINAL MORAINE OF LEWIS AND WRIGHT, THE HEAVY SHADING THE SO-CALLED "MORAINE OF THE SECOND GLACIAL EPOCH" (CHAMBERLIN).

THE RETREAT OF THE ICE SHEET.—In time the conditions which gave rise to the Glacial Period began to change, and the ice supply was no longer able to maintain the ice front at the southernmost limit.* Then this line was abandoned and the ice front slowly melted back again, uncovering the country over which it had formerly advanced. This retreat or recession of the ice was intermittent, for we find evidence that at certain places the ice halted, and the front remained long enough to build terminal moraines, or *moraines of recession*, closely resembling that formed at the outermost terminus. Thus, for instance, after having passed well down into

* No attempt is made here to consider the question whether there was more than one advance of the ice, partly because it is a question still open and in controversy, but chiefly because its bearing upon the physiography of New York is not known.

Pennsylvania,* the ice halted for a long time along the line of the so-called "moraine of the Second Glacial Epoch," which is shown for central New York upon the map.† Numerous other halts were made, as shown by the map of the western New York moraines.‡

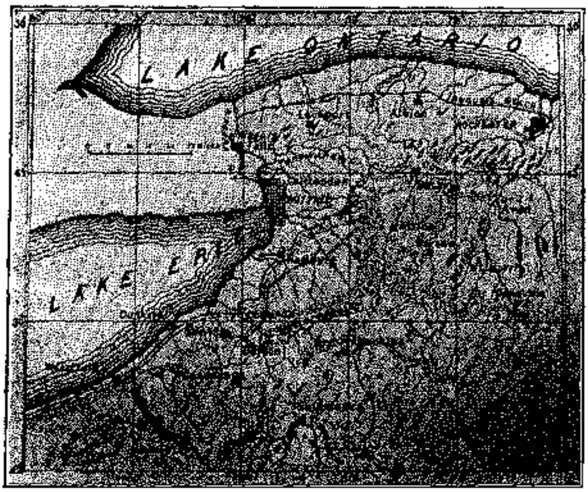

FIG. 11.—MAP OF MORAINES IN WESTERN NEW YORK. DIRECTION OF ICE MOVEMENT SHOWN BY ARROWS. DRUMLINS MARKED SOUTH OF ROCHESTER. OLD BEACH LINE SHOWN ALONG ERIE AND ONTARIO SHORES (LEVERETT).

Each of these halts is marked by a more or less well-defined moraine, formed at the terminus of the receding glacier. During the time of formation of these moraines the conditions at the glacier margin must have been closely like those described for the southernmost margin. Between these successive moraines the glacial recession must have been relatively rapid, for the front did not stand in any one place for a long enough time to permit the dragging of *débris* to the margin in sufficient quantity to accumulate morainic hills.

Thus it is seen that in New York State the ice front first *advanced* across the surface, visiting each part of the State, though the record of what it then did was mostly destroyed by the continued advance over all points excepting the deposits at the southernmost margin. Then this was followed by the ice *withdrawal*, during which each

* Lewis, Proc. Am. Phil. Soc., XX, 1882–3, 662; Proc. Am. Assoc. Adv. Sci., 1882, XXXI, 389–98; Am. Journ. Sci., 1884, Ser. III, XXVIII, 276–285; Report Z, 2nd Geol. Survey Pa.; Wright, Bull. 58, U. S. Geol. Survey, 1890.

† Chamberlin, Trans. Wis. Acad. Sci., IV, 1876–7, 201–234; Am. Journ. Sci., 1882, XXIV, Ser. III, 93–97; 3d Ann. Report, U. S. Geol. Survey, 1883, 291–402.

‡ Leverett, Am. Journ. Sci., 1895, L, Ser. III, 1–20.

part of the State was visited by the glacier front, this time, however, leaving a record of its visit which can now be read, especially at those places where the ice front lingered for a while and built moraines.

Thus it came about that moraines were formed at various points in New York, and that all over the State, every here and there, the water from the melting ice made deposits of gravel and clay derived from the glacier. These deposits, being made by water, are assorted and stratified. All glacial deposits are called *drift*, a name inherited from the time when they were explained as flood deposits. These

FIG. 12.—CROSS-BEDDED STRATIFIED DRIFT, ITHACA, N. Y. (PHOTOGRAPH BY C. S. DOWNES).

water deposits are called *stratified drift*, or sometimes *modified drift*, because they are not deposits direct from the ice, but modified through the intervention of water. Naturally the stratified drift is most commonly found in valleys, for it was here that the water went; but it is not *confined* to the valleys, for many a stream from the ice top, or from beneath the glacier, reached the edge of the glacier upon a hillside, or even, in some cases, upon a hilltop. Not only does the position vary, but the depth also, though, in general, the stratified drift is deepest in the valleys, being in some cases two or three hundred feet deep.

Held firmly in the ice, and dragged along beneath it, were rock fragments, bits of clay, pebbles, and great boulders, all journeying southward; and, side by side, were coarse and fine fragments. As the ice was withdrawing, and these rock fragments were loosened by melting, some of them went away in the water to be deposited as stratified drift, but much fell directly to the ground or stayed in its place beneath the glacier. This drift was not definitely assorted, but was made of clay, sand, pebbles and boulders mixed indiscriminately together, for the ice was able to carry a large boulder as well as a bit of clay, a thing which water under ordinary conditions cannot do. Those deposits from the glacier form the characteristic soil of New York, particularly of the hillsides and hilltops, and, in places, of the valley bottoms. This is known as *till* or *boulder clay*. Thus it happens that a farm in one part may be bouldery and clayey, in another part clayey without boulders, and still elsewhere either sand or gravel. In each of these cases there was a cause, which, by careful study, can often be determined, though sometimes this is impossible because of the complexity of conditions attending the withdrawal of the ice, the full evidence of which is sometimes lacking. Many a resident of New York has been puzzled to know the reason for these variations.

With the withdrawal of the ice the conditions were again made favorable for the existence of animal and plant life upon the surface. Foot by foot the country was relieved of its ice blanket, and slowly the soil left by the glacier began to be made to nourish plant life and to furnish a dwelling place for animals. At first skirting the ice front there must have been strips of land entirely without vegetation. Then came the light-seeded grasses and small plants, and then the forest. During this bare condition the rain fell, and gathering into mud-laden rills, washed much of the imported soil away, as it now does on the roads and ploughed fields; and this sediment was added to the stratified drift from the glacier.

There is good reason to believe that the rains were perhaps heavier then than now, for the presence of the ice to chill the moisture-laden winds from the south, and the large amount of vapor that would be produced from the floods of the glacier-supplied waters, would bring about conditions favoring heavier rain. At this time, also, where the slope was sufficient for the removal of the sediment, the streams must have had more power to cut than now; and probably much of the gorge cutting in central New York was accomplished during this time,* when there was probably more water and when certainly the water that fell upon the surface flowed away more quickly, in the form of floods, than it did later

* Tarr, Amer. Geol., XIX, 1897, 135.

when its run-off was retarded by the forests. Also, at this time the streams had more sediment to serve as cutting tools than later when the soil was held in place by the roots of the forest trees.

What happened among the mountains with the *advance* of the glacier probably also happened with its withdrawal. The last stage of glacier retreat in Greenland, upon land from which the glacier has just withdrawn, is that of local valley glaciers. The same was true in New Hampshire and Maine; and, no doubt, when studies of the Adirondacks have been made, evidence of local valley glaciation will be found there in many places. At present no evidence of this has been put forward, and it therefore stands merely as an inference of probability.

MORAINES.—*Topography.*—In many places where the ice front stood for only a very short time, the moraine which accumulated at the margin is not very deep. Sometimes it is merely a tract of unusually numerous boulders; but in many places so much has been

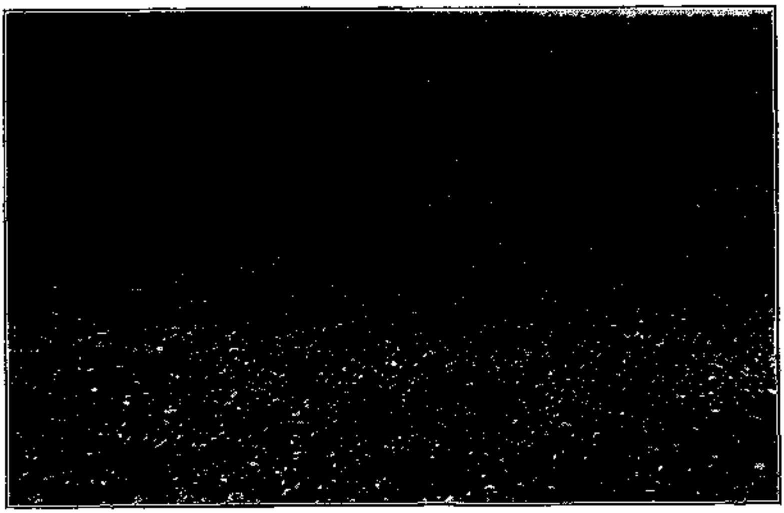

FIG. 13.—THE TERMINAL MORAINE, WEST DANBY, IN CAYUGA VALLEY SOUTH OF ITHACA, N. Y. (PHOTOGRAPH BY C. S. DOWNES.)

deposited that the moraine forms a very striking feature of the landscape. This is particularly true of many parts of the so-called terminal moraine of the Second Glacial Epoch.* Among some of the moraines of recession to the north of this, as well as in the

*Chamberlin, 3rd Ann. Rept. U. S. Geol. Survey, 1883, 291.

earlier Pennsylvania moraine to the south of it, the morainic topography is also very strongly developed.

The terminal moraine is essentially complex, and this applies both to form and structure. In form, or topographic detail, it is typically a system of hummocky knolls, with intermediate valleys, often saucer and kettle shaped, forming distinct, closed basins. The hummocks may reach to the dignity of good-sized hills, perhaps 200 or 300 feet high, though commonly not more than half this. Their form is often quite circular or sometimes elliptical, and again ridge-like. The hummocky hills are put together in such a confused manner that there seems to be no order whatsoever, the form being, on a much larger scale, somewhat the same as that produced when many loads of sand are dumped near

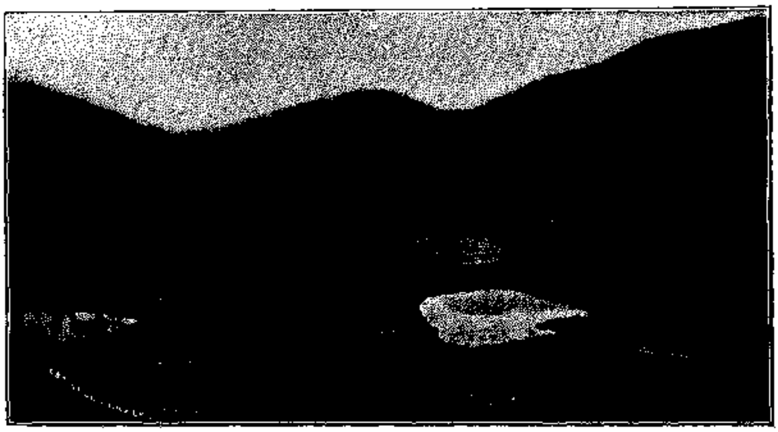

FIG. 14.—LAKES IN KETTLE HOLES IN MORAINE OF COLORADO ROCKIES (PHOTOGRAPH BY JACKSON, DENVER, COLORADO).

together without any attempt at order. Some of the hummocks are steep, others gently sloping, some symmetrical, and others distinctly unsymmetrical. I know of no type of topography which simulates that of the moraine with the exception of the wind-blown sand deposits in a sand dune region. In such places, judging from the form alone, one might often imagine himself upon a moraine.

The moraine is not a distinct ridge, but a range of low hills and valleys, with a breadth from north to south of rarely more than two or three miles, though sometimes, as in the southern end of the valleys of the larger Finger Lakes of New York, from ten to fifteen miles in a north-south direction. When seen in a near view, the moraine exhibits a striking topography; but when looked at as part of a general hilly region, its importance becomes entirely masked,* because of the lowness of the hummocks. Indeed, many moraines in hilly districts have not yet been detected because of this very fact.

Next of importance to the hummocks are the valleys, which are often true basins called *kettle holes.* In places these are so prominent that the moraine has been called a kettle moraine. † In these basins there is often no water, because the bottom is too porous and the water supply slight, coming merely from the rim of the tiny basin; but where the drainage area is larger, or the bed more impervious, the kettles are often transformed to ponds or swamps. Indeed, in some places there are so many that the moraine is literally dotted with tiny morainic ponds (Fig. 15). The depth of

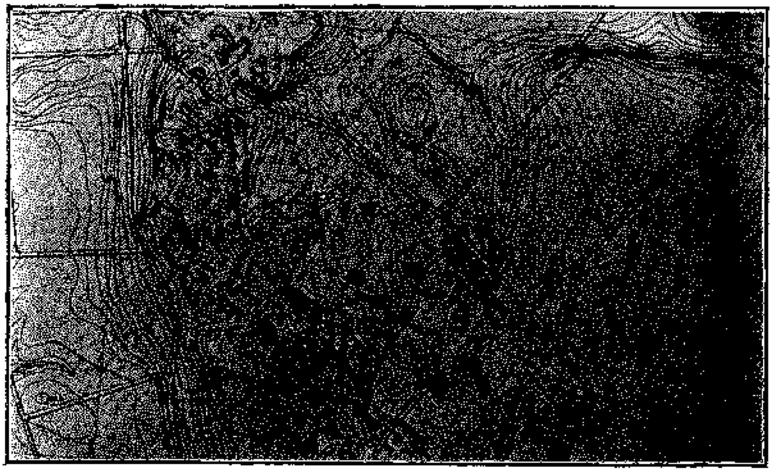

FIG. 15.—A PART OF THE NEW JERSEY MORAINE SHOWING (BY SHADING) NUMEROUS KETTLE PONDS (SALISBURY).

these kettles varies greatly, some mentioned by Koons being 50–90 feet deep.‡ These basin-like depressions are sometimes circular or elliptical or irregular, apparently being formed irregularly, as were the hills. Indeed, in many cases they are the spaces where morainic deposits were not made. The two types of form, valley and hill, cause a resemblance to the topography of sand dunes, in

* See Fig. 15 in Article III of this series, Bull. Am. Geog. Soc., XXX, 1898, where a very pronounced moraine, occupying nearly the entire valley south of Lake Cayuga, is masked by the general topographic features.

† Chamberlin, Trans. Wisconsin Acad. Sci., IV, 1876–77, 201.

‡ Koons, Am. Journ. Sci., 1884, Ser. III, XXVII, 260–264; Same, 1885, Ser. III, XXIX, 480–486.

which, between the more or less conical hills, there are numerous crater-shaped depressions or kettles.

Structure.—The internal structure of the moraine is also exceedingly complex. As in the case of the till sheet, it is sometimes almost free from boulders, sometimes exceedingly bouldery. In New York, the moraine is commonly rather free from large

FIG. 16.—THE BOULDERY CAPE ANN (MASS.) MORAINE (PHOTOGRAPH BY J. L. GARDNER 2ND).

stones, as is the till sheet also, the reason for this being that the rocks of the State are prevailingly soft and easily ground down. This is particularly true of central and western New York, where the scattered large boulders are mostly Canadian in origin; but in eastern New York there are places where boulders are more common, because of the greater hardness of the rock of the neighborhood and immediately to the north. In New England the prevailing condition of the till is bouldery, for the same reason.

When a morainic hummock is cut into and its internal structure revealed, it may be found to be till throughout, or it may be entirely made of gravel, or there may be a certain proportion of each of these. There is a complexity of structure which is most confusing; and one can see no law in the distribution of materials. Some moraines are prevailingly sand and gravel, others prevailingly till. One can rarely tell what will be found when a morainic hummock is cut through. There may be all till or no till, all stratified clay or none of this, all sand and gravel or none; or some of each of these deposits may occur. Sometimes beds of sand or gravel are found

FIG. 17.—SECTION THROUGH A PART OF THE MORAINE IN CAYUGA VALLEY SOUTH OF ITHACA, SHOWING STRATIFIED DRIFT ON RIGHT AND UNSTRATIFIED TILL ON LEFT (PHOTOGRAPH BY C. S. DOWNES).

upon till. Again they occur beneath the till, or possibly sandwiched between two till beds.

Explanation of Morainic Irregularities.—There must be a cause for this variety of form and structure. In any specific case it would be exceedingly difficult to find the cause for each of the hills and kettles; and, indeed, even in general terms the explanation of these irregularities is not agreed upon. Professor Salisbury * considers moraines to be chiefly the result of accumulations of drift under the frontal edge of the ice, to which place it has been dragged and there left, because near the thinner ice edge it was impossible to carry the drift load further southward. To this cause is of course added certain supplies of material which was dumped from the ice-front as that melted, as well as some that was pushed or "shoved" up to the margin by ice advance; but these two last causes are believed to be subordinate. Other glacialists assign to the dumping process the chief importance, and still others believe that shoving has been of most importance. In fact, Professor Shaler † speaks of the "shoved moraine" as a synonym for a part of the terminal moraine.

* Ann. Rept. New Jersey Geol. Survey, 1891, 81.

† Ninth Ann. Rept. U. S. Geol. Survey, 546.

This is not the place for a discussion of the merits of this question. In fact, little good would come from such a discussion, for the matter resolves itself largely into a consideration of just how the individual conceives that the ice worked. It seems very probable that, at different times, or in different places, as the circumstances varied, either of these causes may have predominated. My own conception of how a moraine is built is that the dumping predominates in the main, with shoving as of secondary importance, while submarginal accumulation is more rarely of prime importance. This is based partly on my own conception of ice work, partly upon a somewhat wide-extended view of the terminal moraine of the eastern part of this country, and partly upon a study of the extensive moraine now forming in Greenland along a part of the margin of the great continental glacier. The statement that follows is therefore advanced purely as my own conception, and not necessarily that of others. It is recognized that very likely in the west, where the ice load was greater, submarginal accumulation may have been very much more important than it seems to have been in the east, and vastly more important than it *is* in Greenland.

The ice carried a greater amount of *débris* to some places than to others, partly because it actually had more material to carry, and partly because it was moving faster in some places than in others. This is one element of irregularity. Here and there this difference in supply may express itself in morainic accumulations *under* the margin of the ice; but wherever I have carefully studied the moraine there has been found no evidence that this was so. In Greenland, and evidently also in New York and New England, the chief moraine supply seems to have been from the ice front. This ice this season perhaps different from last, just as living glaciers change front, while holding a general position, shifted somewhat, being their front in different seasons. Hence material previously deposited at the glacier front may have been overridden, and perhaps shoved up into ridge-like hills; or, if the ice withdrew, new areas would be opened to the process of dumping.

All of this time the ice is moving up to the end, bearing its load, which, when the ice melts, slides down to the base in the form of pieces varying from bits of clay to large boulders, and more perhaps coming to some places than to others. This process may be actually seen in Greenland to-day. If the ice advances, overriding, or possibly even shoving some of the moraine in front of it, the deposits are heaped up even more irregularly than by the first dumping. That something of this sort has happened is indicated by the fact that in the moraine the strata are often tilted and broken, showing that they have been subjected to some force.

Hills and valleys are formed as the ice front changes its line of dumping. This is the cause for the hummocky topography in the Greenland picture (Fig. 8), and seems perfectly competent to explain the similar irregularity in this country. In fact, until proof is brought to the contrary, this view seems to stand best supported by fact.

The irregularity of form described above, as well as the irregularity of texture, is increased greatly by the action of water from the ice. In some cases the moraine is being built upon a hillside sloping away from the ice, and then the water may remove much that the ice brings; but if the opposite is true, very little escapes, so that, with the same rate and amount of till supply, we may have great or small moraines built according to whether or not the water carried off much of the drift.

This cause for the irregularity applies equally in a small way. Here a stream was cutting a hummock away; there it was depositing a part of that which it had removed, perhaps in little marginal lakes extending along the ice front. Hence the conditions were exceedingly complex, so that, naturally, the results were complex both as to structure and form. This complexity of conditions exists along the Greenland ice margin at present and probably also existed in this country.

While advocating this view, it is not insisted that submarginal accumulation is impossible, nor are the three causes above mentioned *all* that were possible. The surface of the ice may have become covered with rock *débris*, as may be seen in the Malaspina Glacier of to-day; and this, through irregularity of melting of the ice which the *débris* covered, may have assumed distinctly morainic form and structure, and then, as the ice melted, have been dropped to the ground to add to the other accumulations. Again, *débris* washed from the land to the ice margin, or even out upon it, may have helped make the moraine. Such an origin is indicated for a part of the moraine in the Lake Cayuga valley, and apparently accounts, in part, for its remarkable development in that valley, while elsewhere along the same morainic line, the topography is generally especially marked only in the valleys, and is sometimes almost indistinguishable.

The Extent of the Moraine in New York.—No attempt will be made here to tell in detail about the distribution of the New York moraines. What little is known is mostly told upon the accompanying maps (Figs. 10 and 11); but it is to be understood that the Chamberlin map is an approximate and generalized expression of morainic districts and will not bear the test of local criticism. Numerous moraines are not placed upon it, and those that are, are not always correctly placed. It was based upon a preliminary reconnaissance, and, unfortunately, nothing of a more accurate nature has since been done in the greater part of the State.

A few words of a general kind may accompany this map. It will be noticed that the moraine enters New York from the southwest, just to the southwest of the lower end of Chautauqua Lake. There at Jamestown it is remarkably well developed, and, from this point, the lines of moraine diverge, one passing northeastward toward the west boundary of the Genesee Valley, the other passing very near Salamanca southeastward into Pennsylvania, and thence on to New Jersey.* With the interpretation of Lewis and Wright, that the southernmost moraine is in reality the outermost moraine of the last glacial advance, I am in full agreement. The facts presented by these writers have never been satisfactorily disproved, and one who has gone over the region can hardly fail to accept their conclusions. Therefore, notwithstanding the difference of opinion expressed upon Chamberlin's map, I accept the interpretation of the Pennsylvania geologists.

According to this view the actual terminal moraine entered New York State, aside from the Long Island region, in only one place, which is the place where the ice front stood farthest north in eastern United States. The reason why the glacier did not reach farther south in western New York is partly the effect of the very high plateau region of rugged topography which exists in northern Pennsylvania and southwestern New York. This actual terminal moraine of Lewis and Wright is well developed in central New Jersey, and again enters the State of New York in New York Bay, where it crosses to Long Island. The sandy and hummocky hills of this island are in large part due to the remarkable development of the terminal moraine,† which may be traced still further east-

* This moraine is the one described by Lewis and Wright. See reference, page 193.

† Bryson, Geol. Mag. X, 1883, 169–171; Amer. Geol. III, 1889, 214; Same, 1893, XII, 127, 402; Same, 1894, XIII, 390; Same, 1895, XV, 188; Same, 1895, XVI, 228; Dana, Amer. Journ. Sci., 1890, XL, Ser. III, 425–437; Same, 1891, Ser. III, XLI, 161; Hollick, Trans. N. Y. Acad. Sci., XII, 1893, 189–202, 222–237; Same, 1895, XIII, 122–130; Same, 1894, XIV, 8–20; Same XV, 1895, 3–10; Same, XVI, 1896, 9–18; Lewis, Am. Journ. Sci., 1877, XIII, Ser. III, 142–146; Mather, N. Y. Geol. Survey, 1st Dist., 1843, 271; Merrill, Ann. N. Y. Acad. Sci., 1883–5, III, 341–364; Upham, Am. Journ. Sci., 1879, XVIII, Ser. III, 81–92, 197–209.

ward upon Block Island, the Elizabeth Islands, Martha's Vineyard and Nantucket. Although probable, it is by no means certain that the Long Island moraine is the actual terminal moraine, for it is still possible that the ice front to the south of New England was at one time in the sea to the southward of Long Island. In that case the Long Island moraine may correspond with one of the later halts, possibly with the well developed one in west central New York. Much careful work is necessary before the exact correlation of the several moraines is possible.

North of this extreme terminal moraine are numerous morainic patches, and somewhat indistinct lines of morainic topography, many of which are not yet located and correlated. There is also some moraine in the valley of the Chemung and Susquehanna Rivers, as well as in some of their tributaries, indicating a series of brief halts of the ice. Still further north, in the Genesee Valley, and along the headwater region of the Finger Lakes, and thence northeastward to the Mohawk, there is much moraine, indicating a prolonged halt of the ice, with the front by no means uniform in position. The history marked by this development of moraine has never been worked out, though it is not so simple as might be supposed from the map (Fig. 10). There were numerous minor halts and fluctuations of position in the general stand in this vicinity. This moraine is strongly developed, but from the valleys alone one would get an erroneous notion of its importance. There are places on the hills where this moraine, strongly developed in the valleys, is traced with difficulty. The detailed work of Leverett,* indicated by the map (Fig. 11), gives some idea of the complexity of the ice withdrawal from western New York.

North of this well developed morainic band there are others, the best developed one being north of the Finger Lakes, and not shown by the Chamberlin map. In the Adirondack region there are other moraines of recession.† Concerning the moraines of the Adirondacks, the Catskills, and other sections of eastern New York, practically nothing is known.‡ There certainly are moraines in this region, as there are in New England; and in all probability the

* Am. Journ. Sci., Ser. III, L. 1895, 1–20.

† For an interpretation of the withdrawal of the ice front from North America, see Upham, Am. Journ. Sci., 1895, XLIX, Ser. III, 1–18; Bull. Geol. Soc. America, VII, 1896, 23; Chalmers, Amer. Journ. Sci., 1895, XLIX, Ser. III, 273–275.

‡ Some notes on Glacial Geology of New York will be found in the following: Dana, Am. Journ. Sci., 1863, XXXV, 2d Ser., 243–9; Stevens, Amer. Journ. Sci., 3d Ser., 1872, IV, 88–90; Julien, Trans. N. Y. Acad. Sci., III, 1883, 22–30; Brigham, Amer. Journ. Sci. 1895, Ser. III, XLIX, 213–228.

recession of the ice from this section of the State was much more complex than in the central and western portions; for, in addition to the moraines made by the great ice sheet, very much influenced by the rugged topography, and hence scattered and difficult to trace, there were no doubt local glaciers in the mountain valleys, as there are now in Greenland, and as there were at the close of the Glacial Period in New Hampshire and Maine. The mapping and correlation of these moraines is one of the important problems on the geology of New York and one that will do much to tell what the ice really did. Until such work has been done in New England and New York we will have but a meagre knowledge of the great American ice sheet.

OVERWASH PLAINS AND VALLEY TRAINS.—These have already been mentioned in the third article of this series* and can therefore be briefly dismissed here. Where the glacier front stood for a long enough time to build morainic hills, the floods of water, being commonly overburdened with sediment, built up deposits of stratified gravel on the southern side of the moraine. Where the topography was not rugged, numerous ice-derived streams built sloping plains resembling low alluvial fans. These are well seen on Long Island and Martha's Vineyard, and to those of the latter place Professor Shaler has given the very descriptive name of frontal aprons.† The plains on the southern slope of Long Island are of this origin, and they are often crossed by the channels of the streams that built them, though now at times no water flows in them.‡ Overwash plains, as these are also called, are not confined to this section, but in less perfect development are found every here and there on the southern side of the New York moraine, particularly in the south sloping valleys. The best instance with which I am familiar outside of Long Island is that upon which the town of Horseheads, north of Elmira, is situated.§

These plains often merge into valley trains of stratified drift. Practically all the south-sloping valleys of western New York have been embarrassed by these deposits,‖ which are sometimes very deep. The Susquehanna and its tributaries, even beyond the boundary of New York, contain deposits of this origin, so that now

* Bull. Am. Geog. Soc., XXX, 1898, 42–44. See Salisbury, 1892 Report, New Jersey Geol. Survey, 96–125.

† Shaler, 9th Ann. Rept. U. S. Geol. Survey, 1889, 548.

‡ See references above to the Long Island moraine.

§ Fairchild, Bull. Geol. Soc. Amer., VI, 1895, 367.

‖ Brigham, Bull. Geol. Soc. Amer., VIII, 1897, 17–30.

this stream, as in the case of many others, is flowing high above the old rock bottom of the preglacial valley. By this means much of the glacial drift was removed well beyond the ice margin, and not a little of it reached to the sea. The stream valleys sloping away from the ice all show some effects of this flooding with sediment-laden glacial water. These deposits grow finer and finer as we proceed down stream, being coarse gravel near the moraines and oftentimes fine clay near the sea.

The surface of overwash plains, valley trains, moraines and sandplains (described just below) is often pitted with little kettle-shaped depressions.* These kettles are sometimes caused by irregularities of deposit, either through differences in supply of material, or in direction or form of currents which were swirling about, forming eddies here and there. In other cases, and perhaps the majority, the kettle has resulted from failure to deposit material, because that particular part of the surface was occupied by an ice fragment or stranded iceberg, which had stratified drift deposited all around it and finally over it, and then, melting away, left the material to settle down, forming a kettle hole. In the marginal lakes on the coast of Greenland instances of this may be seen; and it is probable that while the American ice sheet was melting away, the conditions favoring this mode of formation of basins were in operation.

LAKE DEPOSITS.—As will be shown in a later article under the discussion of the Great Lakes, during the retreat of the glacier many lakes were made in regions where now they are impossible. Then there were ice dams where now there is no barrier to the free northward flow of the rivers. As the ice front withdrew, passing north of the Allegany and Susquehanna-St. Lawrence divide, each of the valleys that sloped northward was dammed by the glacier, forming lakes in their southern ends, the area of which grew as the glacier front stood farther and farther north, until, finally, the withdrawal was sufficient to admit of a northern outflow, when the lake level fell. This distinct lake history by itself has been interesting, and is told by the deposits made during the time that the waters were thus ponded.†

Along these lake shores, beaches and bars were in some cases built, while deltas were very commonly formed at the mouths of

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* See references to Koons, p. 198, and Woodworth, Amer. Geol., 1893, XII, 279.

† Fairchild, Bull. Geol. Soc. Am., VI, 1895, 353–374; Lincoln, New York State Museum Report, XLVIII, Part 2, 1894, 74–77.

the tributary streams. These, however, are not strictly glacial deposits, though in cause intimately related to the glacier. But in the lakes, deposits of stratified drift were also made from material derived directly from the ice. As the streams emerged from the glacier into these lakes, they poured their volumes of sediment into the quiet lake waters, where it settled, the coarsest near the glacier, the finer farther away, forming there a layer of lake clay. This is especially well developed along the southern shores of Lakes Erie and Ontario, though not absent from the numerous smaller valleys of the Finger Lake region. To these were added deposits dropped from the glacier itself, and still others floated away into the lake, buoyed up by the tiny icebergs that must have floated away from the ice front.

These deposits have not notably modified the surface of New York, though they have added somewhat to the glacial modifications of the details of topography. Near the ice margin, at its various stands, deposits must have been rather extensively made near the mouths of the sub-glacial rivers. No doubt such deposits are common in portions of the State, though they have not been described from there. In New England they are found quite commonly, especially near the coast, where they are called sandplains.* These are really deltas in a body of water now absent. The material was supplied from the melting of the ice, and the form of the deposit is that of a true delta, flat-topped, with steep front, and traversed by stream channels, and sometimes pitted on the surface by kettles, probably formed by the same means as those mentioned above (page 206).† Future study will no doubt discover sandplains in New York.‡

KAMES.—Throughout New York, commonly in association with the moraines, but often isolated, are single hills, or groups of hummocky hills, of stratified drift called kames.§ In topographic form they resemble moraines and are often a part of these deposits; but elsewhere they seem to bear no relation to morainic bands. Single

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* There is reason for believing that some of the New England sandplains are really deltas formed in the sea when the land was somewhat lower than at present, as it was during the close of the Glacial Period. The evidence of this will be published in a forthcoming number of the American Geologist.

† For a discussion of sandplains see Davis, Bull. Geol. Soc. Am., I, 1890, 195–202; Davis, Proc. Boston Soc. Nat. Hist., 1892, XXV, 477–499; Gulliver, Journ. Geol., 1893, 1, 803–812; Salisbury, Ann. Rep. New Jersey Geol. Survey, 1892, 99–102.

‡ Tarr, Bull. Am. Geog. Soc. XXX, 1898, 45.

§ Salisbury, Ann. Rep. N. J. Geol. Survey, 1891, 92–95; Same, 1892, 84–95.

hummocks may be found upon hillsides or even hilltops. They sometimes show a confused stratification with the layers dipping in various directions, and exceedingly variable in texture. Moreover, the layers are sometimes broken, showing disturbance subsequent to deposit. In different places their origin is apparently quite different. Glacial water has evidently made them ; but there are various ways in which this water may construct hills of stratified drift. Deposits in caverns under the ice, hills made by cascades carrying much sediment down the ice front or through crevasses into the ice, and deposits in tiny lakes upon the surface of the glacier, and later lowered to the ground when the ice melted, are some of the more common ways in which kames may have been made. By this action hills several scores of feet in height have been constructed.

Naturally the conditions favoring such deposits will exist only near or at the ice margin; but as this front was in all parts of the State at different times, kames may be found in any part of New York, and indeed they do occur all over the State, sometimes rising in what appear to be the most unnatural positions. Where the ice stood longest they would be most abundant; and hence they are most common in association with the moraines. Slight forward movements of the ice would break and disturb the layers as we find them. Few specific cases of kames have been described in New York,* but they are known here and have also been described from various parts of the country.†

ESKERS OR SERPENT KAMES (OSARS).—Ridges of gravel, bearing a close resemblance to embankments, are frequently found within the glacial area. In these the material is usually coarse. Sometimes they are made of good-sized and well-rounded pebbles, oftentimes several pounds in weight. Sometimes, however, eskers are made almost entirely of sand. The stratification, while often noticeable, is usually somewhat confused, and the ridge may be coarse in one place and much finer in another.

In the form of eskers there is much variation. Typically they are distinct, narrow-topped ridges, extending in a more or less irregular or serpentine course. Some are mere low banks; others

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* See particularly Fairchild, Am. Geol. 1895, XVI, 39–51 ; Same, Journ. Geol. IV, 1896, 129–159; Brigham, Bull. Geol. Soc. America, VIII, 1897, 17–30 ; Lincoln, New York State Museum Report, XLVIII, Part 2, 1894, 72–74.

† For instance, see Upham, Hitchcock's Geol. of New Hampshire, Vol. III, 1878, 12–176; Lewis, Second Geol. Survey Pa. Rept. Z, 1884, 35–36; 61–65; 78–81 ; 100–111, etc.; Chamberlin, Journ. of Geol. 1893, I, 255–267.

have a height of several scores of feet. In some cases the crest of the ridge is level; but more commonly it undulates somewhat and has a gradual slope in one direction, normally sloping downward in the direction of ice movement as revealed by the striæ upon the bed rock. Variations from this normal form are common. At times the ridge is interrupted, or it may end abruptly, or even very gradually, often terminating in a broad, sandy area. Some eskers

FIG. 18.—SIDE VIEW OF ESKER, AUBURNDALE, MASS. (PHOTOGRAPH BY JOHN RITCHIE, JR.).

end in sandplains.* These ridges may even end in a tiny valley cut in the till.

As for location, they may be found anywhere within the glacial belt, though they are more common near the moraines. They are very abundant in eastern New England, and have been well described for the Boston region.† Among the mountains of Maine ‡ and New Hampshire § they are common. The term esker is an Irish name,‖ and these peculiar ridges are common in Ireland, as

* See Davis, Bull. Geol. Soc. Am. I, 1890, 195–202; Davis, Proc. Boston Soc. Nat. Hist., 1892, XXV, 477–499; and Gulliver, Journ. Geol. I, 1893, 803–812.

† Bouvé, Proc. Boston Soc. Nat. Hist., XXV, 1891–92, 173–182.

‡ Jackson, Geol. of Maine, 1st Rept., 1837, 64; Stone, Proc. Amer. Assoc. Adv. Sci., 1880, XXIX, 510–19.

§ Upham, Hitchcock's Geol. of New Hampshire, Vol. III, 1878, 12–176. For New Jersey eskers, see Salisbury 1892 Report New Jersey Geol. Survey, 79–83.

‖ Young, Report Brit. Assoc., 1852, XXII, Part 2, 63–64; Kinahan, Amer. Journ. Sci., 1887, Ser. III, XXXIII, 276–278.

elsewhere in the British Isles * and northwestern Europe. In Scandinavia they are called äsar (anglicized osars). Little work has been done upon the eskers of New York, though they occur in association with the moraine. † Instances of eskers may be seen near Freeville, New York, and along the Lehigh Valley Railway west of Geneva. In all probability they are common, particularly in the more hilly sections, such as the Adirondacks.

As for the details of location, eskers are very commonly found in valleys, but by no means confined to them. They have been found upon hillsides and are known to cross valleys, extending

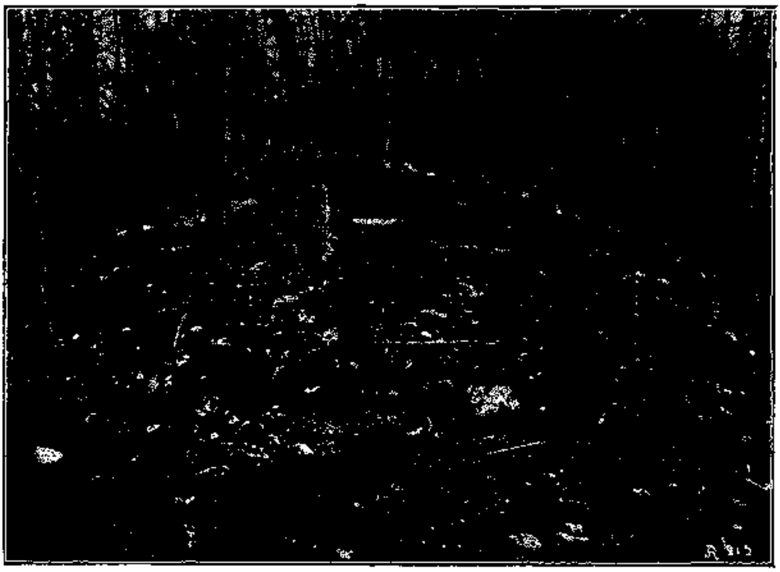

FIG. 19.—CREST OF ESKER, AUBURNDALE, MASS. (PHOTOGRAPH BY JOHN RITCHIE, JR.).

down one side and up the other. ‡ Such conditions are exceptional, and the type location may be said to be the valley, or else the immediate neighborhood of a moraine. Here they may be but a few score of yards long or may extend for miles. Some of the eskers of Maine are exceedingly long and well developed. When typically developed they have a remarkably artificial appearance, sometimes closely resembling an abandoned railway embankment. They have in some cases been explored in the belief that they were Indian mounds.

* Howe, Report Brit. Assoc., 1861, XXXI, Part 2, 115–6.

† Upham, Proc. Rochester Acad. Sci., II, 1893, 181–200; Fairchild, Journ. Geol., IV, 1896, 129–159.

‡ Shaler, Ninth Ann. Rept. U. S. Geol. Survey, 549.

Their form and characteristics point plainly to stream origin and to the conclusion that they are really the beds of glacial streams. There has been some question whether these glacial stream beds were formed under the ice (subglacial) or in the ice (englacial), or upon the ice (superglacial), and this question is still an open one.* The facts seen in living glaciers †, and those discovered by the study of existing esker deposits, point to a subglacial river origin as by far the most probable ‡, although other facts brought forward seem to show that there are some eskers which have been formed by superglacial or englacial streams.§

Near the ice front streams were flowing in each of these positions, but by far the greater amount of drainage near the ice terminus must have been subglacial. In either case the running water was supplied with much sediment which was being dragged along the stream bed. Wherever more was given than the stream could remove, deposits were necessarily made in the stream bed. Since the ice contained many pebbles and boulders, as well as finer clay, it would not uncommonly happen that the stream could not remove as much sediment as was given to it. Then, at the bottom of the ice cañon, an embankment of gravel would be built, held in by ice walls, and resting either upon the ice (in englacial or superglacial valleys), or on the ground if subglacial. When the ice withdrew, the stream deposits would settle, the sides taking the slope of gravel at rest ‖, but retaining the average slope of the stream bed (if this were on the ground) and its meandering direction. Therefore the esker represents a fossil glacial stream bed, whether subglacial or superglacial or englacial.

The confused stratification is due to the irregularity of deposit, later settling, and possibly to disturbances caused by ice movement. The interruption of form may be due to ice movement or to failure

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* Davis, Proc. Boston Soc. Nat. Hist., 1890–92, XXV, 477–499; Chamberlin, Journ. of Geol., 1893, I, 255–267; Upham, Bull. Geol. Soc. Am., V, 1894, 71–84; Amer. Geol., 1894, XIV, 403–405; Winchell, Am. Journ. Sci., 1881, XXI, 358–60; Sollas, Report British Assoc., 1893, 63, 777; Russell, Am. Journ. Sci., 1892, Ser. III, XLIII, 178–182; Same, Thirteenth Ann. Rept. U. S. Geol. Survey, Part II, 81–82; Reid, 16th Rept., Part I, U. S. Geol. Survey, 442.

† Russell, Amer. Journ. Sci., 1892, Ser. III, XLIII, 178–182; Same, Thirteenth Ann. Rept. U. S. Geol. Survey, Part II, 81–82; Reid, 16th Rep., Part I, U. S. Geol. Survey, 442.

‡ Davis, Proc. Boston Soc. Nat. Hist., 1890–92, XXV, 477–499; Chamberlin, Journ. Geol., 1893, I, 255–267.

§ Winchell, Amer. Journ. Sci., 1881, XXI, 358–60; Upham, Bull. Geol. Soc. Am., V, 1894, 71–84; Am. Geol., 1894, XIV, 403–405.

‖ Woodworth, Proc. Boston Soc. Nat. Hist., XXVI, 1895, 197–220.

to deposit in particular places; and the broadening out in places, from the ridge slope to the low sandy areas, may either represent the terminus of the esker stream, at the glacier margin, or some broad part of its ice-walled valley. The location of eskers upon hillsides may be easily accounted for. If formed on or in the ice, the valley location is essentially accidental; and when the ice disappears the eskers may settle upon the hillsides, as well as in a valley. If, on the other hand, as seems much more commonly, if not almost universally, the case, the esker stream was subglacial, the water building the esker was flowing in an ice channel under considerable pressure, so that it might even flow up hill, if the hill were not higher than the pressure head, for the same reason that water flows through the pipes to the second story of our houses. In this case the esker location would generally be along valleys, and this is the case.

THE TILL SHEET.—The material that was on, in, or under the ice (superglacial, englacial and subglacial till) at the time it melted away from any given place, was left upon the surface of the country

FIG. 20.—SECTION IN VERY BOULDERY MORAINIC TILL, CAPE ANN, MASS. (PHOTOGRAPH BY J. L. GARDNER 2ND).

as a till sheet, that part removed by water being of course excepted. This till sheet, which covers the greater part of New York, and particularly the hillsides and tops, varies greatly in character from place to place. Typically and prevailingly it is a *boulder clay*, which, as the name suggests, is essentially a boulder-bearing clay.

The percentage of boulders varies from nearly boulder free to a class of till in which more than one-half the mass is made of boulders. The clay is a rock flour made by the grinding of the rocks as they are dragged along by the ice; and this abrasion is further indicated by the fact that many of the boulders and pebbles are grooved and polished.

The color of the till sheet varies greatly, depending in large measure upon the color of the rocks over which it passed just before it was deposited. This indicates a rather local origin for much of the till; and this is borne out by the fact that among the boulders are found many of local origin. Still, in a region where the

FIG. 21.—BOULDER-STREWN SURFACE OF MORAINIC TILL, CAPE ANN, MASS. (PHOTOGRAPH BY J. L. GARDNER 2ND).

rocks are soft, as they are in the shale country of central New York, these fragments are worn so rapidly that they may be less numerous than the Canadian boulders and pebbles which, though brought from afar, being harder, have been better able to stand the long journey than the shale fragments were the much shorter one. The farmers have practically asserted this fact when they have called these foreign boulders, resting in the midst of soft shale strata, by the very descriptive name of "hardheads." In the region from which the hard heads have come boulders may be so common that, as in parts of New England, the soil is almost incapable of cultivation.

While the color of the drift is variable, its general color, when fresh and unoxidized, is blue, grading to a yellow near the surface where stained with the limonitic iron stain formed during oxidation of iron-bearing minerals. The blue color is due to the finely comminuted and undecayed dark particles, and may be present even when the till has been derived from light colored gneissic and granitic rocks.

Although typically a clay, the till is sometimes sandy, though not commonly. When very clayey it is often so compact that it is difficult to dig through it with a spade. This has been given the name of "hard pan," and it owes its compactness not merely to the fineness of the clay, but also, at times, to the fact that it has been pressed into a compact condition by the weight of the ice which once rested upon it.

The mode of origin of this till sheet was, first, the removal of loose fragments from the surface, then, with the aid of these, the grinding off of others, accompanied by the grinding of the various particles into finer bits. In position, while some of the fragments may have been upon the ice top, and some within the ice, the greater part was dragged along, either just beneath the ice, or frozen in the lower layers of the glacier. In Greenland the latter is the common mode of transportation of the *débris* load. This glacier has a smaller burden of rock fragments than the American glacier, and the till sheet which it is depositing is, therefore, much less developed. There is good reason for believing that some of the American till was dragged along beneath the ice, so that here, as in some other respects, the Greenland glacier of to-day is not a fair guide for conditions prevailing in America during the Glacial Period.

This rock load, wherever carried, was left upon the surface of the land with the retreat of the glacier. In examining the surface of a large area, like that of New York, we find that this till sheet varies greatly in depth. There are places where there is almost none except in the little depressions, and this is particularly the case among the high gneissic peaks of New England and the Adirondacks. This means either that none was deposited or else that it has been removed; and sometimes one explanation is correct, sometimes the other. This is the prevailing condition in Greenland, where the slopes are great and the original till deposit slight. Frequently the till is but a few inches or feet in depth, and then the rock is reached in ordinary trenches. This condition is most common upon hilltops or upon those hillsides where we may believe the ice movement to have been relatively rapid. In such places little was left, because little was held under the ice, the movement being rapid enough to prevent such accumulations, somewhat as a river with rapid flow, during the time of flood, can clear its bed of the gravel bars that were accumulated at some time of less rapid movement.

The thickness of the till sheet varies progressively also over wide areas. As a general statement, subject to many modifications locally, the till sheet of New England and eastern New York is thinner than that of western New York, and this is thinner than that of the Central States, where it is sometimes two or three hundred feet deep.* This general change in thickness is parallel with a change in topography from mountain to hill and then to plain. Over the latter the ice slope was slight and the current probably less rapid than in the more irregular regions of the east. The variation is also parallel with a change in rock texture. In the east the strata are prevailingly hard; in the west relatively soft, although of course to this there are certain local exceptions. From a region of soft rock more drift is supplied than from one of hard, and this is one of the reasons why the Greenland glacier has so little drift. It follows from this that in the central west the ice wrested more drift and was less able to remove even a small supply than in the east. Hence beneath the ice much till was accumulated in the western section, while in the east the opposite holds true, as a general statement.

As has been said, this general statement needs modification locally. Among the Adirondacks, and in New England, the ice currents were often retarded by some rocky hill, around which the ice must flow. Upon the southern or lee side of such a hill the conditions favored deposits beneath the ice; and consequently, while the north side of such hills is nearly bare of drift, the southern side often has a deep till soil. Here very often the rocky hill has been prolonged southward as a drift hill formed by the deposit of a tail of drift upon which, very likely, a farm is situated, while all around is untillable and hence wooded land. This drift material, combed down from the hilltop and sides, and accumulated in the slack ice current on the lee side of the hill, forms a distinct element in the landscape of many of the hilly sections.

Still another case may be introduced. Rather narrow east-west valleys extended across the course of the south-moving glacier, as

* Calvin, Amer. Geol., I, 1888, 28–31; Leverett, Am. Geol., IV, 1889, 6–21; Claypole, Bull. Geol. Soc. Am., III, 1892, 150–151.

was very commonly the case in central and western New York. Down into these the ice currents could not move as readily as along the hilltops, and hence here too, material from the hilltops was combed off and dragged beneath the ice into the valleys. The result

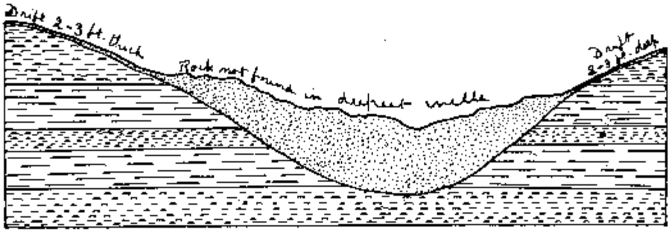

FIG. 22.—SECTION TO SHOW DEEP DRIFT FILLING IN NARROW EAST-WEST VALLEYS NEAR ITHACA, N. Y.

has been that in such valleys the till is deep, gradually becoming thinner upon the hillsides. The diagram is based upon these conditions as exhibited in scores of places near Ithaca, N. Y. In these cases the valley has been made more shallow and its bottom broader than before the ice came, and by these causes the topography of the New York-Pennsylvania plateau has been greatly modified.

Not only have valleys been shallowed, but in some cases they have been entirely obliterated. Near Ithaca there are numerous

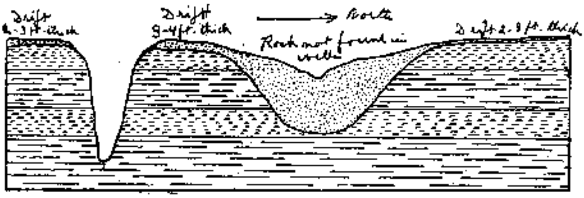

FIG. 23.—SECTION TO SHOW BURIED VALLEY OF TAUGHANNOCK CREEK, NEAR CAYUGA LAKE, N. Y.

buried valleys, the position of some of which is not now indicated in the landscape, while that of others is shown by a gentle sag in the hillside. The diagram (Fig. 23) is based upon these conditions now to be found just north of Taughannock gorge on the west side of Lake Cayuga, a few miles north of Ithaca. Where the general drift sheet is thick, and the original topography less irregular, as in the central west (and apparently also in the Ontario region*), the preglacial drainage lines are almost entirely obliterated. By boring for oil, some of them have been discovered, where, without the

* See article III of this series, Bull. Amer. Geog. Soc. XXX, 1898, 52–54.

facts thus obtained, the extent of the preglacial land irregularities would not be known.*

There are several other causes for irregularity in the depth of the till sheet, the exact causes of which are not apparent. Sometimes the till is locally thicker than elsewhere without any evident relationship to the topography. Its surface rises and falls in gentle swells, or rises into hummocks or ridges. This irregularity has led Professor Chamberlin † to suggest certain names, such as mammillary hills, till tumuli, etc., to designate the several types. Nothing more can now be said about the cause for these than that they must be related either to some unusual variations in supply, or in ice currents, or be due to the influence of minor topographic features, the nature and extent of which is not always easy to determine. They fall among the category of the altogether too numerous instances of unexplained glacial phenomena. We need specific studies of these forms and the collection of facts concerning them.

DRUMLINS.—Among the irregularities of the till none form such a striking element of the topography as those till hills which are classed as drumlins. These were first fully described in Ireland, whence their name.‡ In this country they occur in eastern Massachusetts§ and southern Connecticut, as well as in other parts of New England.‖ They occur also in Wisconsin.** Generally they are found in clusters, though many isolated drumlins are known. These peculiar hills are said to occur in the Adirondacks and in eastern New York,†† though I find no description of these localities; but one of the most notable accumulations of drumlins in the world exists

* Newberry, Geol. Survey Ohio, 1869, 24–33; Andrews, 60–64; Newberry, Geol. Survey Ohio, Vol. I, 1873, 85–88; 174–184; Orton, 425–434; 438–449; 455–462; Gilbert, 537–556, and other parts of Report.

† Chamberlin, Third Annual Rept. U. S. Geol. Survey, 1883, 296–309; Compte Rendu, Congrès Géol. Inter. Washington, 1891, 176–192; Journ. of Geol. 1894, II, 517–538.

‡ Kinahan and Close. General Glaciation of Iar-Connaught, Dublin, 1872.

§ Shaler, Proc. Boston Soc. Nat. Hist., XIII, 1869–1871, 196–204; Upham, Proc. Boston Soc. Nat. Hist., XX, 1878–80, 220–234; Marbut & Woodworth, 17th Annual Rept. U. S. Geol. Survey, Part I, 995; Davis, Science, IV, 1884, 418–20; Amer. Journ. Sci., 1884, XXVIII, Ser. III, 407–16.

‖ Hitchcock, Proc. Boston Soc. Nat. Hist., 1876–78, XIX, 63–67; Upham, Hitchcock's Geol. of New Hamp., Vol. III, 1878, 287–309; Hitchcock, 309; Upham, Proc. Amer. Assoc. Adv. Sci., 1879, XXVIII, 309.

** Chamberlin, Journ. Geol., 1893, I, 255–267; Upham, Am. Geol. 1894, XIV, 69–83.

†† Upham, Bull. Geol. Soc. Am., III, 1892, 142.

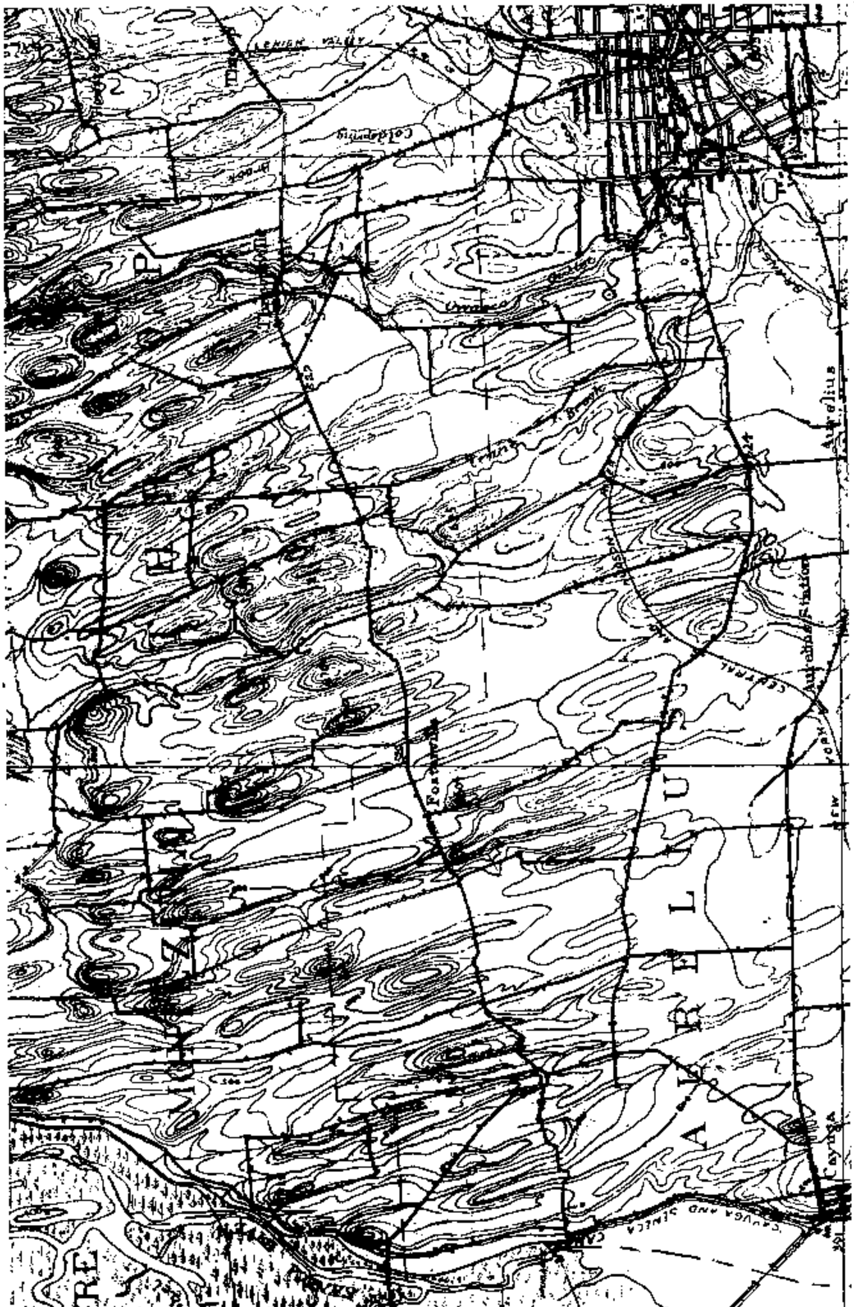

FIG. 24.—A PART OF THE DRUMLIN REGION NORTH OF CAYUGA LAKE (U. S. GEOL. SURVEY TOPOGRAPHIC MAP).

in the region between Syracuse and Rochester along the line of the New York Central Railway. As in the case of most of the other glacial features of New York, we have no adequate description of these interesting hills.*

The New England drumlin is typically a beautiful and symmetrical hill, elongated in form, having a shape resembling that of an egg when half submerged in water, with the long axis parallel to

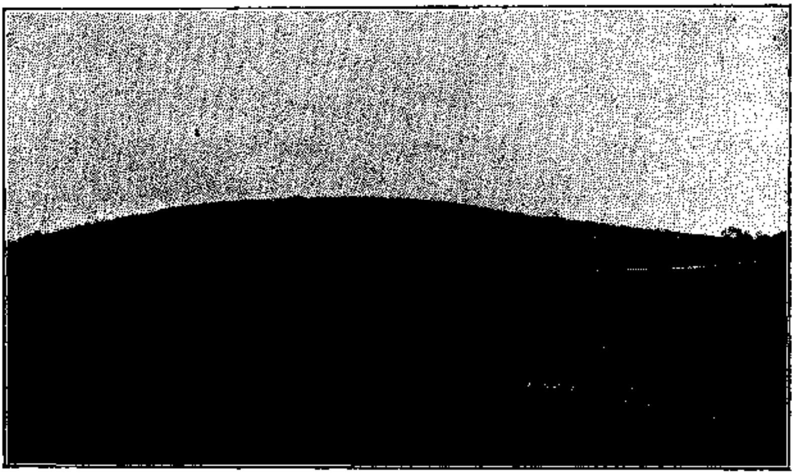

FIG. 25.—A TYPICAL NEW ENGLAND DRUMLIN NEAR IPSWICH, MASS. (PHOTOGRAPH BY J. L. GARDNER 2ND).

the water surface. The length may be a half to three-quarters of a mile, the width a fifth to a half a mile at the base, and the height perhaps one to two hundred feet. There are longer and shorter, broader and narrower, and higher and lower forms than this type. The curves are wonderfully regular, but commonly the northern end is steeper than the southern. This type is well illustrated by scores of hills in Boston harbor, and near Boston, especially north of that city as far as the Ipswich coast. The long axis of the New England drumlin is parallel to the direction of ice movement, and the material of which they are composed is mainly till, though very often they contain stratified drift.† The Wisconsin drumlin is

* Hall, Geol. of N. Y. 4th Dist. 1843, 341; Johnson, Ann. N. Y. Acad. Sci., II, 1882, 249–66; Abstract in Trans. N. Y. Acad. Sci., 1882, I, 77–80; Davis, Science, IV, 1884, 419; Lincoln; Am. Journ. Sci., XLIV, 1892, 290–301; New York State Museum Report, XLVIII, Part 2, 1894, 69–71.

† Upham, Proc. Bost. Soc. Nat. Hist., XX, 1878–80, 220–234; Same, XXIV, 1888–89, 127–141; Same, XXIV, 1888–89, 228–242; Same, Amer. Journ. Sci., 1889, Ser. III, XXXVII, 359–372; Crosby & Ballard, Amer. Journ. Sci., 1894, Ser. III, XLVIII, 486–496; Marbut and Woodworth, 17th Annual Rept. U. S. Geol. Survey, Part I, 995; Upham, Amer. Geol. XX, 1897, 383–387.

often much shorter and less symmetrical,* the Irish type much longer.†

The drumlins of central New York approach the Irish type much more closely than those of New England. Their form varies from the southern margin to the northern. In the latter part of the belt, they are often very much like the Boston type, though considerably less symmetrical and with steep northern faces. Near the southern margin of the drumlin belt they are exceedingly long and low ridges, the length being sometimes more than two miles and the height very often less than one hundred feet at the highest point, which is close to the northern end. Some ridges, perhaps three-quarters of

FIG. 26.—LOW DRUMLIN RIDGE NEAR SOUTHERN MARGIN OF NEW YORK DRUMLIN AREA, JUST EAST OF CAYUGA (PHOTOGRAPH BY W. B. GREENLEE).

a mile long, are not more than forty feet high at the highest point. In fact, these low drumlins simulate the esker in form. Even many of the higher drumlins of this section change to low and long ridges in the southern part, and their exact southern terminus is often incapable of location, for it flattens out into the undulating till sheet very gradually. Sometimes this terminus is in the irregular morainic topography. In all cases the northern end is well defined and relatively steep.

While some of the drumlins are long and low, with an even-topped crest line, sloping gradually southward, others have an undulating crest, giving a very ragged sky line. Whether this is a part of the original form of the drumlin, or has been caused by later

* Chamberlin, Geol. Survey, Wisconsin, I, 1873–79, 283.

† Kinahan and Close, General Glaciation of Iar-Connaught, Dublin, 1872.

denudation has not been determined, though there are some reasons for supposing that the latter is true.

Between the long and low type at the southern margin of the belt, and the shorter type at the northern margin there is a grada-

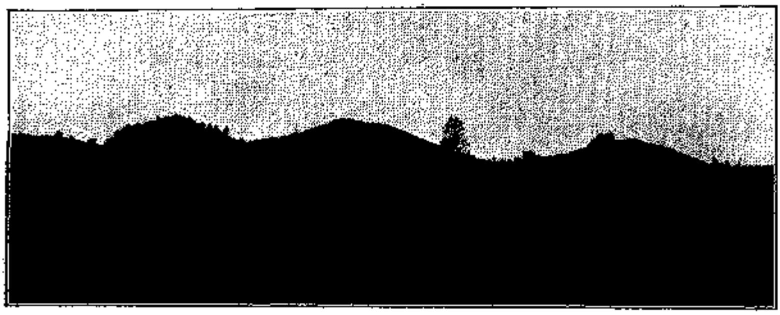

FIG. 27.—THE NORTHERN ENDS OF THREE OF THE NEW YORK DRUMLINS NEAR MONTEZUMA (PHOTOGRAPH BY W. B. GREENLEE).

tional form to which a student of Cornell University applied the descriptive name of "tadpole" drumlin. The northern end of such a drumlin resembles the northern type quite closely, while the southern end is a low ridge, and the two different parts are connected by a rather noticeable slope, somewhat like the southern

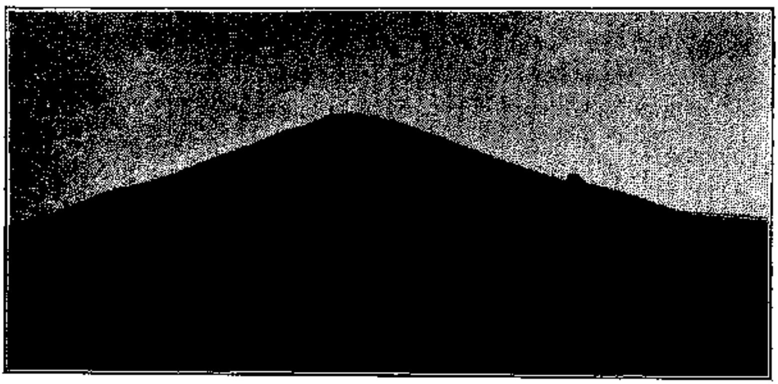

FIG. 28.—NORTHERN END OF A HIGH DRUMLIN AT MONTEZUMA, N. Y. (PHOTOGRAPH BY W. B. GREENLEE).

end of a New England drumlin. Hence the drumlinoid form, somewhat closely resembling the typical New England drumlin, quickly changes to a low and long ridge, causing a rather remarkably close resemblance to a tadpole body with the appended tail. Some of the New York drumlins are quite like the New England type in form, and all so far studied are made of unstratified till. The question of the nature and origin of these drumlins is now under investigation, and it is probable that the intermediate "tadpole" forms will throw light upon the question of drumlin origin.

As in the case of all drumlins, the long axis is parallel to the direction of ice movement, which, in this section, was approximately southward. The material composing them seems to be till

FIG. 29.—RIDGE-LIKE DRUMLIN, NEAR MONTEZUMA, N. Y., SHOWING NORTHERN END ON LEFT (PHOTOGRAPH BY J. O. MARTIN).

of the normal kind, perhaps somewhat more pebbly than commonly; but upon this point definite statements cannot be made until further studies have been carried on. Nor can we say how many drumlins there are, though it is certain that there are many hundreds in this area; and one may stand upon the crest of one and count scores which stand in plain view with their ends overlapping. The topography of the drumlin region is quite unique in New York State, and has probably given rise to more inquiries from residents than has any other section of the State of equal population. Every year several students ask me for the interpretation of this region, a fact true of no other part of the State.

The origin of drumlins is still an open question, or at least should be, though there is a tendency on the part of some to consider it settled. Numerous theories for their origin have been suggested,*

* See preceding references, and also Wright, Ice Age in North America, 251–267; Geikie, Great Ice Ace, 3rd Ed., 743–745; Russell, Glaciers of North America, 24–28; Geikie, Geol. Soc., Glasgow, 1867, Vol. III, 54; Wright, Proc. Boston Soc. Nat. Hist. XIX, 1876–78, 58; Salisbury, Ann. Rept. N. J. Geol. Survey, 1891, 71–75; Upham, Am. Geol., 1892, X, 339–362; Upham Am. Geol., 1895, XV, 194; Russell, Journ. of Geol., 1895, III, 831; Upham, Bull. Geol. Soc. Am., VII, 1896, 17–30; Tarr, Am. Geol., 1894, XIII, 393–407. In the latter, I have attempted to consider the two theories fairly, and have advocated the reopening of the question of origin.

two of which still seem probable, while against the others numerous facts can be brought. One of these theories is that drumlins have been caused by erosion, resulting from slightly different ice currents; the other, and more generally accepted theory, is that they have been *built* by irregular deposit from the ice, somewhat as sandbars are built in rivers. The latter has more supporters than the former; but the question can hardly be considered closed, since no facts of importance have been brought forward to disprove the former. So far the theories have been stated as conceptions of the process which probably formed the hills. Careful studies of drumlin areas are now needed to test these theories, especially since there are facts difficult to explain upon the basis of the theory of construction which has so many adherents.

GLACIAL EROSION.—That the ice eroded is proved by the fact that it was able to deposit; for it must have obtained what it deposited, together with that which went off in the water furnished by ice melting. It is further proved by the scratched stones and the glacial scratches upon the ledges; but *how much* it eroded is more difficult to prove. The old notion was that ice performed wonderful tasks and greatly modified the topography as a result of this. From this extreme view there has been a reaction, and opinion has perhaps become nearly as extreme in the other direction, for there are those who deny to ice the power to do much work of this kind. That it did not erode enough to materially modify the surface in a *great* way, seems evident from an examination of the topography on the two sides of the extreme terminal moraine. Careful observation is necessary to detect the differences, which would not be the case had the ice scoured greatly in the glaciated district.

One thing every one will admit is, that in most places the ice removed the loose *débris* that had accumulated in preglacial times; still there are places in New England, and probably also in New York, where this was not done. This also argues against extreme glacial erosion; but these facts may be admitted without necessitating the view that erosion was everywhere slight.*

All facts, as I see them, indicate marked difference in power of erosion in different places. The hilltops were scoured more than the east-west valleys, and in all probability the hilltops of central and western New York were perceptibly lowered by ice-scouring. The proof of this would be difficult, for we know absolutely nothing of the detailed conditions before the ice came.

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* See Lincoln Proc. Am. Assoc. Adv. Sci., 1893, XLII, 177–8; Same, Am. Journ. Sci., Ser. III, 1892, XLIV, 290–301; Same, 1894, XLVII, 105–113.

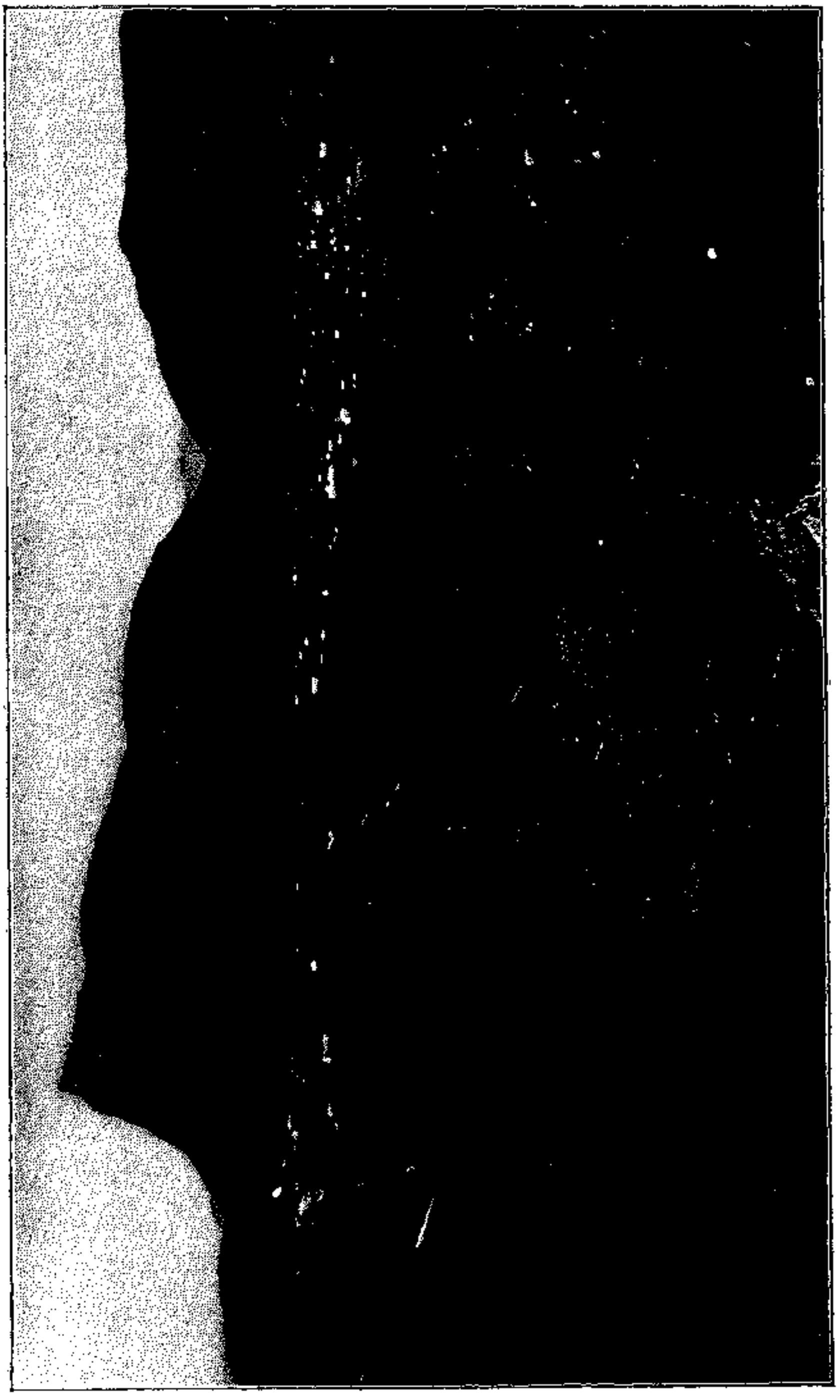

FIG. 30.—GLACIATED SURFACE OF UPPER NUGSUAK PENINSULA, GREENLAND, SHOWING SMOOTHED NORTH SIDE AND STEEP SOUTH SIDE OF A HILL CALLED THE DEVIL'S THUMB ON THE DANISH MAP (PHOTOGRAPH BY J. O. MARTIN).

East-west valleys of narrow width, being transverse to the ice direction, were probably less eroded; but broad north and south valleys, like those of the Finger Lakes,* furnishing free passage to the ice, were perceptibly lowered and broadened. In such places I believe that we find the maximum ice erosion. It is in broad valleys extending in the direction of the ice movement that we find the most rapid ice movement, and hence erosion, at the margin of the existing Greenland glaciers. This is true not merely because of the breadth, but because the ice was deep in these valleys, and had a free and hence more rapid movement. These facts would seem to be sufficient proof of this view.

There was also more rapid erosion upon the north or *stoss* side of hills than upon the southern or *lee* side, against which the ice-currents had little chance to scour. That this is so is amply proved by the topography of New York and other regions, where the northern slope of hills is prevailingly more regular and rounded than the southern sides. The differences may amount to a difference between an inaccessible precipice on the southern and a gentle slope on the northern side of hills. This is beautifully shown in the Adirondacks, as it is also in New Hampshire and Maine, as well as in Greenland, where the ice has just left the land.

Therefore, it seems that by erosion the hilltops have been slightly lowered and rounded, hill-slopes modified and rounded upon the northern or stoss end, and broad valleys parallel to the direction of ice movement both broadened and deepened. If it were necessary ample proof of this position could be brought forward. This is a belief in moderate but irregular erosion, by which the topography of the State has been perceptibly modified in details; but to *just* what extent this modification has operated, how much the hills have been lowered and rounded and the valleys deepened, may never be determined.

Effect upon Drainage.—Of all the effects of the glacier this is probably the most notable. Lakes have been formed and allowed to disappear. Others now existing have been caused by one or another of the effects of the glacier. Streams have been turned temporarily across divides and others given permanently to different streams, while many have been turned either partly or wholly out of their old valleys. The drainage of New York is the complex result of preglacial topography and glacial modification. The consideration of this important effect of the ice must be left for later parts of this series.

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* This question will be discussed much more fully in a later number of this series.