GEOLOGICAL SURVEY OF NEW JERSEY

HENRY B. KÜMMEL, State Geologist

The Glacial Geology

Of New Jersey

BY

ROLLIN D. SALISBURY

ASSISTED BY

HENRY B. KÜMMEL

CHAS. E. PEET

GEORGE N. KNAPP

Volume V of the Final Report of the State Geologist

TRENTON, N. J.:
MacCrellish & Quigley, Book and Job Printers.

1902

CONTENTS.

PART II.—LOCAL DETAILS.

ILLUSTRATIONS.

PLATES.

FIGURES IN TEXT.

Board of Managers.

His Excellency FRANKLIN MURPHY, Governor,
and *ex-officio* President of the Board, ...Trenton.

I. Congressional District.

CLEMENT H. SINNICKSON, ...Salem.
Vacancy, ...

II. Congressional District.

EDWARD C. STOKES, ...Millville.
EMMOR ROBERTS, ...Moorestown.

III. Congressional District.

HENRY S. LITTLE, ...Matawan.
M. D. VALENTINE, ...Woodbridge.

IV. Congressional District.

WASHINGTON A. ROEBLING, ...Trenton.
WILLIAM J. TAYLOR, ...High Bridge.

V. Congressional District.

FREDERICK A. CANFIELD, ...Dover.
ERNEST R. ACKERMAN, ...Plainfield.

VI. Congressional District.

GEORGE W. WHEELER, ...Hackensack.
WILLIAM F. HALL, ...Pompton Lakes.

VII. Congressional District.

WENDELL P. GARRISON, ...Orange.
HERBERT M. LLOYD, ...Montclair.

VIII. Congressional District.

FREDERIC W. STEVENS, ...Newark.
HARRISON VAN DUYNE, ...Newark.

IX. Congressional District.

Vacancies.

X. Congressional District.

S. BAYARD DOD, ...Hoboken.
JOSEPH D. BEDLE, ...Jersey City.

Letter of Transmittal.

To His Excellency, Franklin Murphy, Governor of the State of New Jersey and ex-officio President of the Board of Managers of the Geological Survey.

SIR—I have the honor herewith to submit Vol. V of the Final Report Series of the State Geologist.

I am

Yours respectfully,

HENRY B. KÜMMEL,

State Geologist.

TRENTON, N. J., June 17, 1902.

PREFACE.

THE REPORT on the Glacial Geology of New Jersey forms Volume V of the series of "Final Reports of the State Geologist." The previous volumes are, Vol. I, Topography, Magnetism and Climate (edition exhausted); Vol. II, in two parts, Mineralogy, Botany, Zoology; Vol. III, Water Supply; and Vol. IV, Physical Geography. Copies of all these except the first can be obtained upon application to the State Geologist by payment of postage or expressage.

The glacial deposits of the State received comparatively little attention in the earlier years of the Geological Survey, although some facts regarding them are given in the Annual Reports of 1877, 1878 and 1880. In 1890, however, an arrangement was made by Dr. John C. Smock, then State Geologist, with the United States Geological Survey, whereby the surface deposits of the State were to be studied and mapped by the State Survey, while the geology of the underlying formations was to be studied by the National Survey. In acordance with this plan, work upon the surface formations was commenced by Mr. R. D. Salisbury in 1891, and has been continued intermittently by him and his assistants to the present time. The field work upon the glacial deposits, which occur only in the northern part of the State, was essentially completed in 1894, but the preparation and publication of the final report has been delayed to the present, as only a small portion of Mr. Salisbury's time has been available for this work. Reports of progress, however, were made in the Annual Reports from 1891 to 1894, inclusive.

In the prosecution of the field work upon the glacial deposits Mr. Salisbury was assisted by Messrs. C. E. Peet, H. B. Kümmel, G. N. Knapp, A. L. Whitson and G. E. Culver. Although the report is issued under the direction of the present State Geologist, it is proper to record the fact that the field investigations were carried on and the manuscript in part prepared during the incumbency of Prof. J. C. Smock, whose interest in this work was strong.

In the first part of the report, the general phenomena of glacial deposits and glacial epochs are described. The characteristics of the sheet of drift which mantles northern New Jersey are given and the correctness of its reference in origin to an ice-sheet is proven. The conditions which determine and control the formation of glaciers, the manner in which they affect the surface of a region over which they pass and the forms and disposition of their deposits are analyzed in detail. In short, Part I gives a thorough discussion of glaciers and glacial deposits with reference to the deposits of New Jersey in particular. This portion of the report, being more general in its scope, cannot fail to be of great value to all interested in a most important epoch in geological history—an epoch which profoundly affected the northern portion of our State.

Part II is more detailed in character. The three subdivisions of the northern part of the State—the Appalachian province, the Highland belt and the Triassic plain—are taken up in succession and the glacial deposits are described, in part by counties and townships and in part by drainage basins. This part, therefore, will be of particular value to the local resident who has an intelligent interest in the geology of his home district; to the teacher, who desires local illustrations of geologic processes and formations; to the prospector and miner, who must differentiate between local and foreign materials; to the farmer, who is interested in the origin of the soils and subsoils; to the engineer, who in planning reservoirs, laying out roads, erecting buildings and bridges, and sinking artesian wells, needs a fuller knowledge of the deposits which overlie the older rocks beneath.

In order to insure the fullest possible understanding of the problems presented, the report has been richly illustrated by maps, by half-tone plates and by line drawings. The maps are both topographical and geological, the former representing the form of the surface, which in many regions is dependent in no small degree upon the glacial deposits, the latter showing the distribution of the various classes of deposits in typical portions of the State. The half-tones, chiefly selected from the numerous photographs taken in connection with the field work, illustrate in a more vivid way the facts described in the text. It is believed that the greater cost of the report due to these illustrations, is warranted by its increased value to all readers.

Acknowledgment is due to Messrs. MacCrellish & Quigley, the printers, and to Julius Bien & Co. and A. Hoen & Co., the engravers, for the mechanical excellence of the typography and maps.

HENRY B. KÜMMEL,
State Geologist.

ERRATA.

Page 12.	Plate VIII is in a pocket at the back of the book.
Page 80.	On Plate XXVI, Fig. A., instead of "Fig. 6" read "Fig. B."
Page 154.	Second line, read "Plate XXXVII" instead of "Plate XXXII".
Page 514.	Eighth line, read "Montville" for "Montvale".
Page 608.	Sixth line, read "Westwood" instead of "Westfield".
Page 628.	Third line, read "DRIFT" instead of "RRIFT".

PART I.

THE DRIFT AND THE GLACIAL PERIOD.

CHAPTER I.

THE DRIFT AND ITS ORIGIN.

CONTENTS.

The northern part of New Jersey is overspread with a mantle of clay, sand, gravel and bowlders, which, taken together, are commonly grouped under the name of *drift*. Sections of the drift may be seen at hundreds of places along the railroads and wagon-roads in the northern part of the State, in most of the sand and gravel pits of the same region, and in numerous temporary excavations which are open wherever grading, building or construction of any sort is in progress. The most obvious characteristics of drift as seen in sections, are two: first, it is composed, in part at least, of materials unlike the underlying rock; and second, coarse material and fine are often, though not always, mingled together without regard to order.

The surface of the drift is hardly less characteristic than its constitution, as seen in sections. The surface is often characterized by the presence of large stones or bowlders, sometimes of huge size, and by various peculiarities of topography, the most obvious of which is the presence of depressions without outlets. Many of these depressions contain standing water. So characteristic of the drift are ponds and lakes, that its southern limit may be said to be marked approximately by the southern limit of ponds and lakes of natural origin. In New Jersey this limit is an irregular line extending from Perth Amboy on the southeast to a point on the Delaware a little below Belvidere on the west (see map, Plate XXVIII).

In the early days of geology this surface material, which often effectually conceals the solid rock beneath, was regarded as uninteresting in itself, and as an obstacle to the study of the underlying formations, which were regarded as the proper field of geological inquiry; but within recent years the drift has been the subject of critical investigation, and there are now few departments of geology which are attracting a larger share of professional attention, and few departments which have yielded, or are yielding, more interesting and more important results.

The various sorts of materials (Plate I) which compose the drift, clay, sand, gravel and bowlders, are sometimes intimately commingled, and sometimes more or less distinctly separated from one another (Plate II). In the former case the mixture is often so complete that there is no sign of arrangement of the clay, sand and gravel in layers. Such drift is unstratified. Where these materials are separated, or partially separated from one another, the differentiation may take on various phases. If its parts are arranged in layers, the drift is *stratified*. An area may be covered by assorted gravel or sand arranged in layers, but much the same from top to bottom; or gravel, sand and clay may alternate with one another in vertical section, each sort of material being in layers; or still again, any or all of these varieties of stratified drift may alternate with that which is unstratified (Plate III). In the interbedding of the stratified drift with the unstratified, all possible combinations exist. Either may be below the other, or either may be between beds of the other type (Plate IV).

PLATE I.

Section showing the physical heterogeneity of the drift in the northeast part of Newark.

PLATE II.

Section showing stratified drift. Rutherford.

Section showing assorted and stratified drift, over unassorted and unstratified. Madison.

PLATE IV.

Section showing interbedding of assorted and unassorted drift.

Bosses of bare trap-rock projecting through the drift. Near Marion.

PLATE VI.

Quarry in Newark, showing drift over the stratified rock.

An area where the drift is all stratified may be contiguous either to an area where the drift is all unstratified, or to an area where the two types are more or less commingled. Where the bowlders, gravel, sand and clay are associated without sign of separation or arrangement, any one of them may predominate over the others to any extent, or all may be commingled in approximately equal proportions.

Through the drift, the underlying rock often protrudes, sometimes standing up as bare knolls or hills (Plate V). Many natural and artificial sections also reveal the rock beneath (Plate VI).

DRIFT INDEPENDENT OF UNDERLYING ROCK.

The drift is not restricted to any particular sort of rock, but is found over all the various formations in the northern part of the State, from the oldest to the youngest. The variety of formations which it covers in our State is shown, or partially shown, on Plate VII. The drift overlying any particular formation of rock generally contains stones which could not have been derived from it. Where, for example, the underlying rock is limestone, bowlders of sandstone, conglomerate or gneiss, along with those of limestone, may be found in abundance in the drift. The bowlders of sandstone, conglomerate and gneiss cannot have come from the disruption of the limestone, for limestone does not contain the materials of which they are composed. In like manner the drift which overspreads the surface of the trap often contains, in addition to bowlders of trap, bowlders from a great variety of other formations, such as gneiss, sandstone, limestone and shale. Disintegration or disruption of the trap could by no possibility have given rise to these bowlders, since the trap contains nothing from which these sorts of rock could have come.

While the drift covers all formations alike, the drift on one formation is not identical with that on another. Generally speaking it contains a relatively large proportion of material derived from the underlying rock, but to this generalization there are exceptions.

It was long since recognized that the materials of the drift did not originate where they now lie. Long before the drift began to be carefully studied, it was conjectured that it had been brought or "drifted" to its present position from outside sources, by means of water. It is to this conception of its origin that the formation owes its name.

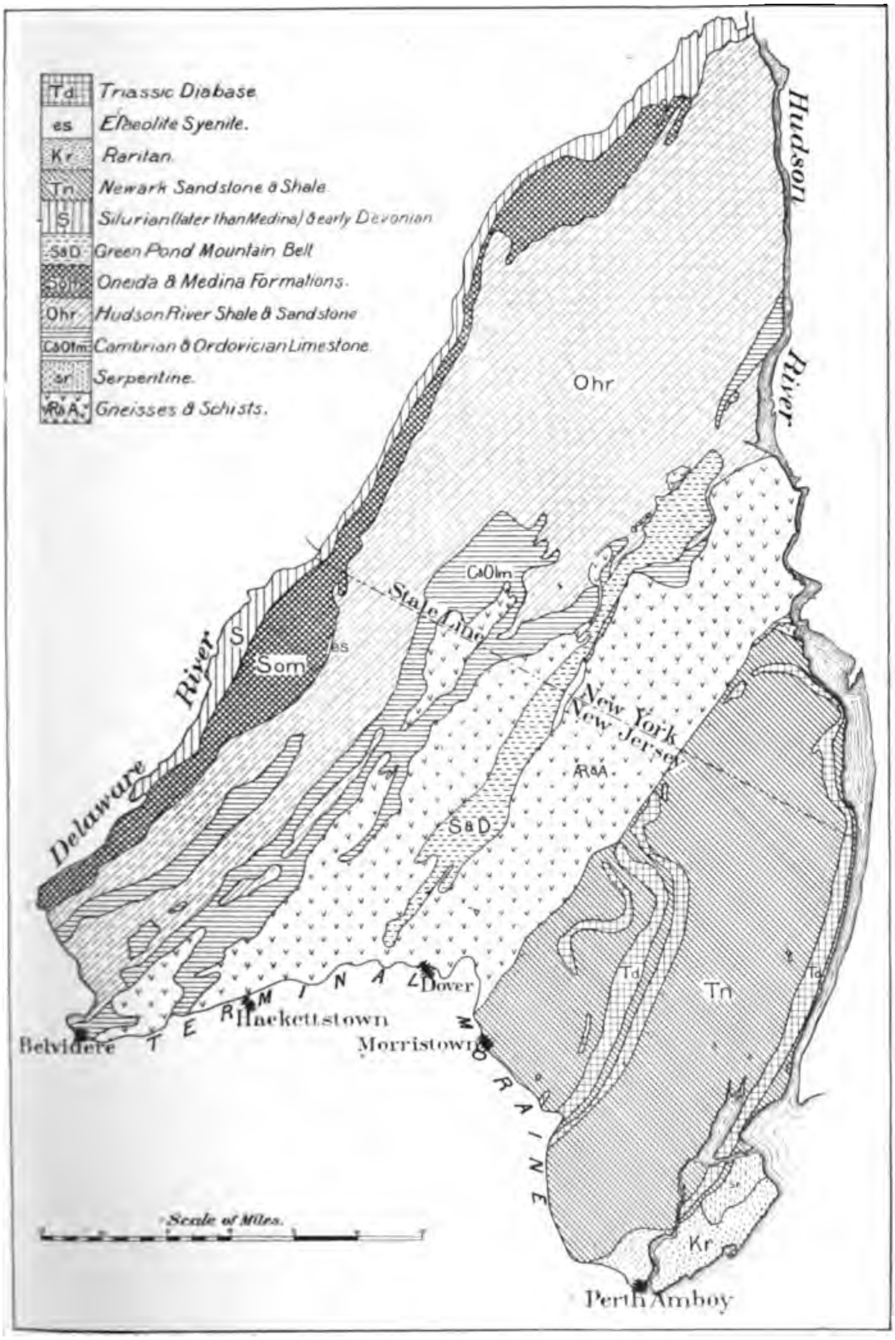
DRIFT INDEPENDENT OF TOPOGRAPHY.

In its distribution, the drift is as indifferent to topography as to rock formations. Within the general area of its occurrence, it is found at all elevations from sea level on the one hand up to 1,800 feet, the height of the highest point in the State, on the other. Between these elevations it is found in valleys, on plains and plateaus, and on hills, ridges, and mountains, even where their crests are narrow and their slopes steep. Since it is disposed with indifference to topography, it must be inferred that the mountains, hills, valleys, plateaus and plains antedated the drift, and that the latter was spread out over a surface the topography of which, so far as its larger features are concerned, was not unlike that of the present time.

THICKNESS OF THE DRIFT.

The thickness of the drift varies greatly, ranging in New Jersey from zero on the one hand to known depths of more than 250 feet on the other. Its average thickness within the State is probably somewhere between twenty and forty feet. Much greater thicknesses, 500 feet or more, are known at various points outside the State (Ohio and Western New York) in regions affected by the drift. The variations in thickness of the drift may be great within short distances. One hill may have barely enough to cover the rock, while the next may be composed of drift from base to summit. This is often a matter of practical importance. Thus in the construction of the great dam for the reservoir at Boonton, the site first selected was abandoned because the hills between which the dam was to be constructed were composed of loose drift which would not afford a foundation

PLATE VII.



Map showing the distribution of the principal rock formations in Northern New Jersey and the adjacent part of New York.

sufficiently strong, and another site a little farther up the valley was chosen, where the drift was thin and solid rock close to the surface.

The drift may be thin on the hills and deep in the adjacent valleys (Fig. 1), or, less commonly, the reverse is the case. In

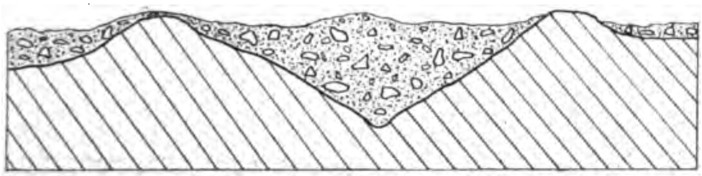


Fig. 1.
Drift thick in valleys, and thin on ridges of rock.

some parts of the State it is thick on the lower slopes of the valleys and thin (or even absent) from both the valley bottoms and upper slopes (Fig. 2). In the mountainous portions of the

Fig. 2.
Drift thick on the lower slopes of the valleys, and thin both in the bottom and on the upper slope.

State, especially where the summits are narrow, as in the case of the Kittatinny and Green Pond mountains, the average thickness of the drift is slight, and the larger part of that which does exist is in the valleys. Even here the amount is sometimes slight, as in most parts of the great Kittatinny valley.

EFFECTS OF THE DRIFT ON TOPOGRAPHY.

Relatively little of the drift-covered part of the State is flat, or even of slight relief, but where the surface approaches planeness, excavations and borings have shown that the surface of the rock beneath the drift does not always correspond in configuration to the present surface. The rock surface is more irregular than the drift surface in some places, less irregular in others, and of about the same degree of irregularity in still others; that is, the drift may be so disposed as to diminish the relief, to increase it, or not to noticeably affect it. If the rock surface beneath the drift be plane, and if the drift be evenly distributed, the shape of the surface is not changed whatever the thickness of the drift (Fig. 3). If the rock surface be plane,

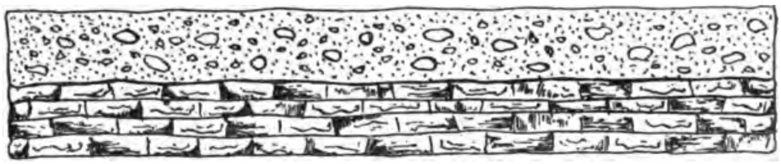


Fig. 3.
Drift so disposed as not to change the topography.

or nearly so, the drift may be so disposed as to give the surface an increased relief (Fig. 4), and the resulting topography is due

Fig. 4.
Drift so disposed as to increase the relief of the surface.

primarily to the drift. Again, if the rock surface have a relief of 100 feet, and the drift a thickness ranging up to 100 feet, the drift may be so disposed as to even up the surface (Fig. 5). In

Fig. 5.
Drift so disposed as to diminish the relief of the surface.

this case, also, the drift controls the existing topography, but the relief has been diminished. In general the drift may control, or fundamentally influence the topography where its thickness is great, *relative to the relief of the rock surface beneath.* If, on the other hand, the relief of the rock surface greatly exceeds the thickness of the drift, the rock control of the topography must always be greater than that of the drift. Drift twenty feet thick cannot fundamentally alter the topography of an area which has a relief of 200 feet, though its effects may be seen in detail.

Small areas where the drift control of the topography obscures or overcomes the rock control are numerous. They are found most commonly in the lower parts of the broad valley plain between the Palisade ridge on the one hand, and the Watchung mountains on the other, and in the extensive area occupied by the waters of the extinct lake Passaic (see Plates XXXVII to XLII). In the former area, the drift control of the topography is pronounced over much of the area between the latitude of Englewood on the north and Perth Amboy and Dunellen on the south, though even within these limits the rock affects the configuration of the surface at many points. Where the drift control predominates within this area, its influence is sometimes to roughen the surface, as along the broad, irregular ridge which extends from Fanwood to Metuchen and thence southeasterly to Perth Amboy; and sometimes to make it planer, as about Plainfield. Plate IX puts these two types of surface in contrast, both the planeness of the plain (at the left) and the roughness of the ridge just east of it being due to drift (compare Figs. 4 and 5). Again, the depth of drift in the Hackensack and Newark meadows is very great, locally as much as 250 feet. Were it removed, a deep bay would extend north over the sites of these marshes and beyond. Here, then, a great depression in the rock has been filled by the drift, leveling up the surface.

Within the area of Lake Passaic, the most pronounced topographic features are certain trap ridges; but these aside, the topography is more largely dependent on the drift than on the rock below. Here, too, the effect of the drift is sometimes to roughen the surface, and sometimes to produce the opposite effect. Thus the broad ridge which extends from Morristown to Madison, and which has been made one of the most attractive regions in the State, is composed entirely of drift (Plate X). Here the effect of the drift has been to increase the relief. On the other hand, the flat region between Basking Ridge and Madison owes something of its flatness to the leveling up of a somewhat uneven surface of rock, by the drift. The same is true of the flat parts of the area between Madison and Morristown on the southwest, and the Rockaway and Passaic rivers, above the mouth of the Pompton on the northeast. Rising above the flats of this area, there are, however, very considerable hills, composed largely or wholly of drift.

Where the relief of the surface is notably greater than the thickness of the drift, the larger features of the surface are necessarily due to the rock and not to the drift. The Palisade ridge, the Watchung mountains, and Green Pond and Bearfort mountains, many of the peaks and ranges of the Highlands, and the Kittatinny mountain (see Plate VIII), all the most notable elevations of the State, are of rock. The amount of drift which covers them is so slight that its removal would change the topography but little. The mountains and valleys would still retain their relative positions, and almost their relative elevations. Here and there notable changes would be occasioned by the removal of the drift, for in some places, as in the Second mountain at Short Hills, it fills a notable gap in the range (Fig. 6).

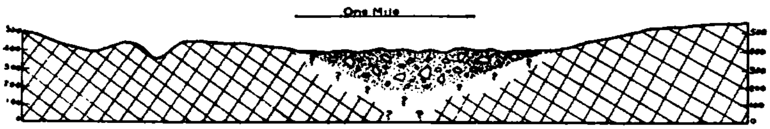


Fig. 6.

Illustrates what is known of the valley across Second mountain at Short Hills. The drift is known to extend down to the depth indicated, and is believed to extend much lower.

The depth which the pass through these mountains would have if the drift were removed, is not known, but the filling exceeds

EXPLANATION OF PLATES

VIII, IX, X.

PLATE VIII.

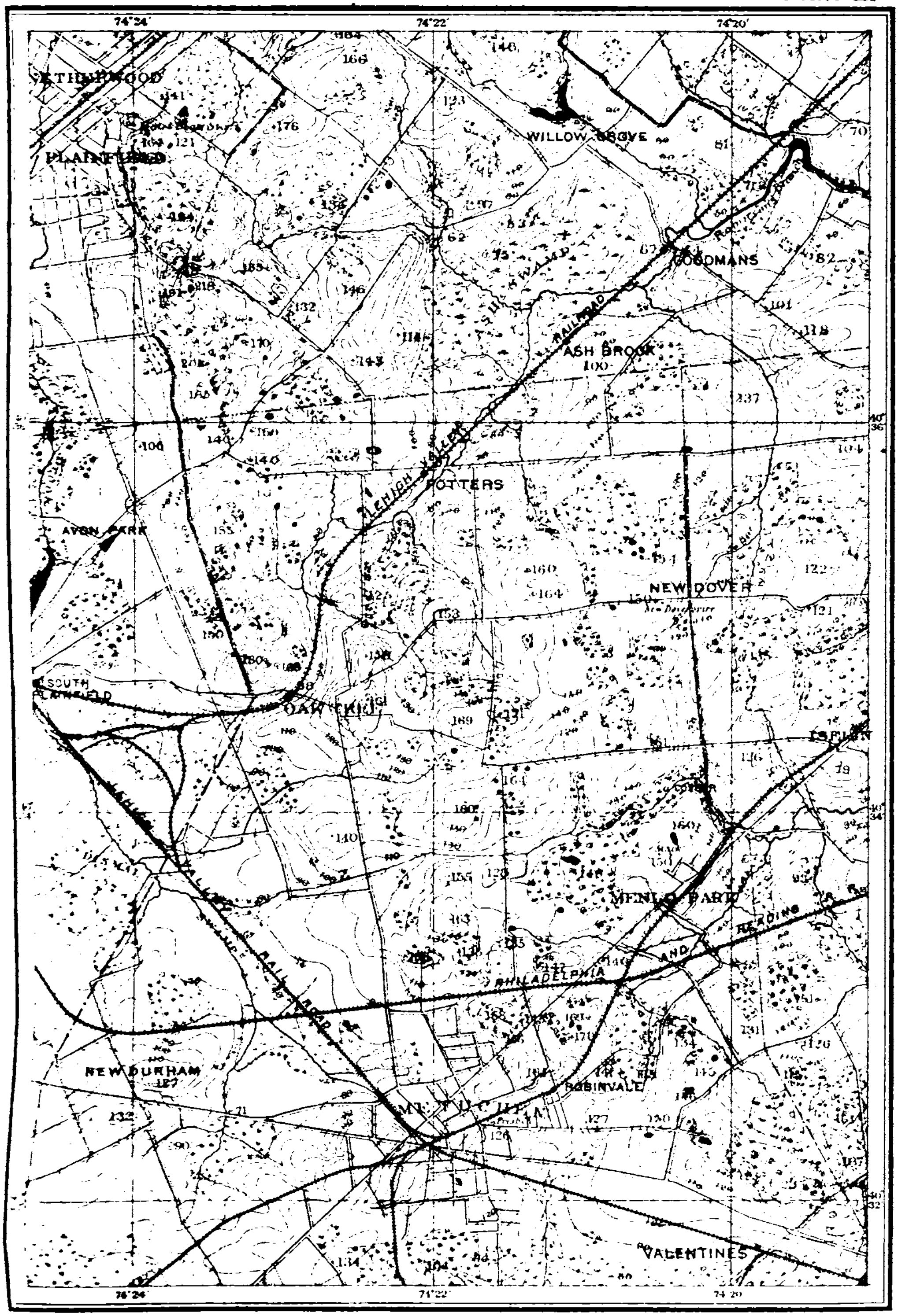
Relief map of the northern part of the State, showing the southern limit of the drift, and, by arrows, the general direction of ice movement.

PLATE IX.

Topographic map showing the moraine as a rough, ridge-like belt, between Perth Amboy and Fanwood. Southwest of the moraine, especially northwest of Metuchen, there is a flat, covered with gravel and sand, washed out beyond the moraine by water. Plainfield stands on this plain.

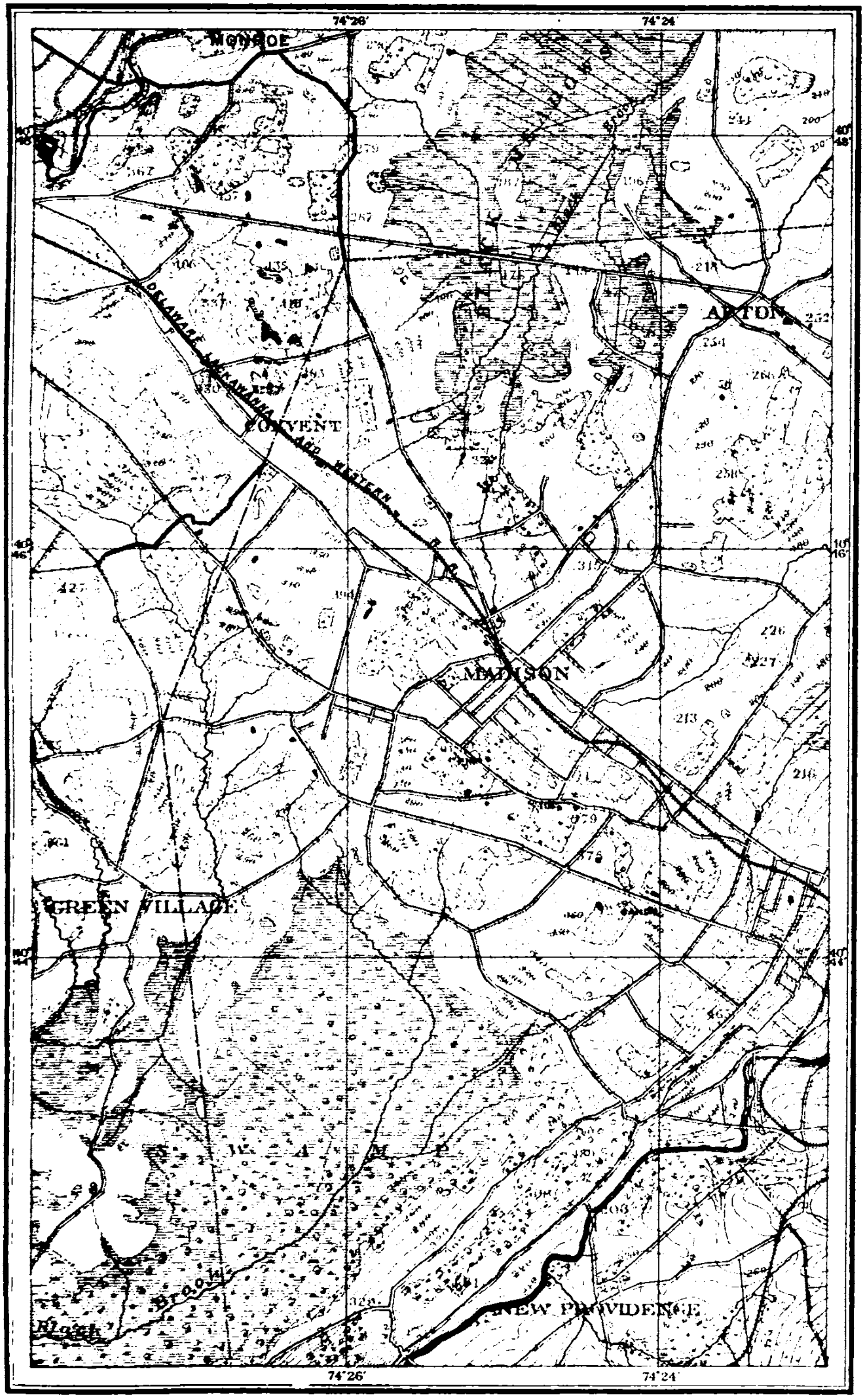
PLATE X.

Topographic map showing the moraine as a broad ridge between Madison and Morristown.



THE MORAINE SOUTHEAST OF PLAINFIELD, N. J.

Scale 1 inch to a mile



THE MORAINE NEAR MADISON, N. J.

Scale 1 inch to a mile

200 feet[1], for the boring for a well, carried down to that depth, did not reach rock. Similar rock-filled gaps at other points have possibly escaped discovery.

The greatest topographic changes which would result from the removal of the drift in the mountainous parts of the State would be the deepening of the valleys, for, on the whole, the drift is thicker there than on the elevations between them. The removal of the drift would, therefore, increase the relief, though, except about Newark and Hackensack, not in a very large way.

Since the drift was formed, the streams have partially removed it (Fig. 7) from the valleys, and in some cases they have cut

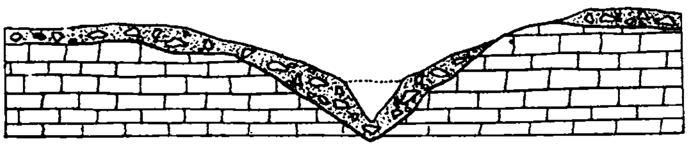


Fig. 7.

The drift of the valley has been partially removed by stream erosion in post-glacial time. The part below the dotted line illustrates the position of the surface as it may have been left by the ice.

quite through it, and now flow in the old rock channels which antedated the drift (Fig. 8).

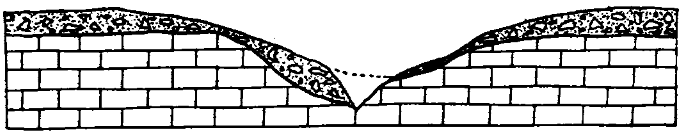


Fig. 8.

The stream has removed all the drift from the bottom of the valley on one side.

But while the larger geological features of the northern part of the State are due to rock and not to drift, there are many minor ones which owe their existence to the latter. Many of these minor features are unobtrusive, and not readily designated,

---

[1] Annual Report of the State Geologist, 1893, p. 304.

but some of them are easily recognized. In many of the valleys, there are terraces and plains of drift. Many of the plains resulted from the filling up of the valley bottoms with drift (Fig. 9),

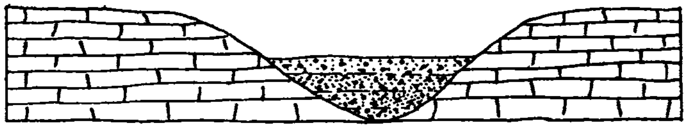


Fig. 9.
Cross section of a valley plain produced by aggradation.

and the terraces are the remnants of these flats, after the rivers have cut them partially away (Fig. 10).

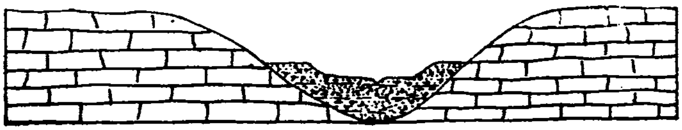


Fig. 10.
Partial removal of the filling shown in Figure 9 leaving terraces.

On the terraces of the streams are many of the best farming lands in the northern, and especially in the northwestern part of the State. In many places, too, the valley flats have greatly facilitated the construction of high roads and railroads. Of the railroads which cross the northern part of the State from east to west, one follows a valley, the Pequannock, while the other, the D., L. & W., runs along a belt of thick drift which evens up an irregular rock surface.

Again, all the numerous beautiful lakes[1] in the northern part of the State owe their origin to the disposition of the drift, or to the action of the forces which produced it. Most of them occupy depressions in its surface, or basins formed in valleys, across which the drift is disposed as a dam.

While, therefore, the geographic features occasioned by the drift in the northern part of the State are mostly small as compared with those which are due to the rock beneath, they are not without interest and significance, whether to the economist or to

[1] Reservoirs are not here included.

Two views of a huge bowlder on road west of railway, west of Glen Rock.

PLATE XII.

Unstratified drift, the principal constituent of which is clay. Newark.

Stratified clay. Pit below Hackensack, west of the river.

the lover of natural scenery. Nevertheless, it must not be lost sight of that, except for a limited area, the drift is but a thin mask, veiling the minor features of the rock surface, but not obscuring the major ones.

CONSTITUTION OF THE DRIFT.

Reference has already been made to the fact that the drift is heterogeneous, both as to the size of its constituents, and as to the kinds of rock entering into its composition. So far as concerns the former, the drift is made up, at the one extreme, of huge bowlders 20 feet and even 30 feet in diameter (Plate XI), and at the other impalpable earthy matter. Between these extremes there are materials of all grades, and the proportions of coarse and fine are subject to the greatest variation. The drift is more likely to be coarse in mountain regions where bowlders abound, though fine clayey earths are often associated with them. The finer phases of the drift are more common over the Triassic shale and sandstone (Plate XII), though even here bowlders are not usually wanting. Locally, as at the brick yards near Morristown, Hackensack (Plate XIII), and Little Falls, the drift which can be seen is made up almost wholly of fine clay. In the first two places, coarse drift underlies the fine, and in the last the reverse is the case.

As to the kinds of rock found in the drift, it is to be noted that most of the drift of the State seems to have been made from the rock formations of that part of the State where it occurs, or from formations very similar to them. Crystalline schist and gneiss, similar to the crystalline schist and gneiss of the Highlands, are the principal constituents of the drift on and about the Highlands. The drift of the Kittatinny valley is made up largely of shale, slate, sandstone and limestone, similar to those which underlie the valley; but on the western side of the valley there is a considerable admixture of stones and bowlders from Kittatinny mountain, and on the eastern a lesser admixture of materials from the Highlands. In the area where the Newark (Triassic) series is the underlying terrane, the drift is made up in large part of fragments, large and small, derived from the sandstone and shale below, or from similar formations elsewhere, and, in keeping with this constitution, is conspicuously red. With materials of such origin there is often a large admixture of trap, especially in the vicinity of the trap ridges, and of bowlders of gneiss and crystalline schist, especially in the vicinity of the Highlands, and of conglomerate, quartzite, etc., like those of the Green Pond mountain range or its northern extension, the Skunnemunk mountain of New York.

The rock formations of the surrounding regions being known, analytical study of the stones of the drift makes it possible, in most cases, to say what formations they came from, and so the direction whence they came. In this way it is known that most of the drift of New Jersey came from the formations beneath it, or from their northward extensions in New York, but that a small proportion of the stones of the drift came from more distant sources to the north.

From a careful study of the stones of the drift in relation to their sources, it is sometimes found that the stones and bowlders of the drift have been lifted much above the ledges from which they come. Thus bowlders of the Newark sandstone are often found on the crest of the Palisade ridge, sometimes hundreds of feet above their source. A still more remarkable case of this sort occurs on the southeast side of Jenny Jump mountain, where there is a limestone bowlder 50 ft. x 22 ft. x 15 ft., which must have been carried up some 300 or 400 feet over the crest of the mountain, and then down on the other side.

Generally speaking, the average size of the bowlders becomes less, with increasing distance from their source, though individual exceptions to this rule are sometimes striking. This diminution in size might be accounted for on either of two suppositions. Either the agents which made the drift were not able to move the large bowlders so far as the smaller ones, or the size of the bowlders was reduced in the process of movement. The extreme physical heterogeneity of the drift clearly indicates that the drift agents were, on the whole, very independent of the size of the materials handled, and in view of this fact, the conclusion that the decrease in size of bowlders with increasing distance from their source is the result of wear suffered during transit, seems well sustained. If this conclusion be correct, the force or forces which produced the drift must have been able to wear effectively the materials which they carried. This conclusion is corroborated by many other facts.

The study of the earthy matter of the drift, commonly called clay, shows that it is generally made up, for the most part, of the same materials as the bowlders, gravel, and sand with which it is associated, and that it represents these same materials in a state of finer subdivision. In other words, if the coarse material of the drift in any locality were so finely comminuted as to be impalpable, it would, as a rule, resemble the clays of the drift of the same region. This corroborates the conclusion that the agents which produced the drift were to some extent able to crush and grind the coarse materials.

To this general rule that the grinding of the coarse materials of the drift would produce the fine, there are some notable exceptions. For example, in the area east of the Highlands, the fine material of the drift is largely of pulverized red shale and sandstone, while the bowlders of the same region are largely of gneiss, conglomerate, trap, etc. The comminution of the latter would not produce the former.

STRUCTURE OF THE DRIFT.

Stratification.—Much of the drift is distinctly stratified, and much of it is altogether void of stratification. In some regions the unstratified drift predominates greatly over the stratified, while in others the reverse is the case. On the whole, stratified material is more abundant in valleys and on low lands adjacent to high areas than on the high areas themselves. Thus in the lowlands west of the Palisade ridge stratified drift prevails, while on the ridge itself the drift is mainly unstratified; stratified drift also predominates in the sub-valleys of the Kittatinny valley, though the unstratified covers the intervening divides, so far as they are covered by drift. There is, however, no hard and fast topographic relation between the two types, and many conspicuous hills, such as those just south of Hamburg and northeast of Rivervale are of stratified gravel and sand.

Lenses or pockets of stratified gravel and sand sometimes occur in unstratified drift, and the reverse is also sometimes (though less commonly) true. Where the stratified drift occurs in extensive beds, it may overlie or underlie the unstratified, or the two may alternate with each other repeatedly in vertical succession in a single section. In a broad area in the eastern part of Morris county, between Second mountain and the Highlands, a relatively thin body of unstratified drift overlies stratified. In some places at least this is again succeeded below by unstratified drift. At the brick yards at Hackensack and Little Falls the stratified clay used for brick is underlaid by unstratified, bowldery clay. At Little Falls unstratified bowldery clay locally overlies the stratified brick clay.

Stratified drift sometimes lies by the side of unstratified drift without alternating with it. This relation is well shown between Plainfield and Metuchen, where stratified drift lies southwest of the drift ridge already referred to (Plate IX). In many places the line of junction between two such areas is well defined, and in many others it is ill-defined.

The associations of the two phases of drift are often such as to leave no room to doubt the essential contemporaneity of their origin. The lithological likeness (*i. e.*, composed of the same sorts of rock) of their materials leaves no room to doubt that the two phases of drift came from the same general sources. From these considerations it is concluded that the drift agent or agents must have been capable of producing deposits which were sometimes stratified and sometimes unstratified, and that in many places the deposition must have occurred under such circumstances as to allow of the frequent change from the one phase of deposition to the other.

Foliation.—While the finer part of the bowlder-clay—the matrix in which the bowlders are set— shows no stratification, it frequently has a sort of indistinct structure which may be termed *foliation* (Fig. 10a). The foliation is a crude sort of *cleavage, the planes* of which are somewhat irregular, but *usually approximately* horizontal, or approximately parallel with the surface. Foliation is restricted to the unstratified portion of the drift, though even here it is by no means universal. It is rarely so distinct as to be obtrusive, and may easily escape the observation of those whose attention has not been called to it. It appears to be the result of pressure or shearing.

The foliation of the drift is best shown in New Jersey, where the drift is made up largely of material derived from the Highlands. Even where this is the composition of the drift, foliation

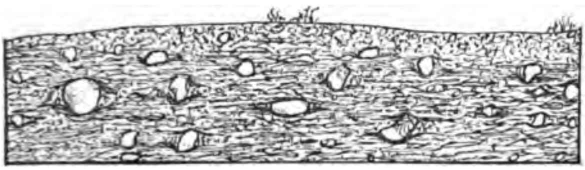


Fig. 10a.
Diagram to illustrate foliated structure of till.

is by no means universal, and rarely appears in the upper well-weathered portions. It is generally seen to best advantage some feet below the surface, in cuts which have been exposed to the weathering of a few weeks or months, but which have not yet been coated over with wash or talus. Foliation is not rare, even in till of other constitution.

SHAPES AND MARKINGS OF THE STONES IN THE DRIFT.

The stones of the unstratified drift possess significant features. Many of them have smooth surfaces, but their forms are, on the whole, unlike those of stones rounded by rivers or by waves. While some of them are round or roundish, many others are many-sided. They have been worn, but the wear appears to have been effected by planing, rather than by rolling (Plate XV). The plane sides may meet one another at any angle, though the angle of junction is rarely sharp. With these planed and subangular bowlders and stones which characterize the unstratified drift, there are few or many well-rounded ones showing none of the characteristics just noted. With them, also, there are occasional angular masses of rock bounded by fracture faces, which do not appear to have suffered notable wear.

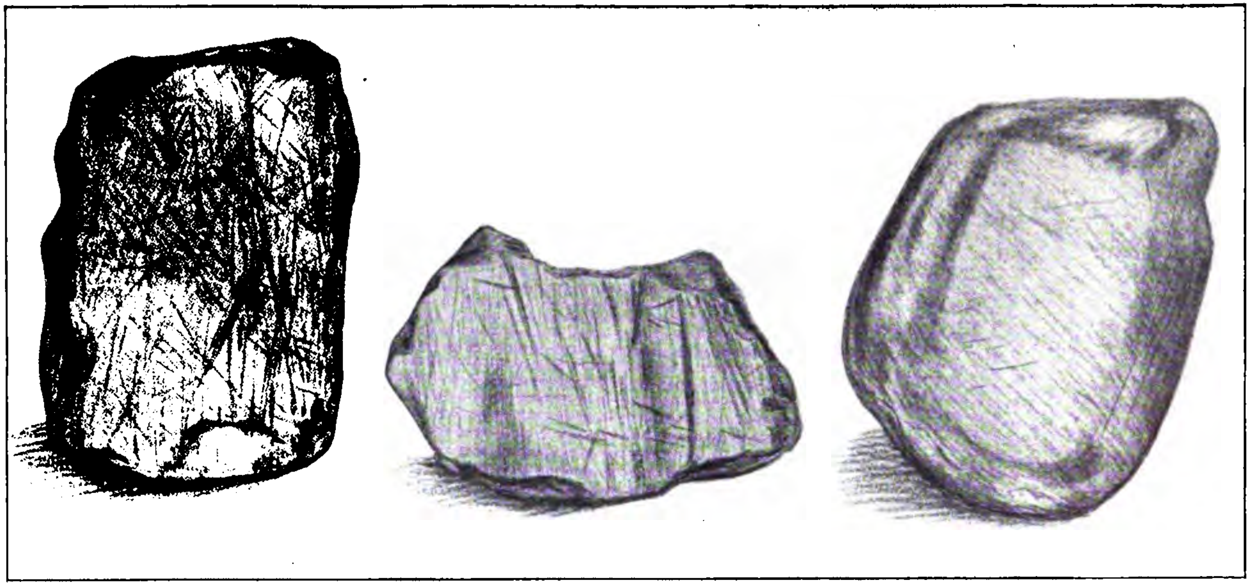
In the stratified drift, rounded, water-worn forms predominate. The many-sided, plane-faced forms, such as those shown on Plate XV, are often altogether absent, though they are sometimes present, and rarely in considerable numbers. This distinction affects large and small stones alike.

Another peculiarity goes with the foregoing. The planed, sub-angular bowlders and rock fragments which characterize the unstratified drift are often distinctly marked with one or more series of lines or scratches on one or more of their faces (Plate XV). The lines of each series are parallel with one another, but the lines of separate series may cross at any angle. Similar markings are rare, though not unknown, on the well-rounded stones of the drift.

These markings, or striæ, as they are called, do not affect all the stones of the drift, or even all the sub-angular ones. They are rarely seen on stones which have lain long at the surface, but are to be sought in fresh cuts in the drift, which show the stones which have not yet been subjected to weathering. The striæ are much more abundant on the less resistant sorts of rock, such as limestone, than on the more resistant, such as quartzite. If fifty per cent. of the stones occurring in the unstratified drift of any locality are striated, this is to be looked upon as a large proportion. Locally, striated stones are very rare, even in the unstratified drift.

RELATION OF DRIFT TO THE UNDERLYING ROCK.

The plane of contact between the drift and the underlying rock is generally sharply defined, and the surface of the rock is likely to be firm and fresh (Figs. 3, 4 and 5). This relation is less distinct where the drift is too thin to protect the rock beneath from considerable changes of temperature, and from the effects of those other disintegrating agencies which affect the surface to depths of two to four feet. Locally, however, as on some parts of Jenny Jump mountain, and in Knowlton township (Warren county) southeast of the limestone belt, this relation *does not hold.* In the former place the drift rests on rock which *is thoroughly decayed,* and in the latter the shale beneath the drift



Characteristic glacial stones.

PLATE XVI.

Polished and striated surface of trap-rock. Near Englewood.

is so broken that the line of demarkation between drift and rock is not readily seen. The same relation is occasionally seen in the Triassic plain.

STRIATION AND PLANATION.

The rock surface beneath the drift, and especially beneath the unstratified drift, is frequently polished and striated (Plate XVI). These features are found at many points throughout the drift-covered area, and at all elevations at which the drift occurs. The general direction of the striæ observed on the rock beneath the drift in New Jersey is indicated on the map, Plate VIII.

The smoothings and the markings on the bed rock beneath the drift are identical in kind with those already noted as occurring on the bowlders of the drift (Plate XV). So exact is the correspondence that community of origin cannot be doubted. The drift agencies, therefore, must have been capable of striating the rock beneath the drift, as well as the stony materials of the drift itself.

The striæ on the bed rock beneath the drift are generally approximately parallel in any given locality, and tolerably constant in direction over considerable areas. When large areas are studied, however, the striæ are sometimes found to be far from parallel. In some cases, both in New Jersey and elsewhere, their departure from parallelism is according to a definite system. The direction of striæ corresponds with the direction in which the drift has been transported.

New Jersey furnishes a good illustration of the lack of parallelism among the striæ on the rock beneath the drift. The direction of the striæ on Palisade ridge varies from S., to S. 74° E., while elsewhere in the State their direction is generally west of south (see Plate VIII), the strongest westing being in the northwestern part of Sussex county, where, exceptionally, the striæ point west, or even a little north of west. From the map it will be seen that there is a tendency to easterly divergence from the east sides both of the Kittatinny and the Hackensack valleys. At intermediate points, other directions are found to prevail.

In the northwestern part of the State the trend of the striæ, barring certain exceptions, as near the ends of Kittatinny mountains, is roughly parallel to the trend of the more prominent topographic features; but this correspondence is less perfect in the northeastern part of the State, especially on the Palisade ridge, where the trend of the topographic features is also northeast and southwest. At various points, too, there are pronounced local divergences from the general course of the striæ of the region, and such divergences are generally associated with pronounced topographic features. Thus the course of the striæ is often locally in harmony with the course of the more pronounced ridges and valleys, even where this is not the general direction of the striæ for the surrounding region. This relation suggests that pronounced topographic features sometimes influenced or even determined the course of the striæ.

On the other hand, the relations between the course of striæ and pronounced topographic features, is not always one of parallelism. Thus on the Palisade ridge the striæ have a notably greater easting on the crest of the ridge, where their average direction is about S. 45° E., than along its western slope, where their average direction is about S. 20° E. Again, at the east base of the north end of Kittatinny mountain, the striæ have a westing slightly greater than that of the bold front of the mountain, but at the crest of the range they turn abruptly westward.

Striæ are not confined to horizontal or gently inclined surfaces. They occur on steep slopes, not infrequently on the vertical faces of cliffs, and, occasionally, even on the under sides of overhanging rock masses. Striæ are seen in all these positions on the Palisade ridge, as well as at other less accessible points. They are, however, nowhere found on the steep eastern face of the Palisade ridge.

SUMMARY OF SIGNIFICANT CHARACTERISTICS.

The characteristics of the drift, as set forth in the preceding paragraphs, leave little room for random speculation concerning its origin. From its variable thickness we know that the force or forces which produced it must have been such as could leave the drift now in thick bodies and now in thin, over limited or extensive areas. From its distribution we know that the force or forces which produced it were largely independent both of underlying rock formations and of topography. From its physical make up, we know that the agency or agencies which produced it must have been able to carry and deposit, at one place and at one time, materials as fine as the finest silt or mud, and bowlders many tons in weight, while they were competent, under other circumstances, to make deposits of much less extreme diversity. From its lithological make up, and from the nature of the finer parts of the drift, we know that the drift forces worked on different sorts of rock, deriving materials from many; that they ground some of the materials into a fine earthy powder or "rock flour", commonly called clay; that they as a rule derived the larger part of the drift of any locality from formations near at hand; and that the materials, even large bowlders, were sometimes carried up to altitudes considerably above their source. From the structure of the drift, it is concluded that the drift force or forces must have been capable of producing deposits which were sometimes stratified and sometimes unstratified, and that the deposition of these two phases of drift was sometimes contemporaneous and sometimes successive, the number of alternations sometimes being considerable. From the striæ on the stones of the drift it is known that the production of the drift must have involved the action of forces which, under some conditions, were capable of planing and beveling and striating many stones, especially the softer ones of the unstratified drift, while rounding and leaving unstriated most of those of the stratified; but that the agency or agencies concerned must have been such that under certain circumstances their activities failed, on the one hand, to leave more than a very small percentage of the stones of the unstratified drift beveled and striated, while, on the other hand, they sometimes permitted the stratification of gravels containing many subangular, plane-faced and striated stones, varying in size from pebbles to bowlders. From the striæ on the bed rock beneath the drift and the unweathered character of the surface of the rock, it is clear that severe wear was inflicted on the surface over which the drift was spread, while the positions in which the striæ are formed show that the agency which inflicted the wear was able to adapt itself to all sorts of surfaces. The general parallelism of striæ in a limited area, and the systematic departure from parallelism over great areas, are also significant of the manner in which they were produced. From the topography of the drift it is known that the forces which produced it must have been such as were able to develop plane surfaces at some points, surfaces marked by more or less symmetrical drift hills which are measurably independent of topography at others, and short, choppy hills, associated with undrained depressions in still others.

The true theory of the drift must explain all these facts and relations. Any hypothesis which fails to explain them all must be incomplete at the very least, and any hypothesis with which these facts and relations are inconsistent, must be false.

AGENCIES WHICH SHIFT MATERIALS ON THE EARTH'S SURFACE.

The agencies prominently concerned in shifting materials on the earth's surface are wind, water and ice. Other agencies of extreme violence, such as earthquakes and volcanic explosions, occasionally affect small areas, and suddenly and locally they accomplish very considerable results; but there is no warrant for believing that catastrophic action of any sort or of all sorts can shift and distribute such materials as those of the drift, as they have been shifted and distributed.

The work of wind.—The geological work of the wind is well known. It is capable of blowing dust and sand about, and of heaping the latter into mounds and low hills (dunes), as seen at many points along the beach, and at a few points in the drift-covered area of the northern part of the State. Although the wind has played a part in the deposition of the material included under the term *drift,* either at the time of its origin or since, its part has been a very subordinate one. An example of its work in the drift-covered part of the State is found in the sand dunes south of Hackensack.

The work of water.—The work of water is also known. Streams make deposits on land, but their deposits are confined to their valleys or to the lakes or seas at their debouchures. They do not cover hills and valleys indiscriminately. Stream deposits, too, have certain well-defined characteristics, both of structure and topography, which are essentially different from those of the drift. Streams, therefore,. were not the principal agency which made the drift, though the disposition of the stratified drift in the valleys beyond the great body of the unstratified. points to streams as the agency of deposition. The same may be said for some of the stratified drift of the valleys within the area of unstratified drift. While, therefore, streams were not the principal agent in the production of the drift, they seem to have played a subordinate role in its distribution and deposition.

The waves of lakes and sea likewise fail to explain the drift. The deposits made along the shores of bodies of standing water—and these are the only places where such bodies of water make considerable deposits—are well known. Their topography and topographic relations, their structure, their relations to the underlying rock, and their constitution, all are notably different from those of the drift. No aqueous conditions or succession of aqueous conditions can be conceived which will allow the waters of lakes and seas to make such formation as the drift, in all its manifold relations.

Evident as this conclusion now seems, the first serious attempt to explain the drift, attributed it to water. "It was conceived that somehow and somewhere in the far north, a series of gigantic waves was mysteriously propagated. These waves were supposed to have precipitated themselves upon the land, and then swept madly on over mountain and valley alike, carrying along with them a mighty burden of rocks and stones and rubbish. Such deluges were styled 'waves of translation,' and the till (unstratified drift) was believed to represent the materials which they hurried along with them in their wild course across the country. The stones and bowlders as they sped down slopes and up acclivities were smoothed and scratched, and the solid rocks over which they careered received a similar kind of treatment. After the water disappeared, the stones were found confusedly huddled together in a paste of clay, but occasional big blocks, often far-traveled, perched in lonely positions on hill-tops, or lay scattered over hill-slopes like flocks of sheep, while mounds of sand and gravel rolled themselves out here and there in the low-lands. Such in a few words was the hypothesis of great debacles or waves of translation. It was unfortunate for this view that it violated at the very outset the first principles of the science, by assuming the former existence of a cause which there was little in nature to warrant. Large waves it was known had certainly been raised by sudden movements of the earth's crust, and had several times caused great damage to seaport towns; but spasmodic rushes of the sea across a whole country had fortunately never been experienced within the memory of man. The speculation had only been advanced in a kind of desperation, for geologists were quite at their wits' ends to discover any natural cause that would account for the peculiar phenomena of the 'drift.' "[1] This speculation was, however, never very strenuously maintained, for it was soon seen that, "even granting the possibility of great waves of translation having swept across the land, still a number of facts remained which could neither be accounted for, nor yet explained away. Such, for example, was the characteristic dressing of the stones. It seemed impossible that these could have been so dressed by running water, no matter how rapidly it flowed. The stones in the bed of a mountain torrent do not show the scratches which are so characteristic of those in the till. They are smoothed, but never glazed or polished, while the mysterious markings that streak the till-stones from end to end are nowhere visible."[2]

There was also difficulty in conceiving how large masses of rock could be carried from one mountain to another across an intervening valley by rushes of water. "The water might roll them down from one hill into a valley, but it could hardly push them up another hill, and so repeat the process often in a distance of many miles. Then, again, how did the stones come to be intermingled with fine clay? Surely the current or wave that

[1] *The Great Ice Age*, Geikie, 3d Ed., p. 26.
[2] *Loc. cit.*, p. 27.

was sufficiently powerful to force along blocks of stone several feet or even yards in diameter must have swept the fine matter—sand and clay—to infinitely greater distances. Thus there were a great many loose screws in the hypothesis, and every new fact discovered threatened to make it collapse altogether. Day by day the great waves of translation became more and more apocryphal, until at last they ceased even to be hinted at, and sank quietly to rest forever."[1]

Though the waves of lakes and seas do not go far in explanation of the phenomena of the drift, yet locally there is drift which was clearly left in its present form by the waves of lakes or seas. Standing water, therefore, played a subordinate role in the deposition of the drift. This is true, for example, of some of the drift along the southwest face of the ridge between Madison and Morristown, and of similar bodies of drift at some other points to be mentioned in Part II.

The work of floating ice.—If the waters of lakes or seas were affected by shore ice, such as affects the coasts of northern lands to-day, certain of the results observed in connection with the drift might be explained, but the action of such ice is limited to a narrow belt slightly above and below the shore line. If the floating ice be in the form of icebergs the case is somewhat better, but the distribution of icebergs, and therefore of the deposits they make, is limited by the bodies of water in which they float. Furthermore, the deposits of icebergs, except near their sources, are believed to be slight. Rarely do the bergs about Greenland carry debris of any sort, even though but a few miles from the point whence they set sail. And this is not, as might be suspected, because the debris is in the bottom of the berg, and therefore out of sight beneath the water; for a large proportion of the bergs show by the wave marks in various positions over their surfaces, as well as by other signs, that they have capsized again and again, and that the original bottom of the berg is about as likely to be above water as below it. Of some thousands of bergs seen in 1895 in a trip along the west coast of Greenland as far north as latitude 80°, less than one per cent. showed any

[1] Loc. cit.

considerable amount of debris, and not more than ten per cent. were judged to be floating with their original bottoms down. Far short as shore ice and icebergs fall of accounting for the drift, the iceberg theory of its origin was for a time seriously maintained. This theory "supposes the land to have been submerged to a certain depth during the accumulation of the till, at which time icebergs setting sail from the tops of the mountains, which then existed as frozen islets, carried with them loads of earth, sand, and rock, which they scattered over the bed of the sea as they floated on their way to the south."[1]

The work of glaciers—The one remaining agency to which we are reduced by the process of exclusion, is glacier ice, though the belief in glacier ice as the chief agency which produced the drift is not based merely on the fact that no other agency explains the phenomena. This is the negative form of the argument. In its positive form it is this: The great body of drift corresponds in all essential respects, both in itself and in its relations, with the deposits now being made by glacier ice. The ice-cap of Greenland is doing for that island to-day what the agency which produced the drift did for northern New Jersey within the area where the drift occurs.

The characteristics of the drift already detailed are characteristics which affect the drift made in recent times, and which is now being made, by the valley glaciers of many mountain regions and the ice-caps of high latitudes. Such differences as exist are differences which result from the different conditions under which the ice has worked.

In general it may be said that the physical and lithological heterogeneity of glacier deposits considered in relation to the sources whence their materials were derived; the sizes, shapes and markings of the coarser parts of these deposits; the physical and chemical condition of their finer parts; the stratified, unstratified, and foliated structures of the various parts of these deposits in their relations to one another and to topography; the relation of these deposits to the rock upon which they rest; the frequent termination of the unstratified parts on declining

[1] *Geikie, Loc. cit.*, p. 27.

surfaces, and the extension of the stratified parts far down the valleys beyond the unstratified; the topographic relations of these deposits and their own topography; the systematically disposed striæ on the rock beneath them taken in connection with the direction in which materials have been transported; the shapes of the hills worn by glaciers, and the relation of these forms to other associated phenomena; the general surface expression of the region worked over by a glacier, in contrast with adjacent regions which have not been so affected; all these phenomena, so peculiar, so distinctive, and particularly all these phenomena in their manifold, and intricate, and peculiar, and nicely adjusted relations, afford a remarkable series of criteria for the recognition of glacier deposits, even in regions which now possess no remnant of ice.

The various marks left by glacier ice on the bed over which it has moved are so many and so distinctive, and stand in such nicely adjusted relations to one another, that it hardly seems credible that any second agency or combination of agencies could produce results so similar as to be mistaken for them, if all the foregoing characteristics and relations are clearly developed and open to observation.

EXTENT OF THE DRIFT.

Drift similar to that of New Jersey affects a very large area outside of the State. It is found throughout almost the whole of the British possessions to the north, and over a large area in the northern part of our own country. The extent of its occurrence is shown on the accompanying map, Plate XVII. It reaches its southernmost limit in Illinois, in latitude 37° 35′, and its aggregate area is something like 4,000,000 square miles. Drift also occurs at many points in the western mountains south of the main drift sheet.

Nor are these phenomena confined to our continent. Europe likewise has a widespread formation of drift covering the northwestern half of the continent. Whether the European drift was contemporaneous in origin with that of North America has never been demonstrated, but their essential contemporaneity is generally assumed.

If glacier ice alone be responsible for the drift, it is necessary to suppose that the whole of the drift-covered area was overspread by an ice-sheet. Alpine glaciers are so small and so restricted to mountains, that, studying them alone, it seems incredible, at first, that any extension of such glaciers could be great enough to account for drift deposits so extensive as those of North America and Europe. Fortunately, our knowledge of glaciers and of glacial phenomena is not restricted to Switzerland, or even to the Alpine type of glaciers. Larger bodies of land ice exist in various parts of the world. The largest of these which has received even a moderate amount of attention is the ice cap of Greenland. But this is accessible with difficulty, and has received little attention compared to that which has been bestowed on many mountain glaciers. While, therefore, the Greenland ice-sheet might afford a closer analogy than Alpine glaciers to the ice which produced the North American drift, it has not been sufficiently studied to give us so reliable a point of departure in the discussion of the subject as the smaller glaciers. But it is so large, and departs so far from the Alpine type of glacier, as to give us an enlarged idea of the dimensions which glaciers may attain, and of the results which they may accomplish.

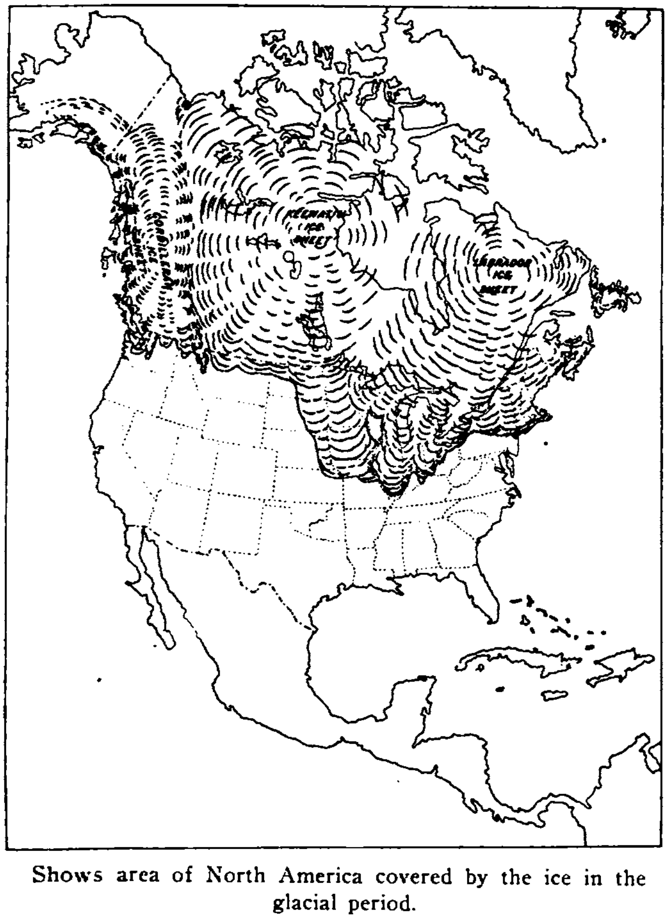
Switzerland has an area of about 16,000 square miles. It is said to harbor 471 glaciers, 138 of which are more than 1.1 km. (about three-fourths of a mile) long[1]. According to official surveys, the 471 glaciers, and the snow-fields associated with them, have a total area of a little more than 700 square miles. The estimated area of the ice cap of Greenland is about 400,000 square miles, an area twenty-five times as great as that of all Switzerland, and nearly 600 times as great as that of the united area of all the Swiss glaciers and snowfields.

The drift of North America is estimated to cover an area of about 4,000,000 square miles[2], an area only about ten times as

[1] Heim, *Handbuch der Gletscherkunde*, 1885.

[2] *Upham*: Appendix to Wright's "The Ice Age in North America."

PLATE XVII.



Shows area of North America covered by the ice in the glacial period.

large as the area of Greenland's ice sheet. Stated in the form of ratios, therefore, the snow and ice-covered area of Switzerland is to the snow and ice-covered area of Greenland, as 1 is to 600; while the snow and ice-covered area of Greenland is to the North American area of drift, as 1 to 10.

But even Greenland does not possess the greatest ice sheet now in existence. The Antarctic continent—for this land and ice mass seems to merit the name of continent—is almost completely covered with ice, so far as known. While its area has not been determined with accuracy, it has recently been estimated to contain at least 4,000,000 square miles, that is, an area equal to that of the great sheet or drift of North America, an area twice as great as that of the drift which covers northwestern Europe. The existence of so great an ice sheet to-day makes it easier to think of the existence of an equally extensive ice sheet elsewhere in the past. It removes the element of incredibility which, at first thought, attaches to so striking a theory as that of the glacial origin of the drift.

From the standpoint of knowledge concerning ice sheets, the glacier theory is a possible theory, but it is not to be understood that the existence of an Antarctic ice sheet, equal in size to the area of the North American drift, is any argument for the glacier origin of the drift. It is more difficult to account for the existence of an ice sheet in temperate than in frigid zones; but in spite of the difficulty, the study of the drift during the last decades has led us to the conclusion that glacier ice was the principal agent concerned in its production.

SIGNIFICANCE OF THE ABUNDANCE OF STRATIFIED DRIFT.

The fact that so much of the drift is stratified has sometimes been thought to be a difficulty in the way of the glacial theory. It is certainly true that the deposits made by glaciers directly are unstratified, and it is equally true that a very considerable portion of the drift is stratified. But it is to be remembered that the larger part[1] of the ice of every former glacier, be the

[1] Some of it evaporated.

same large or small, was finally converted into water, and that most of this water had a longer or shorter course over the surface of the land, either beneath or beyond the ice. In its flow it can hardly have failed to modify the surface of the drift already deposited by the ice, and it often left on the surface of those deposits such gravels, sands and silt as it carried. These deposits were, as a rule, stratified. According to the glacial theory, therefore, the amount of water which was operative, jointly with the ice, in producing the drift, must have been nearly as great as that of the ice itself. The glacier theory of the drift, therefore, not only allows, but demands, that a large part of the drift be stratified. It demands that the water issuing from the ice should carry beyond it such products of the glacial grinding, as its currents were able to transport. This is exactly what is taking place in glaciers to-day, and the stratified valley drift extending beyond the great body of unstratified drift, argues that this is what took place when the drift was deposited.

SUMMARY.

In searching for the explanation of the drift, therefore, if the facts concerning the drift and its relations are before us in their fullness, there is little room for doubtful theorizing. Geologists are now very generally agreed that glacier ice, supplemented by those other agencies which glacier ice calls into being, is the only agent which could have produced it. But it is not to be forgotten that this does not preclude the belief that at various times and places, in the course of the ice period, icebergs may have been formed, or that locally and temporarily they played an important role. It does not preclude the idea that, contemporaneously with the production of the great body of the drift by glacier ice, the sea may have been at work on some parts of the present land area, modifying the deposits made by ice and ice drainage. Indeed, there is abundant evidence that such was the fact, for some regions, now covered by drift, stood lower than now, relative to sea level, when the drift was deposited, or since. The glacial theory does not deny that rivers produced by the melting of the ice were an important factor in transporting and depositing drift, both within and without the ice-covered territory. It does not deny that lakes formed in one way and another through the influence of ice, were locally important in determining the character and disposition of the drift. Not only does the glacier theory deny none of these things, but it distinctly affirms that rivers, lakes, the sea, icebergs and pan-ice must have cooperated with glacier ice in the production of the drift, each in its appropriate way and measure, and that after the disappearance of the ice and the ice water, the wind had its appropriate effect on the drift, before it became clothed with vegetation.

CHAPTER II.

THE DEVELOPMENT OF AN ICE SHEET.

CONTENTS.

For a clear understanding of the history of the drift of New Jersey, and of its relation to similar formations elsewhere, a brief sketch is here given of the development of such a sheet of ice as once over-spread the drift-covered part of the continent.

THE FORMATION AND MOVEMENT OF GLACIER ICE.

The snow field.—The temperature and the snowfall of a given region may stand in such relationship to each other that the summer's heat may barely suffice to melt the winter's snow. If, under these circumstances, the annual temperature were reduced, or the fall of snow increased, the heat of summer would fail to melt the snow of winter, and some portion of the snowfall would endure through the summer, and through successive summers, and constitute a perennial snow-field. Were this process once inaugurated, the depth of the snow would increase from year to year, for a part of each winter's snow remains unmelted. The area of the snow-field would extend itself at the same time, since the snow-field would so far reduce the temperature of its surroundings as to increase the proportion of the precipitation which would there fall as snow. In the course of time, and under favorable conditions, both the area of the snow-field and its depth would become great.

The snow in the lower part of the snow-field would eventually be converted into ice. Several factors would coöperate to this end. (1) The pressure of the overlying snow would tend to compact the lower portions, bringing them nearer the condition of ice. (2) Water arising from the melting of the surface snow in summer would percolate through the superficial layers, and, freezing below, would not only take the form of ice itself, but would at the same time bind together the particles of snow adjacent to it where it froze. (3) Important changes appear to take place in the crystallization of the snow, even without melting and refreezing, the result of which is to render the whole mass more compact and solid. By these, and perhaps other means, a snow-field becomes an ice-field, the snow being restricted to its superficial parts.

Inauguration of movement.—Eventually the increase in the depth of the snow gives rise to new phenomena. Let it be supposed that, in the case of a given snow-field, the depth of snow or ice is greatest at its center, and that its thickness gradually diminishes toward its edges. In cross section, the field of snow, if resting on a level surface, would have some such form as that represented in the diagram (Fig. 11).

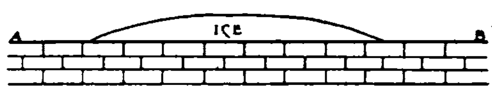


Fig. 11.

Diagram representing in cross section the conception of a small ice cap.

When the thickness of the ice at the center of the field has become considerable, it is evident that the pressure on its lower parts will be great. We are wont to think of ice as a brittle solid. If in its place we had some slightly plastic substance which would yield to pressure, it is evident that it would spread in all directions by a sort of flowing motion.

Under great pressure many substances which otherwise appear to be solid exhibit the characteristics of plastic bodies. Among the substances exhibiting this property, ice is, perhaps, best known. Brittle and resistant as it seems, it may be moulded into almost any desired form, if subjected to sufficient pressure, steadily applied through long intervals of time. The changes of form thus produced are brought about without visible fracture. Concerning the exact nature of the movement which takes place between the particles of ice under such circumstances, physicists are not agreed, but the result appears to be such as would be brought about if the ice were capable of flowing, with extreme slowness, under great pressure, continuously applied.

In an ice-field we have the conditions for great pressure and for its continuous application. If the ice be capable of motion as a plastic body, its great weight would induce gradual movement outward from the center of the field, so that areas surrounding the region of snow accumulation would be gradually encroached on by the spreading of the ice. Observation shows that this is what takes place in every snow-field of sufficiently great extent and depth. Motion thus brought about is glacier motion, and ice thus moving is glacier ice.

Limits of movement.—Two factors determine the limit to which the ice sheet will spread: (1) the rate at which it advances, and (2) the rate at which the advancing edge is wasted. The rate of advance depends on several conditions, one of which, in all cases, is the amount of pressure, the "head" of the ice-mass, which started and which perpetuates the motion. If the pressure be increased the ice will advance more rapidly. If the ice advances more rapidly it will advance farther before being melted. Increase of snowfall will increase the pressure of the snow and ice-field by increasing its mass. If, therefore, the precipitation over a given snow-field be increased for a period of years, the ice sheet's marginal motion will be accelerated and its area enlarged. A decrease of precipitation, taken in connection with unchanged wastage, would decrease the pressure of the ice and retard its movement. The edge of the ice would then recede, and the snow and ice-field would be contracted, not because the ice ceases to advance, but because its marginal waste exceeds its advance.

The rate at which the edge of the advancing ice will be wasted depends largely on the climate. If while the rate of advance remains constant, the climate becomes warmer, the melting will be more rapid, and the ratio between melting and advance will be increased. The edge of the ice will, therefore, recede. The same result will follow, if, while temperature remains constant, the atmosphere becomes drier, since this will increase the wastage of the ice by evaporation. Were the climate to become warmer and drier at the same time, the rate of recession of the ice would be greater than if but one of these changes occurred. A decrease of temperature decreasing the melting, or an increase in humidity decreasing the evaporation, would have the opposite effect. In this connection humidity is, as a rule, of far less importance than temperature.

When the advance of the ice is balanced by wastage, its edge is in equilibrium. The study of many glaciers has shown that they are rarely in this condition. They are now advancing and now retreating, and their fluctuations are believed to be connected with climatic changes.

Ice sheets versus valley glaciers.—The distinction between an *ice sheet,* such as that which produced the drift of our continent, and a *glacier,* in the ordinary sense of the term, is easily understood. If the ice accumulates on a flat surface, it will tend to spread equally in all directions from its center. If the surface on which it accumulates be not plane, movement will not be equal. If the surface be affected by valleys parallel to the direction of movement, the ice in the valleys will be deeper than that over the intervening areas, and will therefore move faster. In valleys, therefore, it will advance farther than elsewhere before being melted. Such valley lobes of ice protruding beyond the body of the ice field which gave them being, are glaciers, in the usual sense of the term.

Between ice-caps and valley glaciers there are many gradations (compare Plates XVIII and XIX). Most of the glaciers with which we are familiar emanate from snow fields which lie in high mountain regions, and the glaciers occupy mountain val-

Fig. A.
An incipient lobe of ice at edge of ice-cap. North Greenland.

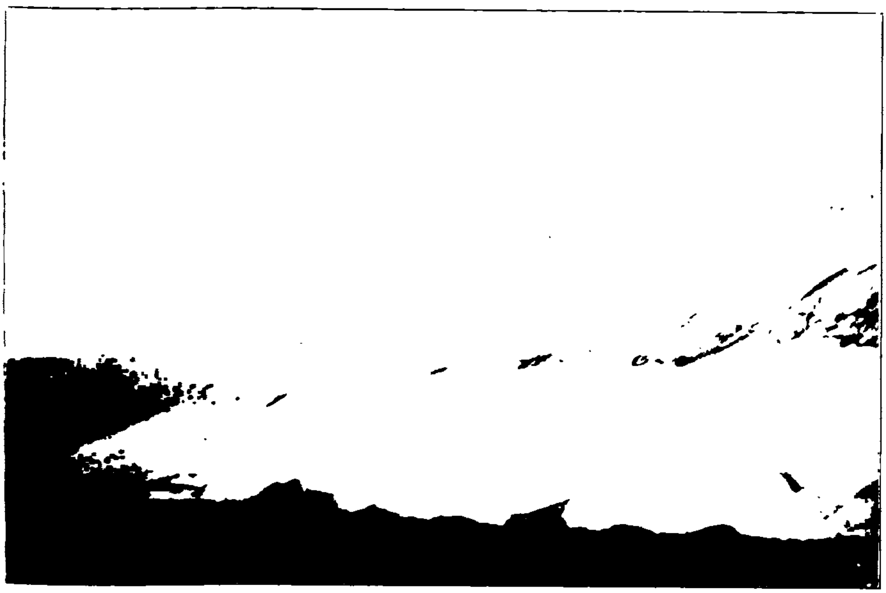


Fig. B.
Edge of ice-cap, North Greenland. Snow is banked against the edge of the ice.

Mountain glaciers in Switzerland.

Fig. A.

The Rhone glacier, Switzerland. A typical valley glacier.

Fig. B.

Glaciers in the Cascade Mountains, near Cascade Pass, Wash. A type of glacier common in the northwestern part of the United States. (Photograph by Willis.)

leys (Plate XIX), but their relation to the originating snow field is the same as in cases noted above. In the mountains the slope of the surface facilitates movement, and a smaller amount of ice suffices to inaugurate it.

THE NORTH AMERICAN ICE SHEETS.

Centers and extent.—From the distribution of the drift of North America, from the direction in which its materials were transported, from the direction of striæ, and from various other phenomena, not susceptible of such brief characterization, it is inferred that the ice which produced the drift consisted in reality of three great sheets, the centers of which lay north of the United States (Plate XVII). The center of one ice sheet (the Labrador ice sheet) was east of Hudson bay; the center of another (the Keewatin ice sheet) was west of the same bay; while the center of the third (the Cordilleran ice sheet) was the mountains of the west, chiefly north of the United States. From these centers, the snow and ice fields expanded, partly by the growth due to the unmelted snowfall about their borders and partly by the outward movement which the excess of snow and ice generated (p. 38). The Keewatin and Labrador ice fields extended themselves north and east and south and west. To the south they became confluent south of Hudson bay, and invaded the United States as one. The Cordilleran ice sheet expanded, especially to east and west, and north of our national boundary, may have become confluent with the Keewatin ice sheet. Just south of our national boundary, in Montana, the ice from the mountains to the west reached the same position as the edge of the Keewatin ice-sheet, but at an earlier time.

The maximum southward and westward extension of the ice sheet made up by the union of the Keewatin and Labrador sheets, is known with approximate accuracy by the distribution of the drift. and is shown on the accompanying map, Plate XVII. To the east, New England was completely buried by the ice. Farther west the ice extended farther south. It crossed the Ohio river in the vicinity of Cincinnati, and pushed out a few miles on the uplands to the south. Still farther west its margin lay in southern Indiana and Illinois, reaching in the latter State its lowest latitude, about 37° 35'. West of the Mississippi, the line which marks its limit curves to the northward, and follows, in a general sort of way, the course of the Missouri river to Montana, where it turns north and crosses the national boundary a short distance east of the Rocky mountains.

Thickness.—If this great expansion of the ice sheet was due principally to movement from a center or centers, the ice at these centers must have been enormously thick, for in the course of its progress it encountered and passed over hills, and even mountains, of considerable height. In the vicinity of elevations which it covered, its thickness must have been at least as great as the height of these elevations above their bases. If such elevations were remote from the center of movement, the ice must have been still thicker at the latter point to afford the necessary "head."

If the centers of the North American ice sheet remained the centers of movement throughout the glacial period, and if the degree of surface slope necessary for movement were known, the maximum thickness of the ice could be calculated. It is probable, however, both that the centers of the ice sheet did not remain the effective centers of movement and that the surface slope necessary for movement was variable.

If the fall of snow toward the margin of the ice sheet greatly exceeded that at its center, an infra-marginal belt, rather than the geographic center of the field, may have controlled the marginal movement of the ice. With excess of infra-marginal accumu-

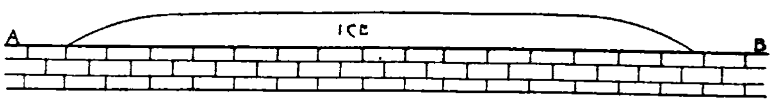


Fig. 12.
Illustrates the form which a large ice sheet may have in cross section.

lation, the surface slope of the ice would be relatively great from the zone of maximum accumulation to the edge of the ice, but might be very slight, or even nil, within it (Fig. 12). Under these circumstances, the extension of the ice being due largely to dispersal from the infra-marginal zone, the maximum thickness of the ice sheet might be notably less than if the geographic center remained the effective dynamic center (compare Figs. 11 and 12).

In an ice sheet like that which was responsible for the drift of North America, it is probable that all influencing and limiting conditions which may exist in an ice sheet were to be found. The varying pressures and temperatures to which its various parts were subject would tend to produce various degrees of mobility in its mass, and varying degrees of mobility would demand varying degrees of surface slope in order to bring about movement. Could the surface slope necessary for movement be determined for any given region, and for any given time during the ice period, it does not at all follow that the same slope would be necessary for the whole ice sheet, or even that it would be necessary for any particular region, at all stages of glacial history.

Both observation on existing glaciers and ice sheets, and considerations of a physical nature, make it certain, first, that the angle of slope must have decreased with increasing distance from the margin of the ice (that is, with increasing thickness of the ice) until, at the center of the field, it approached zero; and second, that at the edge of the ice sheet, where the ice was thin, the surface slope was greatest.

No sufficient data are at hand for determining with accuracy the average slope of such an ice sheet as that which covered our continent, but something is known of its slope at certain points. Near Baraboo, Wis.,[1] the edge of the ice at the time of its maximum extension in that region lay along the side of a bold ridge, the axis of which was nearly parallel to the direction of ice movement. The position of the upper edge of the ice against the slope of the ridge is sharply defined and determinable with accuracy. For the last one and three-fourths miles the average slope was about 320 feet per mile. This, it is to be noted, was at the extreme edge of the ice, where the slope must have been at a maximum. In Montana the slope of the upper surface of the ice for the 25 miles back from its edge has been estimated at 50 feet per

[1] Journal of Geology, Vol. III, p. 655.

mile.[1] Calculations based on data from New Jersey and adjacent parts of New York and Massachusetts, indicate for this region a slope of about 30 feet per mile[2] for the upper surface of the ice when it was there thickest. It is to be noted that the data for this calculation were drawn from localities which, while relatively near the edge of the ice sheet, were still some miles within it. At first thought, a surface slope of 30 feet per mile does not seem excessive. A surface of such a slope would seem to the eye to be nearly plane; yet even so moderate a slope may lead to very extraordinary conclusions.

The southern limit of drift in Illinois is probably not less than 1,200 miles from the center of movement. An average slope of 30 feet per mile for 1,200 miles would give the ice a thickness of 36,000 feet at a point 1,200 miles from its margin, if the slope of the surface on which the ice rested be disregarded, and this slope was so little as not to be of consequence in this connection. This thickness, nearly seven miles, seems hardly credible. If its average slope were but 15 feet per mile, the thickness of the ice at the center of the field must still have been prodigious. Even a slope of 10 feet per mile would give a thickness of more than two miles at the center of the ice sheet. If by reason of relatively great infra-marginal accumulation, the only part of the ice cap which had any considerable degree of slope was its marginal part, the surface of the central portions being nearly flat, so great a maximum thickness would not be demanded.

The observations of Nansen in his journey across Greenland are instructive in this connection. He found that the surface of the ice sheet rose abruptly at either margin, and less and less rapidly as its summit was approached. In the latitude of his crossing the highest point was found to lie nearly fifty-eight miles nearer the east coast than the west. He also found the height of the surface to be "1,000 metres, or 3,300 feet, at nearly fifteen miles from the place of ascent" on the east side. The corresponding elevation on the west coast was found to be twenty-six

[1] Calhoun, Journal of Geology, Vol. IX, p. 718.
[2] J. C. Smock, Am. Jour. Sci., Vol. 25, p. 339.

miles from the edge of the ice. These figures represent a gradient of 1 in 22, or about 220 feet per mile, on the east coast, and 1 in 42, or about 127 feet per mile, on the west, for the first 1,000 metres of ascent.

On the east side, the ascent from 1,000 to 2,000 metres was made in thirty-five miles, while on the west side the corresponding ascent was accomplished in fifty miles. These figures represent gradients of 1 in 57 and 1 in 84, or about 93 feet and 63 feet per mile, respectively. "For that portion of the ice-field which has more than 2,000 metres elevation, the gradients were about 1 in 142 on the east side and 1 in 206 on the west,"[1] corresponding to slopes of about 37 and 26 feet per mile, respectively. It is thus seen that the gradient becomes rapidly less as the distance from the margin increases.

It is not known how far the slope of the ice surface in Greenland is due to excessive accumulation of snow and ice at the center, and how far to underlying topography; but it will be seen that beyond a distance of more than 78 miles from the edge of the ice, the average gradient on the west side of the ice sheet was only about 26 feet per mile. It is fair to conclude that if the ice sheet were much larger, like that of our continent during the glacial period, the gradient would be still less toward its center. It is probable, therefore, that the half or the third of 30 feet per mile may more nearly represent the average slope of the ice during the period of its maximum development, than 30 feet.

Local centers of glaciation.—As the ice cap developed, and gradually extended itself from its Canadian home, it is probable that such mountain regions as those of northern New York and Vermont became centers of local glaciation. They may have harbored snow-fields and glaciers comparable to those of Switzerland or Scandinavia to-day, before the ice advancing from the north reached them. Ultimately, the ice sheet advancing from the north joined and overwhelmed such subordinate fields of ice and snow as there were.

Advance of ice influenced by topography.—The inequalities of surface over which the ice extended in its southward growth were considerable. In the eastern part of the continent, the area

[1] Nansen. The First Crossing of Greenland, Vol. II, p. 465.

with which we are here concerned, the relief of the region affected by ice was several thousand feet.

The high lands which it encountered must have retarded its movement, while the low lands, by contrast, facilitated it. Other things being equal, therefore, the ice should have extended farther from the center of dispersion where the surface was low than where it was high, but to this general rule there would be an exception where the ice reached the sea. Here its edge would be broken off and floated away as icebergs.

Apart from its general altitude, the varying roughness of the surface over which the ice passed influenced its progress, the ice spreading more rapidly over smooth surfaces, and more slowly over rough ones. Inequalities of precipitation must have existed, and tended still further to produce inequality of forward motion. The distribution of the drift shows that when the ice had reached its maximum extension, its margin was affected by irregularities which assumed the form of broad lobes (see Plate XVII). The lobation was, perhaps, not less marked at other stages in the history of the ice sheet.

Successive ice sheets.—It will be seen in the sequel that the drift of North America was produced not by one ice sheet, but by several successive ice sheets, separated from one another by considerable intervals of time. It is not known whether the ice disappeared from the continent between the epochs of its great expansion, or whether it was simply greatly reduced in area. This topic will be discussed later, but it may be here pointed out that in Europe and America there are believed to have been several ice epochs during the glacial period.

STAGES IN THE HISTORY OF AN ICE SHEET.

The history of an ice sheet which no longer exists involves at least two distinct stages. These are (1) the period of growth, and (2) the period of decadence. If the latter does not begin as soon as the former is completed, an intervening stage, representing the period of maximum ice extension, must be recognized. In the case of the ice sheets of the glacial period, each of these stages was probably more or less complex. The general period of growth of each ice sheet is believed to have been marked by temporary, but by more or less extensive, intervals of decadence, while during the general period of decadence, it is probable that the ice was subject to temporary, but to more or less extensive, intervals of recrudescence.

In the study of the work accomplished by an ice sheet, it is of importance to distinguish between these main stages, and, in the last analysis, to take account of the oscillations of the edge of the ice in each.

From the mode of development of ice sheets, as already sketched, it is evident that glaciation began somewhere near the center of the ice field, and that with the spread of the ice sheet, regions farther and farther from its center were successively brought under its influence. Since northern New Jersey was under the marginal part of the ice at the time of its maximum expansion, it follows that it was not buried under ice until glaciation was near its maximum. In the disappearance of the ice sheet, too, the belt covered by its margin was first freed from its dominion, while the ice lingered longest in the central parts. Northern New Jersey, and other regions similarly situated with reference to the edge of the ice, were, therefore, glaciated for a very much shorter period of time than regions nearer the centers of dispersion.

CHAPTER III.

THE WORK OF AN ICE SHEET.

CONTENTS.

Characteristics of Ground and Terminal Moraines.
- The ground moraine.
- The terminal moraine.
  - Its course.
  - Width and thickness.
  - The terminal moraine as a topographic feature.
  - Topography of the terminal moraine.
  - Development of terminal moraine topography.
  - Topographic relations of the terminal moraine.
  - Constitution of terminal moraines.
- The lifting power of the ice.
- Means of determining the direction of ice movement.
  - The shapes of drift hills.
  - The shapes of rock hills.
  - Constitution of the drift.
  - Striæ.
  - Situations in which striæ occur.
  - Other glacial marks.

Attention is now turned to the work effected by an ice sheet as it spreads over the land, with a view to determining the results which it accomplished in New Jersey and in other regions similarly situated. By this study we shall come to an appreciation of many of the peculiar geographic features of the drift-covered part of the State. In this study it is necessary first to understand the nature of the surface over which the ice spread. The condition of that surface may be determined, with a sufficient degree of accuracy for the purpose in hand, from the study of land surfaces which the ice did not reach.

THE PREGLACIAL SURFACE.

The points of significance concerning the preglacial surface of the area which was subsequently glaciated are two, namely, its topography and the nature of its surface materials.

Preglacial topography.—Before the development of the North American ice sheet the surface which it covered had been long exposed to the common processes of degradation. The streams had excavated valleys, and in the process ridges had been left between them. In many places these ridges had been further dissected into hills. The surface of the lands lying south of the drift in New Jersey and Pennsylvania affords good illustrations of the configuration developed by rain and river erosion. In general, it may be said that the preglacial surface of the drift-covered region was comparable to that which now exists in driftless tracts of similar age and altitude. This general inference is warranted by the fact that the glaciation, or, at least, the last glaciation, was so recent that subsequent changes of the surface have been slight. The preglacial surface of the drift-covered part of the Highlands was similar to that about Mendham and Chester, and about Schooleys, Scotts, Musconetcong and Pohatcong mountains[1] (Plate XX), which, especially in the absence of ponds and marshes, is in contrast with the area north of the moraine (Plate XXI). The surface of the drift-covered part of the Newark series was comparable to that in the central and southern parts of Somerset and Hunterdon counties (Plate XXII) and the eastern part of Morris (compare Plate IX, p. 12). The closest analogy to the preglacial surface of the Kittatinny mountain region is to be found in Pennsylvania (Plate XXIII). The difference between this surface and that which was glaciated is seen by comparing Plate XXIII with Plate XXIV. The detailed study of larger areas north and south of the moraine will emphasize the distinction which the accompanying plates illustrate.

In Plates XX and XXIII it will be seen that the regions outside the moraine have strong relief, and that their main topographic features have a northeast-southwest trend. Neither of these features is peculiar to non-glaciated regions, as the maps of the corresponding areas north of the moraine (Plates XXI and XXIV) show. The great relief is the result of altitude and erosion, and the trend of the topographic features is the result of rock structure, the elevations corresponding with the outcrops of resistant rock. The point of especial significance in these contrasted sets of maps is the absence of lakes and ponds and marshes of natural origin south of the moraine, and their presence north

[1] These regions were glaciated, but not by the ice sheet which made the moraine. Their glaciation was so ancient that its topographic effects were destroyed by erosion before the ice of the last epoch reached the State. They therefore illustrate non-glacial topography, as well as if they had never been glaciated.

of it. In other words, the areas south of the moraine are well drained, while those north of it are ill drained. In the former all depressions are stream valleys, and each leads down to one lower than itself. This is the topography developed by rain and the streams to which rain gives rise.

In the case of Plates XXII and IX the relief is not so great, but the differences in drainage are equally conspicuous. In the glaciated areas (Plate IX), too, there are numerous small elevations of irregular distribution, which have no representation in the non-glaciated area (Plate XXII).

Surface earths of the preglacial surface.—The preglacial surface, characterized by hills and valleys, was probably overspread to an average depth of some few feet by a mantle of soil and earth, which had resulted from the decomposition of the rock beneath. This surface earth doubtless contained fragments, and even large masses of the underlying rock, for such masses of rock are found in the soils and surface earths arising from the decomposition of many sorts of rock. Earthy matter of this sort now covers the area which the ice did not reach, as shown in all the Highlands area west of Morristown, and south of Dover and Oxford. This body of earthy matter which mantles the surface of the Highlands south of the drift, is primarily the product of the decay of the rock on which it lies. It is, for the most part, the residuum of rock decay, and is called *residuary* earth. It is, however, to be constantly borne in mind that there is a little drift in these extra-morainic Highlands areas, but it was deposited so long ago that most of it has been washed away by rain and rivers, and the loose material now at the surface is mainly the product of decomposition of the underlying rock.

Within these areas, the residuary earths are not evenly distributed. The rock of the steeper slopes is often bare, for loose material, even if it originated there, would soon be washed away. At the bases of the steep slopes and in the valleys below them, loose material has often accumulated in quantity, though the streams in the valleys sometimes remove the material as fast as it descends the slopes. On the high lands above the valleys the surface earths are relatively deep where the crests are broad and

EXPLANATION OF PLATES

XX, XXI, XXII, XXIII and XXIV.

PLATES XX AND XXI.

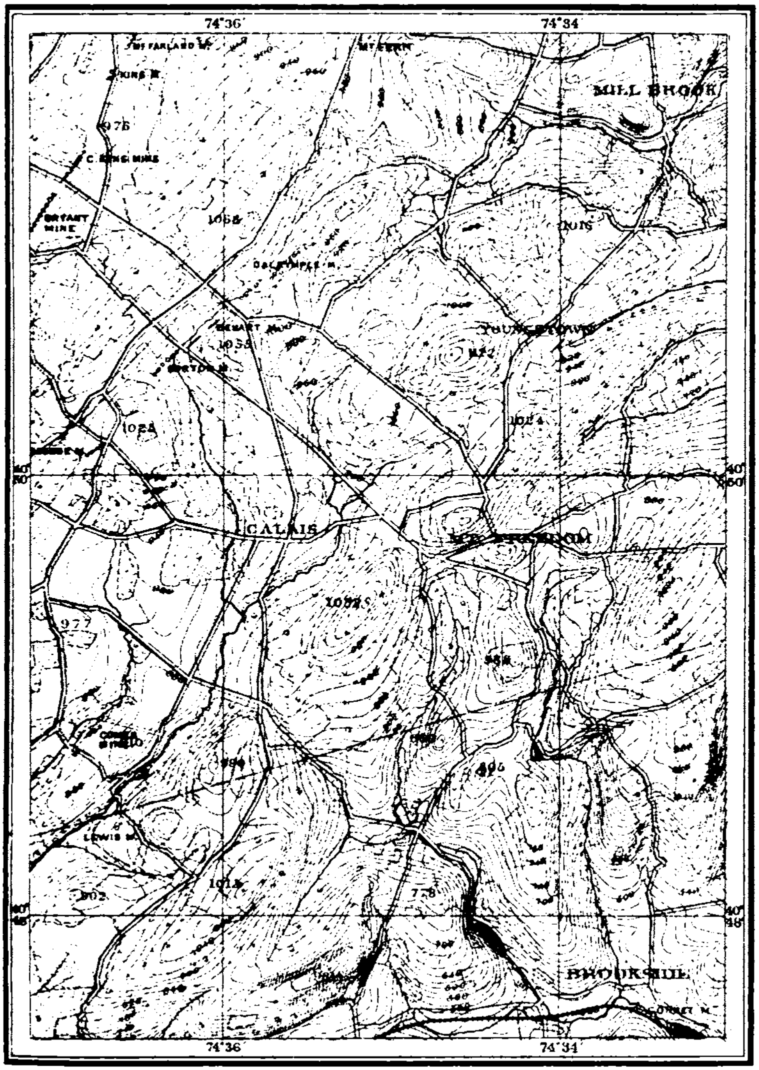
These plates put the non-glaciated and the glaciated types of Highland topography in contrast. The main topographic features in both cases are due to rock. The especial point of difference is the absence of lakes, ponds and marshes in the non-glaciated area (Plate XX), and their presence in the glaciated area (Plate XXI).

PLATE XXII.

Map of a non-glaciated area outside the moraine, in the Triassic belt. This map should be compared with Plate IX, p. 12, which shows the topography of a glaciated tract in the Triassic area.

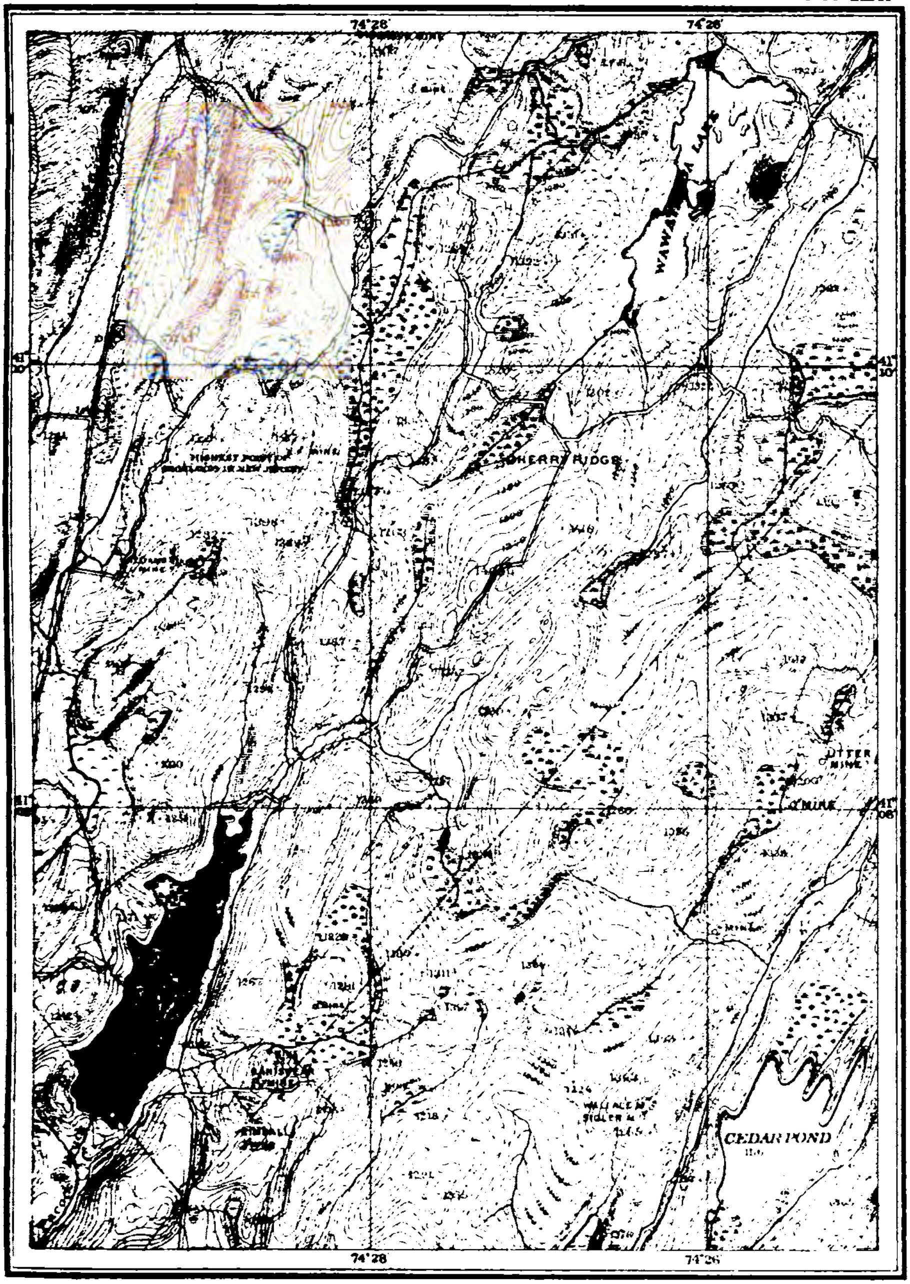
PLATES XXIII AND XXIV.

The maps represented on these Plates put non-glaciated (XXIII) and glaciated (XXIV) tracts in the Appalachian province in contrast. The former type is not represented in New Jersey, and the map of Plate XXIII is from the unglaciated part of Pennsylvania. In both maps the topography is controlled primarily by the rock, the beds of which are tilted. The outcropping edges of hard layers constitute the ridges. The chief difference between the maps lies in the presence of lakes, ponds, etc., in the glaciated area.



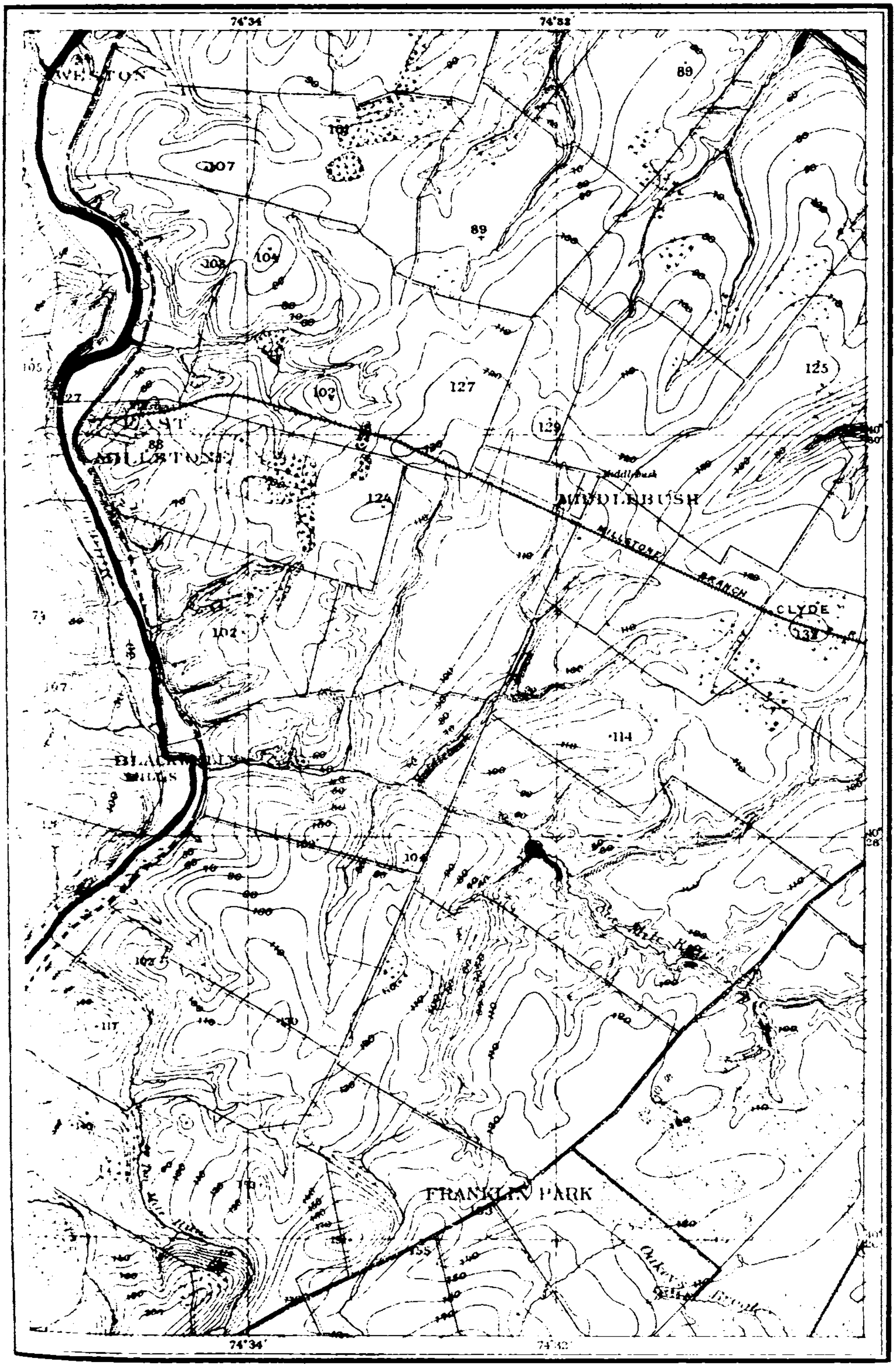
THE TOPOGRAPHY OF A NON-GLACIATED AREA IN THE HIGHLANDS

Scale 1 inch to a mile

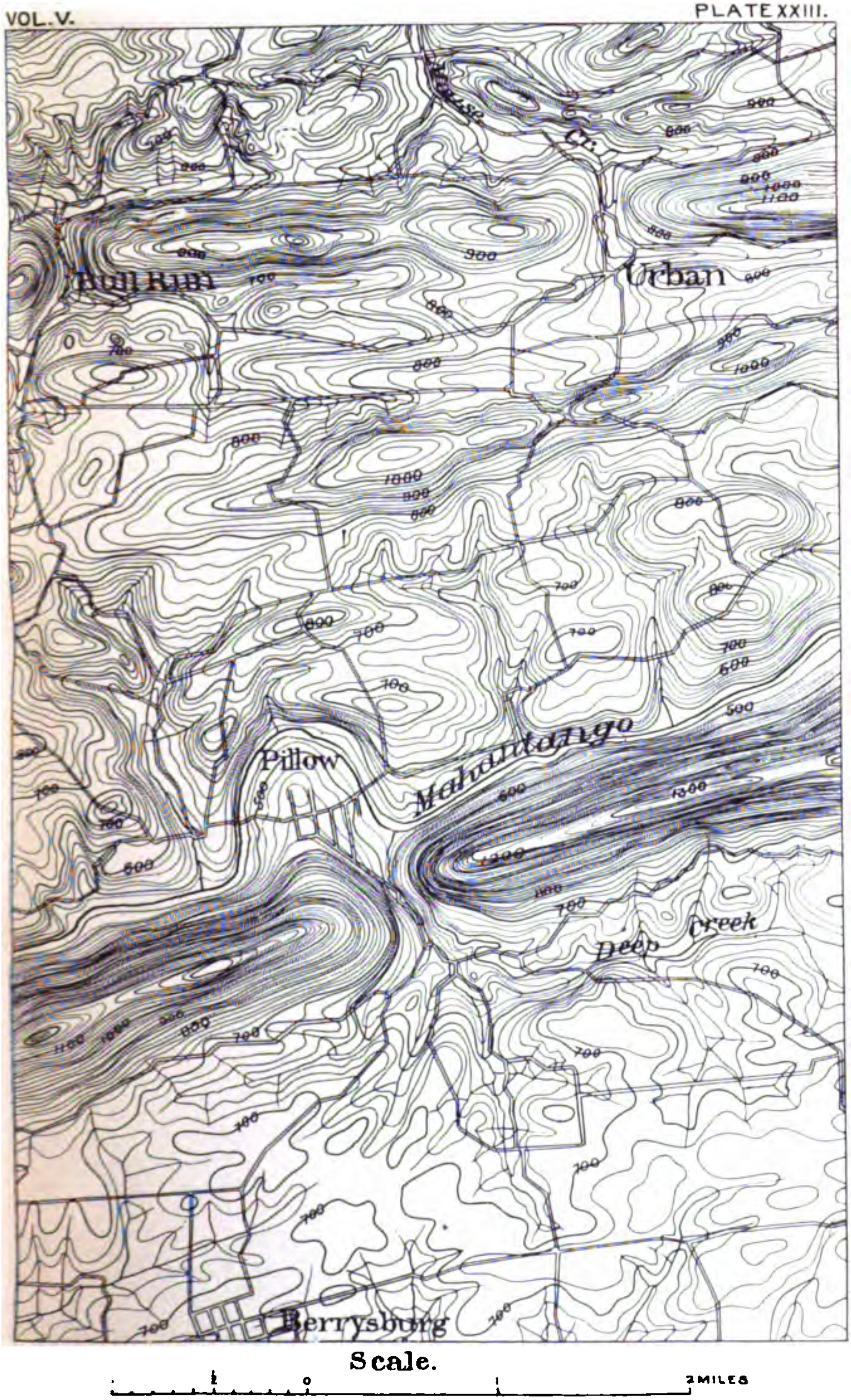


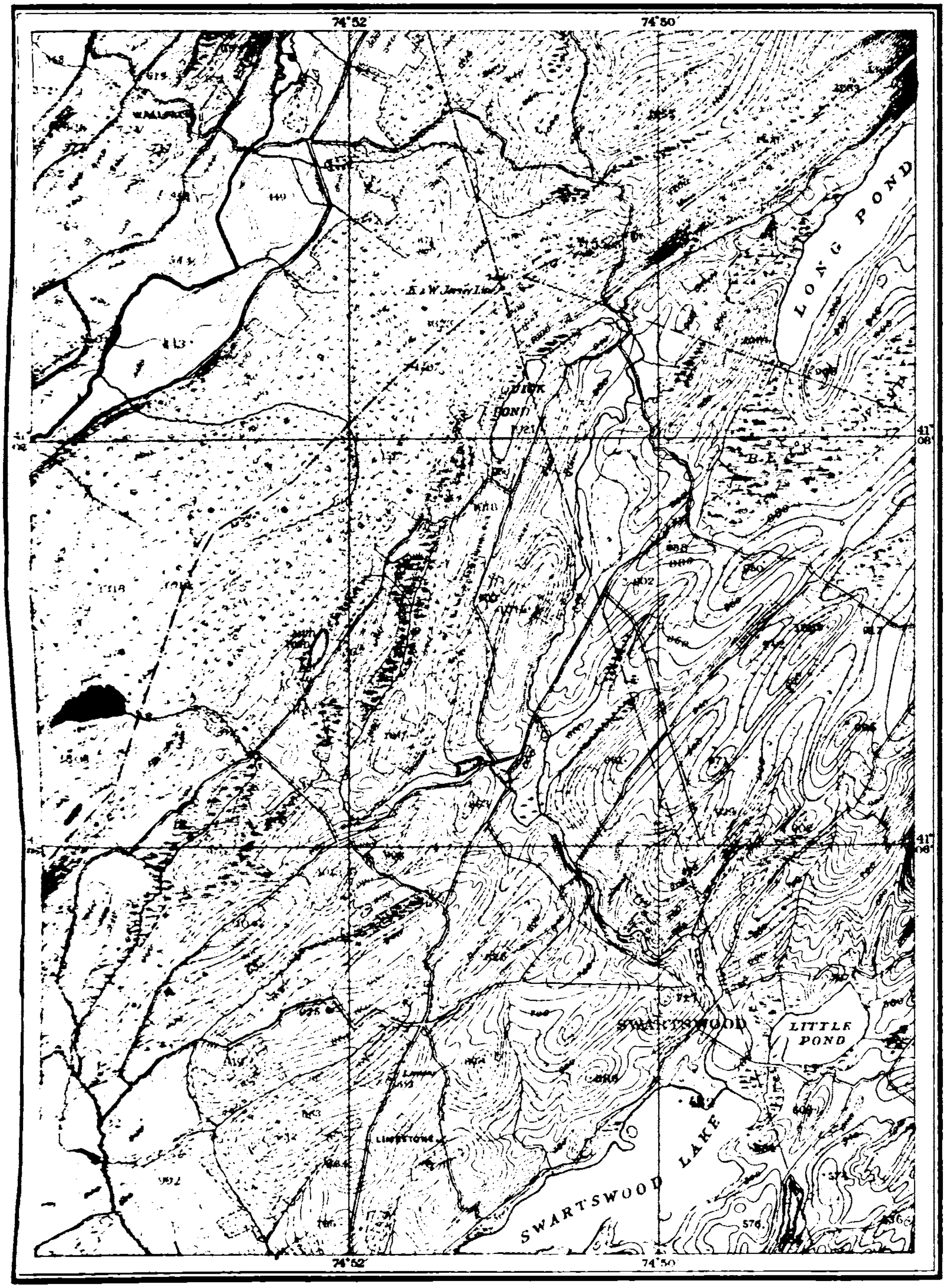
THE TOPOGRAPHY OF A GLACIATED AREA IN THE HIGHLANDS

Scale 1 inch to a mile



THE TOPOGRAPHY OF A NON-GLACIATED AREA IN THE TRIASSIC PLAIN


Bull Run
Urban
Pillow
Mahantango
Deep Creek
Berrysburg
Scale.
2 MILES



THE TOPOGRAPHY OF A GLACIATED AREA IN THE APPALACHIAN PROVINCE

Scale 1 inch to a mile

flat, but thin where they are narrow. The especially significant characteristic of this mantle of earthy matter, barring the slight remnant of old drift, is that it contains nothing which might not have come from the decay of the underlying and closely adjacent formations of rock.

Within the area of the Triassic formation the preglacial surface earths were perhaps less thick, if we may judge from the conditions of the surface of these formations where the ice did not reach them. Where the underlying rock was sandstone, the surface material was sandy; where the underlying rock was shale, the surface earths were clayey; where the underlying rock was conglomerate, the surface material was of a gravelly nature; and where the underlying rock was trap, the surface earths consisted of the clay to which the decay of that rock gives rise. Within this area, the trap formations stood up as prominent ridges, for this rock, being more resistant than that which surrounds it, had been left standing, while the adjacent shale and sandstone had been worn down, and their material carried away to the sea by running water. From the steep slopes of the trap ridges, bowlders and smaller fragments of trap had fallen or been washed down, and were scattered about on the lowlands adjacent. All this had happened before the advent of the ice.[1]

Along the bottoms of the valleys, sediments had been deposited by the streams, forming alluvial plains similar to those along the Neshanic and the lower course of the South Branch of the Raritan at the present time.

When the ice invaded the State there were therefore several sorts of loose material on the surface, all of which had arisen from the decay of the rock. There was (1) earthy matter of clayey nature, representing the finer products of rock decay; (2) sand representing a coarser grade of material arising in a similar way; (3) gravel, especially along the streams, and over conglomerate; (4) and stones and rock fragments of all sizes up to bowlders, representing undecayed masses of rock which had been detached in the general processes of weathering and erosion to which the surface had been subject.

[1] Physical Geography of New Jersey, Vol. IV, Sec. VI.

In addition to these direct products of rock decay there was the surface soil to which vegetation had made its contribution of organic matter, and there was the vegetation itself, for it is not unlikely that the northern part of the State was covered by forests before the ice came down upon it, as in later time.

Such was the character of the preglacial surface, both as to topography and surface material. How did the ice affect it?

The work of the ice in any region was twofold: In the first place, it abraded the surface over which it passed; and, in the second, it sooner or later deposited the material which it acquired. The two phases of ice work are therefore erosion and deposition.

EROSION BY GLACIER ICE.

Nature of glacier motion.—Whatever the real nature of glacier motion,[1] its effect on the surface over which it passes is very much what it would be if the ice were a highly viscous substance. Fluid and other plastic bodies when in motion tend to adapt themselves to the irregularities of the channels or beds through which or over which they move. The degree of adaptation depends primarily on the degree of mobility of the moving body, being greater with increasing fluidity, and less with increasing viscosity. It depends also on the rate of movement, being greater with slow than with rapid motion. Rigid bodies in motion over uneven surfaces, on the other hand, tend to adapt their beds to them-

[1] The real nature of glacier motion is a mooted question, but a question which belongs to physics rather than to geology. Some references bearing on this subject are given below, and further reference to the subject will be made in the following pages.

Charpentier. Essai sur les Glaciers, 1841.
Thompson. Trans. Roy. Soc. Edinburgh, 1849.
Hopkins. Phil. Mag., 1845.
Tyndall. Glaciers of the Alps, 1857.
Moseley. Phil. Mag., 1869.
Croll. Phil. Mag., 1869.
Heim. Handbuch der Gletscherkunde, 1885.
Reid. Journal of Geology, Vol. IV, 1896, p. 912.

selves. Their tendency is to plane off such asperities of surface as they meet, whether their motion be slow or rapid.

Between fluid and rigid bodies no sharp line can be drawn. Viscous fluids, such as tar, are intermediate in their behavior, between such fluids as water and such solids as rock. There are all degrees of rigidity and viscosity, and a substance which, under one set of conditions, seems to be rigid, may show itself to be viscous, or at any rate plastic, when conditions are sufficiently changed. Furthermore, the same substance may exhibit very different degrees of viscosity under different circumstances. Such substances as tar, the viscosity of which varies greatly with temperature, are familiar illustrations. A highly viscous body may so far approach rigidity that, when in motion, it exerts great pressure against any obstacle which opposes its motion, and is in turn reacted upon by the obstacle with great force, before its particles move upon one another in such a manner as to reveal its viscosity.

The degree of mobility manifested by such small quantities of ice as are commonly dealt with is slight. Indeed ice seems to be extremely brittle. In great masses, and under great pressures, or even in small masses, under certain conditions, its plasticity is more evident, for masses of it may be molded, and bars of it bent into almost any desired shape. The chief condition for the successful issue of such experiments is the steady application of the proper amount of pressure.[1] Yet even in glacier ice, the tendency to rigidity is so great that it does not yield readily to opposing obstacles, and, unless they be very resistant, may overcome them. If they be sufficiently resistant, however, and if the pressure behind the moving ice be sufficiently great, it will yield, and pass over or around them by a sort of flowing movement; but so grudgingly does the moving ice yield its right of way, and so reluctantly does it conform to the irregularities in its path, that the obstacles to which it yields are likely to suffer severe abrasion in its passage.

It is not to be understood from the preceding paragraphs that glacier ice always acts like a viscous substance, as that term is

[1] For accounts of experiments illustrating the plasticity of ice, see Aitkin, Am. Jour. Sci., Vol. 5, 1873, and Nature, Vol. XXXIX, 1888.

ordinarily understood. It is certain that the ice is sometimes so rigid that parts of it are slipped or *sheared* over other parts as cards are slipped over one another. It is probably true that the real nature of the motion in the ice is not the same under all conditions. Reference to various phases of motion will be made, incidentally, in the following pages.

Getting a load.—Clean ice moving over a smooth surface of hard rock would effect little wear; but moving ice is not, as a rule, clean, nor is the surface over which it passes commonly smooth or always hard. Furthermore, clean ice would erode a rough surface covered with loose debris.

Before a snow or ice-field becomes a glacier, that is, before movement is inaugurated, its bottom is frozen to some of the debris of the surface beneath it; or to put it in another way, the ice in the soil, formed by the freezing of the water in it, has become continuous above with the ice which has resulted from the compacting of the snow. When movement begins, therefore, the bottom of the ice contains and carries with it earthy, sandy, gravelly and stony matter, the amount of which must vary greatly with varying conditions.

Suppose the surface over which the ice advances to be covered with loose debris, in the form of detached masses of rock, gravel, sand and finer earthy matter. What will the ice do with these materials? Much depends on the topography of the surface, which may be flat, gently relieved, or rough. For a given amount of movement the ice will gather least from the flat surface and most from the rough.

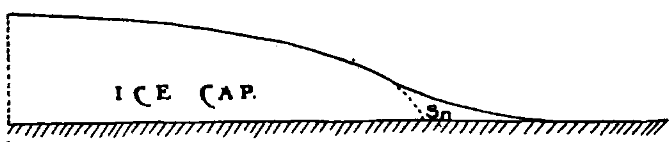


Fig. 13.

Cross section of the edge of an ice cap, illustrating how the same may grow by the addition of marginal snow. Sn represents snow.

Some of the snow which falls about the edge of a growing ice sheet is converted into ice, and becomes attached to the main mass (Fig. b, Plate XVIII, and Fig. 13). This marginal snow-ice will be likely to have frozen to the earthy or stony material beneath it before it itself became involved in movement. Such material then becomes involved in the glacier. Again the ice may be constantly freezing to the loose material beneath its advancing edge, especially in winter, and this material then becomes involved in the moving mass. Materials gathered in these ways may be said to be acquired passively. Their incorporation in the ice is not primarily the result of the movement of the latter. It would be just as true to say that they attach themselves to the ice as that the ice takes hold of them.

The sequenceof events in the acquisition of debris, which results directly from the movement of the ice, is sometimes misapprehended. The ice is not so rigid that it plows up the loose material of the surface in front of it, and pushes it along at its advancing edge. Its ways of getting a load are various. One process may be illustrated by the sequence of events when the end of a glacier or the edge of an ice sheet advances on a large mass of detached rock. As the ice approaches it, the reflection of the sun's heat from the rock melts the adjacent edge of the ice, making a slight re-entrant in it opposite the rock. The ice moves forward on either side and with farther advance, closes around the bowlder, and finally carries it along in the bottom of the moving mass. Where the advance of the ice is unusually rapid and forceful, it no doubt tends to push loose material forward at its edge, but the greater mobility of the ice, as compared with the debris, would result in the constant tendency of the ice to go faster than the debris, and so to override it. Only where ice is vigorously moving up an opposing slope is the push of material in front of it likely to be of consequence.

Where the advancing ice encounters and overrides a surface on which there are projecting points and pinnacles of rock, these may be torn from their foundations and added to the debris which was loose on the surface. These are some of the simpler ways in which ice gets its basal load.

In mountain regions debris sometimes falls on to the surfaces of valley glaciers from the cliffs and peaks above. In the acquisition of such material the ice is passive. Except locally and temporarily, peaks and cliffs did not tower above the ice of the

North American ice sheet, and the amount of debris which fell upon its surface was slight.

A glacier, for an ice sheet is but a huge glacier, is then to be thought of as a mass of ice, moving a few inches, or, at most, a few feet per day, in the base of which there is more or less earthy and stony debris, which it has gleaned from the surface over which it has passed.

As the North American ice sheet spread from its centers of growth, every hill and every mound which it encountered contested its advance, and every sufficiently resistant elevation compelled the ice to pass around or over it. Had the bottom of the ice been free from stony and earthy debris, its effects upon the hills of resistant rock would not have been great. Such hills would have worn the bottom of the ice effectively, but the ice would have produced relatively little effect on them. But the hills, as well as the remainder of the surface over which the ice moved, were more or less covered by residual earths and bowlders of disintegration. These materials were incorporated in the basal part of the ice, or urged along beneath it, and, thus armed, the ice became an effective agent of wear. Advancing, it yielded to obstructions in its course only under great pressure, and as little as might be. It rubbed its rock-shod bottom over the surface of its bed, operating with especial severity on surfaces so situated as to oppose great resistance to its progress. Its action may be compared to that of a huge flexible rasp[1], fitted down snugly over hills and into depressions, and urged slowly forward under enormous pressure.

Conditions determining the effectiveness of glacial erosion.—The amount of abrasion effected by a body of moving ice would depend on two sets of factors which are in some measure independent of each other. The one set has to do with the ice, the other with the surface over which the ice moves. So far as concerns the former, the erosion effected is dependent (1) on the nature and strength of the movement of the ice, and (2) on the abundance and kind of tools with which it is armed. So far as concerns the surface over which the ice passed, the amount of

[1] Chamberlin. Geology of Wisconsin, Vol. I.

erosion depends (1) on its topography and on the trend of its topographic features with relation to the direction of ice movement, and (2) on its constitution and structure. The absolute amount of erosion depends on the relation of these several factors to one another.

Variations in abrasion due to the ice.—It is hardly necessary to state that, other things being equal, the rate of erosion increases with the rate of movement. The erosion is also increased by increased pressure (weight of ice), and by increased rigidity of the moving body. The rigidity is influenced by temperature and by the load of debris which is carried, and, perhaps, by other conditions. The pressure and the rigidity may be in some measure opposed to each other in their effects, since greater pressure will, under some conditions, result in diminished rigidity. On the whole, great thickness of ice and rapid (for ice) motion under conditions favoring rigidity, favor effective erosion.

So long as the surface over which ice moves furnishes it with debris it does not want for tools with which to work. So soon as the supply of disintegrated rock prepared in advance is removed, the ice begins to work upon the rock beneath. Because of its greater resistance, the rock cannot be so easily eroded as the loose debris which originally covered it. Furthermore, since debris is now less readily acquired, the ice is less efficiently armed with the tools by which its most effective erosive work is accomplished. For a double reason, therefore, the rate of erosion is diminished after the loose debris has been removed.

It is not to be inferred either that clean ice is without erosive power, or that ice works most effectively when most heavily charged with debris in its basal parts. So far as concerns the first point, clean ice may gather material from the surface where it passes over loose detritus or slightly resistant rock. So far as concerns the second, detritus in the ice decreases its mobility[1], and decrease in mobility may go so far as to practically destroy motion. In this case the bottom, debris-charged part of the ice becomes stagnant, or nearly so, while the cleaner part above

[1] Russell. Journal of Geology, Vol. III, p. 823.

overrides it (Plate XXV). In this case the surface beneath the glaciers suffers little wear. While, therefore, clean ice is a relatively inefficient agent of erosion, debris enhances its effectiveness up to a certain point only, beyond which, by decreasing its mobility, it diminishes its erosive power. The analogy with flowing water is, from one point of view, perfect. A clear stream is a relatively inefficient erosive agent, if its bed be solid rock. Load (detritus) increases its efficiency up to a certain point, but beyond that point increase of load decreases its erosive power by diminishing its velocity.

The sort of stony material which ice carries likewise affects its rate of erosion. Angular pieces of hard rock are more effective tools than rounded pieces of less resistant material, especially on indurated formations.

Zone of greatest erosion.—The zone beneath an ice sheet where its erosive activities are most effective is not determinable by observation, since the bottom of an ice sheet is not accessible. It is probably not at the extreme edge, because here the strength of movement is too slight, and the load too great relative to the motion; it is probably not at the center, or near it, because, although the pressure is there great, the movement is slow and the ice not properly armed. It is somewhere between the center and the margin, and, in ice-caps of great size, much nearer the latter than the former.

At the margin of an ice sheet melting normally exceeds accumulation. Distant from the margin, accumulation normally exceeds melting. The area where accumulation is in excess of wastage is known as the reservoir, and the area where melting exceeds accumulation is the dissipator.[1] It would appear that the strength of movement in an ice sheet is greatest in the outer portion of the reservoir or area of accumulation (see p. 40 and Fig. 12). This, it is believed, is much nearer the edge than the center of an ice sheet, during at least the advancing and the advanced stages of its history. In the case of the ice sheet of Greenland, the reservoir certainly approaches the edge of the ice-cap very closely.

[1] Reid. Journal of Geology, Vol. IV, p. 912.

Variations in erosion due to underlying surface.—So far as concerns the surface passed over by the ice, it may be said that, other things being equal, the greater the friction the more the erosion. In any ice sheet the amount of friction at any point will depend on the relation between the amount of movement and the resistance offered. For a given amount of basal movement, therefore, friction must increase with increasing roughness of surface.

As it extended itself, the ice sheet of North America encountered surfaces of all sorts, varying from nearly level plains to mountainous tracts. Plane surfaces facilitated its movement as compared with rough ones, but offered too little resistance for effective erosion. That the ice frequently overrode them without much erosion is demonstrated by the preservation at some points of the preglacial soils which it buried beneath its own deposits.

Surfaces of extreme roughness, on the other hand, may retard motion to such a degree as to allow of little wear. The roughness of a surface may indeed be so great as to prevent motion altogether, and therefore erosion. The amount of relief necessary to effect this result depends on the thickness of the ice. A rough topography, of 500 feet relief, might not stop the movement of a body of glacier ice 1,000 feet thick, though it would greatly retard it; but a rough topography of 1,000 feet relief would stop the bodily movement of a sheet of ice 500 feet or even 1,000 feet thick. The topographic condition for greatest erosion would be a mean between extremes of roughness and planeness, and the degree of roughness favorable to greatest erosion would stand in some tolerably definite relation to the thickness of the moving body of ice. Not only the heights and depths of hills and valleys, but their disposition, especially with reference to the direction of ice movement, also influenced the amount of erosion, for in some relations they facilitated and in others they retarded erosion.

The topography of a rough tract is somewhat smoothed by the passage of the ice.

Other things being equal therefore, the topography near the edge of the ice sheet was more favorable for erosion than that near its center, for in the latter situation the ice had been working longer. The amount of erosion accomplished by ice is also affected by the amount of loose material at the surface, by the hardness of the rock, and by its structure.

So far as concerns the removal of loose debris at the surface, it was doubtless most rapid near the edge of the ice, in the territory newly invaded by it, for in other positions where the ice had been working longer it was already removed. So far as concerns the hardness of the rock, the less its induration the more rapidly is it worn away. Under the erosive action of the ice, areas of relatively soft rock, surrounded or partially surrounded by harder, sometimes became notable depressions. The attitude of the strata and the position and abundance of the cleavage planes (joint planes, bedding planes, etc.) affecting it also helped to determine the amount of wear which the ice inflicted. Inclined strata were, by virtue of their position, less able than horizontal beds to resist the ice. This point is of much more significance in the case of hard rock formations, such as trap, than in the case of soft ones, such as clay.

Summary.—In summary it may be said that rapidly moving ice of sufficient thickness to be working under goodly pressure, shod with a sufficient but not excessive quantity of hard rock material, passing over incoherent or soft formations possessing a topography of sufficient relief to offer great resistance, and yet too little to retard too seriously the progress of the ice, will erode most effectively. In those portions of the North American ice sheet where these conditions obtained at any given time, erosion was temporarily most effective. It will be readily inferred that the site of greatest erosion was continually shifting.

SORTS OF MATERIAL GATHERED BY THE ICE.

The variety of materials gathered by the ice from any formation over which it passed was considerable. They consisted of (1) the soil and the remnants of vegetation that had covered it; (2) the residuary earths (sub-soil) which underlay the soil and which had arisen from the decomposition of the rock; (3)

the silt, sand and gravel which the streams had previously concentrated along their courses; (4) the masses of rock which had been detached from their parent beds by the agencies of weathering (bowlders of disintegration); (5) masses of rock, large and small, which, by the help of the stony material it carried, the ice was able to quarry from its bed; (6) such fine material as was formed by the rubbing together of the various products above enumerated; and (7) such fine material as was produced by the rubbing of the coarser materials carried by the ice on the rock floor. In addition to those materials which the ice was active in gathering, two other classes of material reached it; these are (8) the dust blown upon it, and (9) the debris which fell upon it from the adjacent mountains and cliffs.

The variety of material gathered was even greater than this long category indicates, for some of the rock masses were of fresh rock and some of rock which was decomposed. There was the greatest diversity in size of materials also, from bowlders fifty feet or more in diameter to the finest clay. Such was the variety of material derived from each formation. When the ice had passed over many the variety was correspondingly increased.

WEAR OF THE DRIFT IN TRANSIT.

The erosion effected by glacial ice is not confined to the bed over which it passes. The debris which it carries and with which it abrades the bed rock is itself worn. It is worn by friction with the bed rock, and it is worn by friction with itself, for adjacent parts of the debris-filled ice do not move at the same rate. A given stone may be ground and scratched on its lower side by being carried over debris which moves more slowly than it does, and at the same time on its upper side by debris which moves over it at a rate exceeding its own. A little later the same stone may be turned in the ice, exposing new surfaces to similar attrition. Thus are developed the sub-angular, plane-faced, beveled and striated stones which characterize the drift (Plate XV). During this process of wear, whether between the stones of the drift itself or between the stones of the drift and the bed rock, much fine material (rock flour, clay, etc.) is produced. Even the hardest bowlders are thus reduced in size, and, given time enough, they would literally be worn out. Much of the fine material of the drift was produced in this way.

It need hardly be added that the drift in the basal position is that which suffers most wear. That which is in the ice above the base will suffer little attrition, unless its amount is large. That on the surface will not be worn at all.

CONDITIONS AFFECTING EROSION IN NORTHERN NEW JERSEY.

Applying the foregoing principles to northern New Jersey we find, first, that since the region was near the margin of the ice at the time of its greatest expansion, neither the thickness of the ice nor its rate of motion (presumably) were such as to give it erosive power equal to that which it had farther north; and, second, that the topography of the region and the variety of its rock structure were such as to allow the ice to work with varying degrees of efficiency.

The thickness of the ice in New Jersey.—The thickness of that part of the ice sheet which covered New Jersey has never been determined with accuracy, and cannot be; but rough estimates of its thickness not altogether without significance may be made.

1. The border of the principal sheet of drift, that is, the moraine, lies twenty-five to forty miles below the State line, measured along the lines of the ice movement. On the west side of Greenland, where crossed by Nansen, the slope of the surface of the ice was about 127 feet per mile for the first twenty-six miles, and on the east side about 162 feet per mile for the first fifty miles. What allowance is to be made in this case for the topography of the underlying rock is unknown.

2. The slope of the upper surface of the Keewatin ice sheet, in northwestern Montana, for the last twenty-five miles is estimated at fifty feet per mile.

Taking the mean of the Greenland figures as the slope of the surface of the ice in New Jersey, it would have had a thickness of 3,600 to 5,800 feet along the northern boundary of the State.

Taking the Montana figures, the thickness would have been 1,250 to 2,000 feet. The latter figures are not believed to exaggerate the actual thickness of the ice at the State line at the time it was making the Perth Amboy-Belvidere moraine. That the slope of the surface of the ice at its extreme edge was great is shown by the fact that differences of 200 to 400 feet in the altitude of the surface at the edge of the ice did not greatly influence its position. This is shown, for example, in the vicinity of Hackettstown, where the edge of the ice did not extend much farther south in the valley of the Musconetcong than on Pohatcong mountain, though the latter is 400 feet higher. In this place the slope of the surface of the ice must have been several hundred feet in the first mile.

The figures given above for the thickness of the ice may be partially checked in another way. The relief of the surface covered by the ice in the northwestern part of the State, along a line extending from the Delaware across the Kittatinny mountain at High Point, and roughly parallel to the edge of the ice, amounts to nearly 1,400 feet. The ice was thick enough to fill the depressions in this strongly accentuated topography, and at the same time to cover the mountain crests. On the crest of Kittatinny mountain it was sufficiently thick to advance about 40 miles south of the State line. Applying the preceding figures as to slope of the surface of the ice, it would give a thickness of 1,500 or 1,600 feet for the ice on the crest of Kittatinny mountain at the State line. The crest of the mountain is here 600 feet to 1,000 feet higher than the Kittatinny valley to the east. If the thickness of the ice in the valley exceeded that on the mountain by the amount of this difference, the thickness in the valley would have been 2,100 to 2,600 feet thick.

There is a probable error in the preceding calculation as applied to the mountain crest, for the ice which passed along the crest for 40 miles south of the State line was not necessarily all on the crest at the State line, as the preceding statement implies. There is proof, in the direction of the striæ, that ice from the Kittatinny valley moved up over the northern part of the mountain at the north, and that ice from the Delaware valley came up over the mountain to some extent farther south. These facts would tend to reduce the estimates of the thickness of the ice so far as the crest of the ridge is concerned. These upward movements from the east near the State line, and from the west farther south, show that the upper surface of the ice over the valleys was higher than the upper surface of that on the mountain, for ice, as surely as water, moves from the direction of greatest head.

Making allowance for the above conditions of things, it is probable that, at the north line of the State, the thickness of the ice on Kittatinny mountain may have been 1,000 to 1,500, and of that in the north end of the valley 1,800 to 2,500 feet.

At other points along the north line of the State the relief was less, and direct evidence that the ice was so thick is wanting. The same mode of calculation, applied to the eastern part of the State, would give a thickness of 1,000 or 1,200 feet on the Palisade ridge at the north line of the State, and a thickness of 1,500 to 2,000 feet in the Hackensack valley at its western base. It is probably safe to conclude that the maximum thickness of the ice, along the north line of the State, was somewhere between 1,500 and 2,500 feet, and its minimum between 1,000 and 1,500 feet, when the ice was at its maximum stand. From this thickness at the north the ice thinned to the southward, and at its margin its thickness was probably slight. Fig. 14 is a cross section along

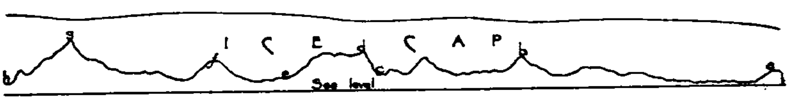


Fig. 14.

Cross section along the northern line of the State, with the surface of the ice as it is conceived to have been during the glacial period. The most irregular line represents the surface of the land, the uppermost, the surface of the ice. The vertical scale of the land profile is exaggerated about twelve times.

the north line of the State, showing the topography, and at the same time the conjectured upper surface of the ice, and represents what is believed to have been the general relation between topography and depth of ice. In the figure, a represents the Palisade ridge; b Ramapo mountain; c Greenwood lake; d Bearfort mountain; f Pochuck mountain; g Kittatinny mountain, and h the Delaware valley. From this figure it is apparent that the average thickness of the ice must have been considerably less than its maximum, and greater than its minimum.

The total area of the State covered by ice was between 1,600 and 1,700 square miles. If the average thickness of the ice was one-fifth of a mile (1,056 feet) the total volume of ice was about 340 cubic miles. If the average thickness was but one-eighth of a mile (660 feet), the total volume was somewhat more than 200 cubic miles. The actual amount was probably between these limits, and probably nearer the former than the latter.

The variable thickness of the ice which resulted from the unevenness of its bed entailed unequal motion. Generally speaking, it moved more rapidly where it was thick, and less rapidly where it was shallow. In the depressions parallel to its direction of movement, such as the Kittatinny valley (between g and f), and the Triassic lowland west of the Palisade ridge (between a and b), where the ice was thicker, it moved faster than on the Highlands (d) and on Kittatinny mountain (g), where it was thinner. In the great depressions, therefore, its erosive power was greatest.

The relief of the surface.—The relief of the surface has been referred to in the preceding paragraphs. It was adequate to offer the ice great resistance, and, therefore, to insure effective erosion. The trend of the most pronounced ridges and valleys is roughly parallel to the direction of ice movement. Though the correspondence was not perfect, the ice, on the whole, moved along the great depressions and ridges rather than *across* them. On the other hand, there were many minor valleys, such as the Pequannock and Rockaway, which were not parallel to the motion of the ice, and which the ice was obliged to cross.

What was true of the valleys was true of the elevations. While the most pronounced ridges, such as the Kittatinny range and the Green Pond mountain group, are approximately parallel to the course taken by the ice, the courses of many lesser ridges, such as the northern end of First and Second mountains, were more or less directly athwart the course of the ice, and in the case of the Palisade ridge, the discordance between its trend and the direction of ice movement was great. But, on the whole, the course of the ice in New Jersey was in the direction in which topography opposed the least resistance.

The formations eroded.—The variety of surface material encountered by the ice was likewise great. Some parts of the surface were thickly covered by the products of rock decay, while others were essentially bare; and when the loose debris had been worn from the surface, the rock beneath offered very different degrees of resistance. The hard rock of the Kittatinny and Green Pond ranges offered greater resistance than the gneiss and crystalline schist of the Highlands and the trap of the Watchung mountains and the Palisade ridge, while these in turn withstood erosion more effectively than the softer rocks of the Kittatinny, Hackensack, and lower Passaic valleys. It was in these valleys, where resistance to erosion was least, that the ice was thickest, moved fastest, and was, therefore, in a condition for most effective work.

CHANGES IN TOPOGRAPHY EFFECTED BY EROSION.

New Jersey was so near the margin of the ice sheet that the ice was less thick and moved with less force than in areas farther north. Furthermore, the ice worked on the surface here for a shorter period of time than elsewhere, for this was the zone which the ice was last to reach and first to leave. Extraordinary changes of topography resulting from ice erosion are, therefore, not to be expected.

Erosive effect of ice on elevations.—The general effect of the passage of an ice sheet, so far as its erosive action is concerned, is the smoothing of the surface over which it moves. Other things being equal, the wear is greatest at points so situated as to offer resistance, but which are themselves weak. It follows that the sharp summits of the hills and the angular rugosities of their surface were filed off and smoothed down to such forms as offered progressively less and less resistance. Tower and pinnacle-like forms of rock, such as are often developed under the influence of weathering, would be promptly worn away. Where the process of abrasion was continued long enough, the forms even of large hills were greatly altered (Figs. 15 and 16), and their dimensions reduced. In general, the wear was greatest on the "stoss" side of a hill, that is, on the side which faced the oncoming ice. Among the results of ice wear, therefore, were a lowering of the hills, a smoothing and softening of their contours, and a modification of their shapes. These results are, perhaps, most obvious in the smoothed knolls of slate and shale in the Kittatinny valley.

Fig. 15.
Form of a non-glaciated hill, and the relation of its soil to the rock.

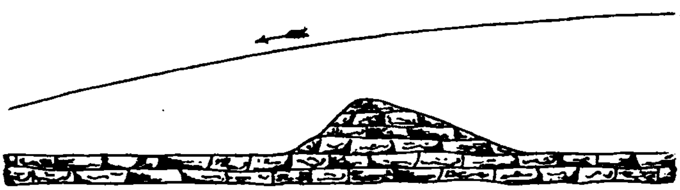


Fig. 16.
Shape of glaciated hill, as modified by erosion.

The lack of smoothing seems to be illustrated in the same region by the rough and craggy hills of limestone which abound along the belts of limestone between the areas of shale. The rough limestone knolls are not as the ice left them. They were probably smoothed down effectively by the ice, and their roughnesses of surface are the result of later weathering, which has affected the limestone more considerably than the shale, and with very different results.

In the Highlands, and in the Triassic region too, the hills and ridges were worn down and smoothed off. The abrasive action of the ice is visible at many points, but the measure of its influence in reducing the hills and ridges cannot be known with precision, since their antecedent roughness is not determinable. It is safe to say that the hills and ridges of rock over which the ice passed were made smoother, so far as the details of their surfaces are concerned, but that the general configuration of the major elevation was not profoundly altered. The crest and the slopes of Kittatinny mountain are doubtless smoother than they were before the ice overspread it, but the range as a whole had much the same relations to its surroundings before the advance of the ice as afterward. The same may be said of the other prominent elevations of the State.

In certain situations, however, the erosion of the mountains and ridges went far beyond the smoothing of their surfaces. The Palisade ridge and the Green Pond and Kittatinny ranges afford illustrations of these exceptional phases of erosion. It has already been stated that the ice moved southeastward across the Palisade ridge, a direction nearly at right angles to the course of the ridge itself. The eastern face of this ridge must have been then, as now, steep. As the ice passed the top of the Palisades face, the situation favored the breaking of huge blocks of rock from the cliff, which the farther advance of the ice carried over to Manhattan, Staten and Long Islands. Over some parts of these islands bowlders of trap are so numerous as to warrant the belief that this took place on an extensive scale. This breaking of rock masses from steep faces over which the ice passes is known as *plucking*. The result of the plucking must have been to cause a recession of the crest of the Palisade face to the westward. At the same time, the crest of the ridge was lowered, though probably not to a great extent.

The same thing happened on the Kittatinny range, or, at least, on its southern part. Here the ice moved obliquely across the range from the west, and it plucked from the eastern escarpment great quantities of rock appropriate for bowlders, and scattered them over the valley to the east.

An estimate based on the bowlders from the Kittatinny mountain in the Kittatinny valley indicates that its crest was lowered but a few feet by the ice. In so far as these bowlders were plucked from the eastern face, as may have been the case near the south end of the range, the lowering of the crest was less considerable. In the nature of the case the data for such an estimate are so imperfect that little importance should be attached to the numerical result; but the figures may be of service as indicating the order of magnitude of the erosion.

Over the Green Pond mountain, too, the movement of ice had such a direction as to carry it obliquely across the crest, whence it gathered numerous bowlders, and carried them out to the Highlands and plains to the south.

Erosive effect of ice on valleys.—It was not the hills alone which the moving ice affected. Where it encountered valleys in its course they likewise suffered modification. Where the course of a valley was parallel to the direction of ice movement, the ice occupied and moved along its axis. Because the ice was deeper in valleys than on either side, it moved there under greater pressure and more rapidly than elsewhere, and its abrading action was correspondingly more powerful. Valleys parallel to the ice movement were therefore deepened and widened by its passage. This was doubtless the case in the Kittatinny valley as a whole, and in its main sub-valleys, in the valleys in the Green Pond-Bearfort belt, and of most of those in the Triassic plain east of the Highlands.

Where the courses of valleys were transverse to the direction of ice movement the case was somewhat different. The ice was not sufficiently rigid to span the valleys, and therefore filled them; but in this case it is evident that the greater depth of ice in the valley did not accelerate its motion, since the ice in the valley-trough and that above it were in a measure opposing each other. Left to itself, the ice in the valley would have tended to move in the direction of the axis of the depression. But in the case under consideration the ice which lay above the valley depression was in motion at right angles to this axis. Under these circumstances three cases may have arisen:

1. The movement of the ice sheet over the valley may have been able to push or drag the valley ice up the farther valley slope and out upon the opposite highland. In this case, that slope of the valley which lay on the side from which the ice came (b, Fig. 17)

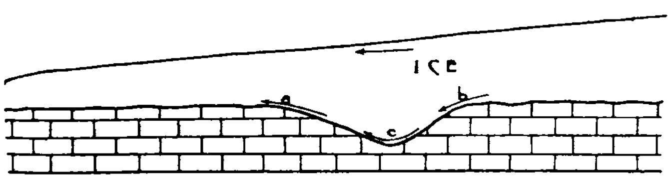


Fig. 17.
Ice crossing valley, the valley ice getting out on opposite bluff.

suffered least wear, since the ice, by its considerable measure of rigidity, helped to support its own weight over this slope. The bottom of the valley was not greatly lowered by erosion, since the ice did not work upon it advantageously; but the slope against which the ice movement was projected (a, Fig. 17) suffered greatest abrasion. The effect was to reduce its angle. As a result the valley was widened, and the widening took place mainly on one side.

Shallow valleys, and those possessing gentle slopes, favored this phase of ice movement. They opposed less resistance to the passage of the ice, both because of the less amount of ice which was put in the attitude of resistance, and because of the easier gradients over which it had to move. Some of the minor valleys of the Kittatinny valley and of the Triassic plain transverse to the directions of the main valleys, were affected by the ice in this way.

2. The upper ice crossing the valley may have passed over the ice which filled the valley-trough, leaving the latter stationary (Fig. 18). In this case the stationary ice of the valley served

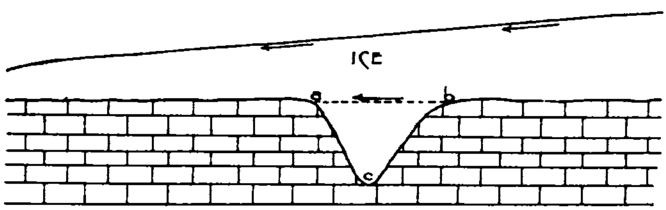


Fig. 18.
The ice in the valley probably without motion, while the ice above crosses the valley on the ice bridge.

merely as a bridge on which the upper ice crossed. In this case the valley did not suffer great wear by the ice so long as this condition of things continued. Valleys which have great depth, relative to the thickness of the ice, and especially those which have steep slopes, must have favored this phase of movement.

No valley in the State can be pointed to as an illustration of the point here made, but some of the valleys of the Highlands may have been affected in this way.

3. In valleys transverse to the general direction of ice movement, currents of ice may have moved along the valley, transverse to the general course of sheet movement. This would be most likely to happen where the thickness of the ice was considerably greater than the depth of the valley crossed, and where the valley was capacious and unobstructed at one end. Under such circumstances the ice in the valley may have moved along its axis, while the upper ice continued in its original course, crossing the valley on the ice which was moving in the direction of the axis of the valley. The movement of the upper part of the ice corresponded with that in the second case cited; but here the ice bridge is itself in motion. In this case the valley was deepened and widened, the wear being effected mainly by the movement along its course, and not by the transverse to it. Clear-cut illustrations of this phase of ice work in connection with individual river valleys in the State cannot be pointed out, but the tendency is shown at various points, and especially well in the northwestern part of the Kittatinny valley and on the adjacent mountain where the ice in the valley next the east face of the mountain moved nearly parallel with it, while at higher levels, well above the bottom, it diverged strongly to the westward. The same tendency is shown to some extent on the west side of the Palisade ridge, where the divergence was to the east.

It probably happened much more commonly than otherwise that the ice movement was neither parallel with the courses of valleys nor normal to them, but oblique instead. In such relations the movement and wear would not have corresponded to the movement and wear in any of the cases cited. The results would have been intermediate between those effected by ice moving parallel to the axis of valleys and that moving at right angles to them, as will be readily seen by the application of the principles already stated.

In general, the erosive effect of the ice must have been to deepen the valleys parallel or nearly parallel with its direction of movement. The bottoms of oblique valleys suffered less deepening, while transverse valleys, unless very wide, were not, in general, deepened at all. While, therefore, the ice tended to reduce relief by wearing off the hills, it tended to increase it by deepening some of the valleys. On the whole, it is probable that the surface relief was increased by the erosive action of the ice. But even if the total relief was increased, it is probable that the rugosities of surface were so far obliterated and softened that the topography of the rock surface beneath the drift, as fashioned by ice erosion, is notably less rough than it was before the glacial period. Even the valleys that were deepened were widened as well, and in the process their slopes often became more gentle.

There is another way of estimating the quantitative effects of glacial erosion, namely, by the amount of drift which the ice finally deposited. Were this accurately known, and were the area whence it was derived determinable, somewhat precise conclusions could be reached. Statements concerning the thickness of the drift for the several regions of the State will be made in Part II of this volume. Suffice it here to say that the amount of drift in the State is not such as to warrant exaggerated sides of the effectiveness of glacier erosion *under the average conditions which prevailed in the State* in the glacial period. Certainly three-fourths, and probably nine-tenths, of the drift in the State had its origin within the State; that is, relatively little was brought in from the north. The average depth of drift within the glaciated area, even including the moraine, may be as low as twenty or twenty-five feet, and quite certainly does not exceed forty or fifty feet.

Since the surface was doubtless covered with soil, loose debris, and decayed rock to the depth of several feet when the ice came in, and since the ice brought some material with it from New York, it will be seen that the amount of erosion effected by the ice in the State was not great. The reduction of surface by erosion was, however, notably unequal, and in some places, especially in the Triassic area, it may have been several scores of feet where conditions were most favorable. It is true that some material was carried from the State into New York, across the Palisade ridge. The amount of it, stated in tons, would be very impressive; but if it were all put back on the surface of that part of the State whence it came (the area east of the Hackensack valley) it would probably not raise its surface five feet.

Again, some drift was carried by water south of the ice. Its aggregate amount was small. All that was carried beyond the ice by water, and out of the State by ice, would not materially add to the figures given above.

It is probable that the greatest topographic changes, both relative and absolute, effected by the erosion of the ice in this State, were in the area of the Newark shales and sandstones. Here the long low hills and ridges of sandstone were probably considerably reduced in height, though perhaps not more than the depressions between them. Similar though lesser changes were effected in the Kittatinny and Delaware valleys, where the hills were rubbed down and the depressions deepened. But in the Highlands, and on the Kittatinny and Green Pond ranges, the ice was probably too thin to greatly change the topography. In many places it probably did little more than carry off the loose debris and semi-decayed rock from the surface, and smooth down the minor roughnesses. That this was done is shown by the character of the surface of the rock beneath the drift.

The modifications of topography which result from glaciation are not simply those produced by erosion, but those produced by deposition as well. The effect of deposition on topography will be considered later.

Changes in the nature of the surface of the rock.—There is a change other than topographic in the rock of a glacier's bed which should be mentioned, a change which, like that in topography, is due to abrasion. The removal of the loose debris, and then of the semi-decayed rock, finally brought the bottom of the ice in contact with the solid rock beneath. In general, therefore, the surface of the bed rock, after the passage of the ice, was fresh and smooth, for the ice had worked quite through the upper zone of disintegration. That it often did much more than this, and that it worked effectively on the solid rock below, is demonstrated by the abundance of bowlders of undecayed rock, which must have come from a zone many feet below the surface as it was when the ice began its work. The abundance of this undecayed rock material in the drift, as well as the subdued topography of the rock surfaces of the glaciated territory, is evidence of the efficiency of ice wear.

Locally and exceptionally, the ice overrode the residuary earth which covered the rock, burying it beneath drift. This may be seen, for example, on Jenny Jump mountain. Where this took place the decayed rock was exceptionally thick or the conditions for erosion unfavorable.

The ice also left the surface of the rock which it had overridden more or less generally polished, scratched or grooved. The polishing was the work of the fine material carried, such as clay. The scratches were due to the sand grains and stones carried in the bottom of the moving ice. The grooves were, perhaps, sometimes the work of large bowlders carried by the ice, but probably oftener the result of inequalities in hardness in the rock itself. The softer parts were worn out more, leaving the grooves. Various other markings left by the ice on the bed rock will be more fully considered in another place.

DISTRIBUTION OF THE DRIFT IN THE ICE WHILE IN TRANSIT.

Immediately after acquisition.—As the ice sheet spread from the centers of accumulation, it acquired different kinds and quantities of debris in different classes of regions, and carried it forward in various positions. In some places it invaded territory which was essentially plane; in others that which was slightly undulatory, and in still others that which was distinctly rough. The roughnesses were sometimes of one sort and sometimes of another. For example, when the ice reached the Appalachians it encountered a series of ridges with intervening valleys, both being essentially parallel to the direction of movement. When it advanced into the Adirondacks, it encountered a surface which was rough, but the elevations and depressions had no common trend, and stood in no common relation to the direction of ice movement. In all these situations the gathering of material was affected by the topography.

In a flat country the ice was able to pick up but little material, since there was little which it could get hold of. It is doubtful if much debris is moved along beneath (that is, strictly below the bottom of) the ice, though the movement of the latter would have a tendency to drag or urge along with it the loose material of its bed. If drift were carried forward in such positions, it would be strictly *subglacial* during transit.

If a flat surface were covered with bowlders, they might be incorporated into the bottom of the ice and carried forward in that position. The material gleaned from a surface of gentle relief, as well as much of that from rough surfaces, is likewise carried along in the bottom of the ice. Drift carried in this position is *basal*. For a few feet, or sometimes for many feet above its bottom, the moving ice is *full* of debris. It seems desirable to limit the term *basal drift* to that which is in the bottom layers which are virtually full.

From a surface of greater relief more material was taken. While the material gathered from such a surface was at the bottom of the ice *at the time it was taken*, some of it might find itself above the bottom a little farther on. This may be illustrated by the case of a single hill. In such a case as that represented by Fig. 19 the ice rends debris from the surface. To the

Fig. 19.
Showing how debris gets up into ice.

lee of the hill the ice from either side may close in under that which came over the top, when the debris from the top will be well above the base. If the top of the hill yields much debris and the sides little, the debris from the former may constitute a well-defined layer above the bottom. This is often seen in existing glaciers. If the relief of the surface over which the ice passes is 100 feet, the material which it yielded to the ice would be confined to something less than the lowermost 100 feet of the ice, and if the slopes of the undulations were gentle, the debris would be still more narrowly confined (Fig. 20).

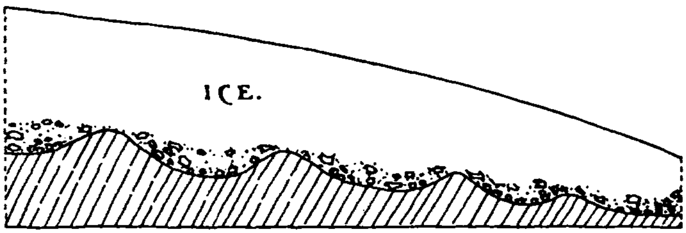


Fig. 20.
Illustrates the same point as figure 19, except that the slopes are gentle and the relief slight.

Where the relief of the surface was great, some of the debris gathered from it by the ice found itself farther above the bottom at a later time, after the ice had passed the elevations (Fig. 21).

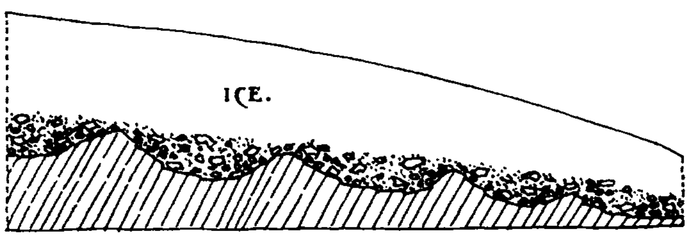


Fig. 21.
Same as 20, except that the relief is greater.

This was especially true where the ice invaded a rough country where the elevations and depressions had an orderless arrangement, or at least an arrangement which was not parallel with the direction of ice movement, and where the ice subsequently came out on a flat surface, or a surface of slight relief. In passing over such regions as the Adirondack mountains, for example, there was abundant opportunity for the ice to acquire material, which, on the lower lands beyond the mountains, would find itself well above the bottom. Drift carried in the ice above the basal portion is *englacial* during transit.

When the ice reached a region such as that of the Appalachians of northwestern New Jersey and Pennsylvania, where the ridges and valleys were approximately parallel to the movement, valley glaciers tended to thrust themselves forward in the depressions between the ridges of hard rock. From these mountains the ice never emerged, and under these conditions the debris gathered by the bottom of the ice was chiefly confined to a basal position, both in the valleys and on the elevations. Wherever the ice passed over isolated elevations in the valleys, such as Pochuck mountain at the north end of the Kittatinny valley, or Jenny Jump mountain at the south, the debris derived from them might later be found as far above the bottom of the ice as the elevations were above their surroundings.

The ice which came into New Jersey had been coming over a region of considerable relief, and might be supposed to have carried a good deal of englacial drift. On the whole, the topography in the State and north of it being considered, more of the drift brought into the State from the north is likely to have been englacial, than of that gathered in the State.

The debris carried on the surface of the ice is *superglacial.* For the acquisition of superglacial drift there was little opportunity, for the ice did not, for the most part, pass through valleys above which there were peaks and cliffs. The ice was deep enough to cover cliffs and peaks, leaving no bare surfaces above from which debris might fall. Such valley glaciers as were developed at the edge of the ice sheet in mountainous regions were short, and the slopes above them were for the most part too gentle to have allowed debris to fall on the ice. If, as seems likely, there were local glaciers in the Adirondacks and other mountains before they were enveloped by the general ice sheet, these glaciers descended from greater altitudes to less. As the main ice sheet invaded such a mountain region, it covered first its lower parts, and when the lower parts were smothered under the general ice cap, and when the upper parts were still above it, glaciers from these upper parts may have descended to the ice sheet below, and may have joined it in such a way as to leave their debris on the top or in the upper part of the ice sheet. Locally, abundant superglacial drift, and englacial drift well up above the bottom, may have originated in this way.

Shifting of debris in the ice.—Superglacial material was liable at any time to fall into crevasses in the ice and become englacial.

Englacial and basal drift also may shift its position, either relatively or absolutely, while in transit. As the ice moved forward it was constantly undergoing waste. The common impression is that the melting was chiefly at the surface, but it is not certain that this was the fact. There was melting at the upper surface throughout the summer season in all the marginal portion of the ice, but there was slower, perhaps very slow melting at the bottom of the ice almost everywhere at all times. Between the two surfaces there was probably slow melting everywhere below the zone of annual change of temperature at all times, and in that zone in summer. In the aggregate, therefore, there was much melting below the upper surface.

If attention be restricted for the moment to the melting of the upper and lower surfaces of the ice, it will be seen that all the melting at the upper surface tended to bring the surface of the ice down to the level of the debris beneath the surface, and that all the melting at the bottom tended to concentrate the debris in transit at the bottom of the ice. By the melting of the ice, therefore, englacial material might become either basal or superglacial. Whether it became superficial or basal would depend on its position with reference to the two surfaces, and on the ratio of surface to basal melting.

There is another way by which englacial or even basal material becomes superglacial. This is by the upturning of the layers of ice (Fig. 22 and Fig. b, Plate XXV), a phenomenon which is

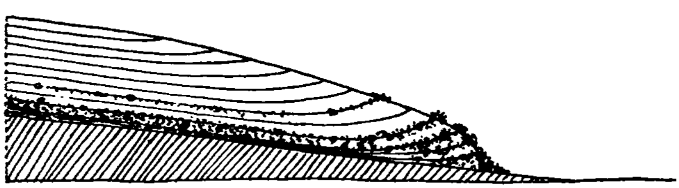


Fig. 22.
Upturning of layers of ice at end of glacier, bringing up of debris.

most conspicuous in North Greenland, and apparently in high latitudes generally. In Greenland the upturning is seen both at the ends and sides of valley glaciers, and at the edge of the ice

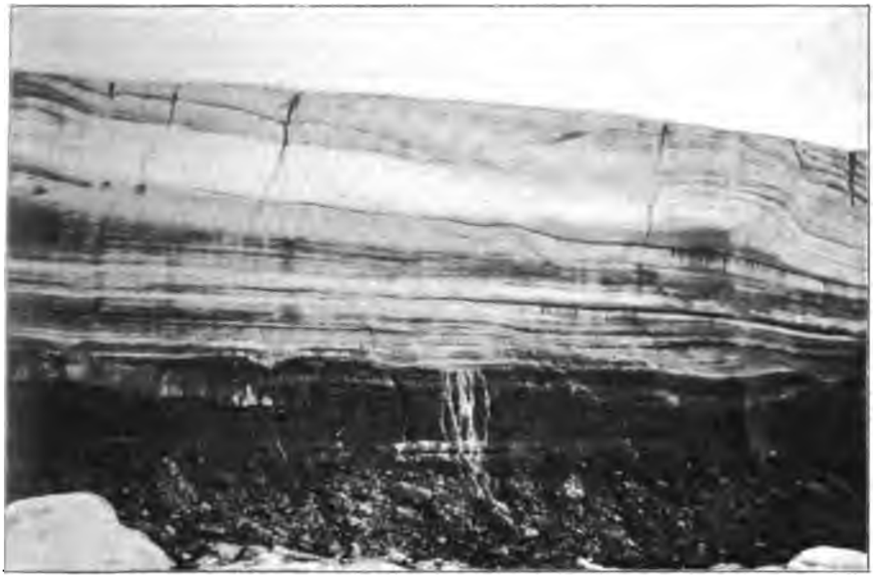


Fig. A.

Side of a North Greenland glacier. The upper part of the ice is nearly free of debris, while the lower part is full of it.

Fig. B.

View of the end of a North Greenland glacier, taken from the side. Shows the upturning of the layers of ice. Olrik's bay.

Fig. A.

A moraine on the ice, the material of which was brought to the surface by the upturning of the layers of ice (See Fig. 6, Plate XXV). North Greenland.

Fig. B.

An isolated heap of debris brought to the surface of the ice by marginal upturning of the layers. North Greenland.

sheet, but is confined strictly to those parts of the ice. Any modifications which it may produce in the distribution of the drift in the ice while it is in transit are therefore confined to the margin of the ice.[1]

That the transfer of debris by this means from below the surface of the ice to the surface is effective, is abundantly illustrated in Greenland, where great ridges of drift (first Fig., Plate XXVI) sometimes lie on the surface close to the edge of the ice sheet, or close to the end of a glacier. That the material has come up from below may often be seen, for the sides of the glaciers are often vertical, presenting perfect sections. It is also shown by the fact that the surface debris in such situations often shows all the marks of basal wear. In two cases seen by the writer there was still further proof, both unique and conclusive, that even *subglacial* material reaches the superglacial position by this process. The cases in point were two glaciers which descended into narrow and shallow bays and moved out on their bottoms. Here the upturning of the layers of ice brought up *shells from the bottom of the bay,* and left them in marginal belts where the upturned layers outcropped. These shells were mingled with other sorts of debris. In one case their quantity could have been measured by some such unit as the wagonload. If this process of upturning were operative during all the stages of the growth of an ice sheet, it will be readily seen that much drift might be brought above a basal position. It is believed, however, that this process is at its best where the edge of the ice is stationary.

Several causes probably conspire to produce this upturning. Where the ice remains stationary for long periods of time, the submarginal accumulation of drift is great and the ice has to mount up over it. In a valley glacier this is most notable at the end, but is not wanting at the sides, for the ice is always moving sideward, in both directions, as well as forward. The accumulation of debris under the sides is less than that under the end, in proportion as the lateral motion from the center is less

[1] For fuller statements concerning this upturning, see Journal of Geology, Vol. IV, 1896, p. 769.

than the forward motion. Again, the mobility of the ice is decreased with decreasing temperature. During the larger part of the year the surface of the ice in Greenland, and in high latitudes generally, is far below the freezing point. During the winter this is true for months at a time, almost without interruption. The result is that the less cold and more mobile ice, which makes up the mass of a glacier, is, during a large part of the time, encased in more resistant ice, which covers end, sides and top. Against this relatively immobile case, the ice of the inside is constantly pushing, and in proportion to the resistance of end and side the layers of ice are made to turn up. At both sides and ends of a glacier the immobility of the encasing ice is increased by the abundant debris. This is, as a rule, in excess at the end, and here the upturning is most conspicuous.

In addition to the considerations which apply to stationary ice fronts in very cold regions, Reid has urged another consideration which applies to all glaciers, which calls for a slight measure of upturning in the dissipator (the part of the glacier where waste exceeds accumulation), the amount increasing toward the end.[1]

Since the tendency of the ice was always to shift the debris which it carried from center to circumference, it is clear that the marginal parts of the ice were on the whole much more heavily loaded than the central parts of the field at all stages.

THE DEPOSITION OF THE DRIFT.

After the ice of a glacier or of a continental ice sheet has melted, all the debris which it at any time carried has been deposited. Different parts of it were deposited in different places and under different conditions. Some of it was deposited while the edge of the ice was advancing, some of it while the edge was stationary, and some of it while the edge was receding. Some of it was deposited while the ice was in vigorous motion, and some of it after it had become sluggish or even stagnant.

---

[1] Journal of Geology, Vol. IV, 1896.

Some of it was deposited at the edge of the ice, and some far back under its thicker parts. In some places the water to which the melting of the ice gave rise played an important role, while in others its influence was nil. All of these conditions and relations need to be taken into account in studying the distribution and disposition of the drift.

It seems best to consider first the deposition of drift beneath the body of the ice back from the margin, and next the deposition beneath its marginal part.

DEPOSITION BENEATH THE BODY OF THE ICE.

While the motion was vigorous.—The debris gathered by the ice in its progress was not always carried forward to its edge. Local conditions of topography often caused its deposition before it had journeyed far. Thus in the lee of a cliff or in a steep-sided valley across which the ice moved, debris would be likely to accumulate as soon as the ice passed over it, and would tend to continue to accumulate until the local topography was changed by the deposition. Deposits in such positions are sometimes known as *crag* and *tail* deposits.

Again, the ice in some places and under some conditions gathered a load heavier than it could carry in other places and under other conditions. Beyond the point of overloading, deposition was always likely to take place.

Debris in the ice decreases its mobility. With a heavy basal load there is a constant tendency for the lower part of the ice to become stationary, while the cleaner part above moves on over it. In such situations it would often be difficult to say where the bottom of the glacier is, even were perfect sections accessible. The motion becomes less and less toward the bottom, and the bottom part looks quite as much like debris with ice in it, as like ice with debris in it. That is, the bottom part might be called ice-conglomerate, the ice simply occupying the interstices between the bowlders and smaller stones. Such material the ice above tends to drag along with it, but it is resistant, and moves most grudgingly and sometimes not at all. When it has ceased to move it must be said to have been deposited. Deposition of this sort would be likely to take place in the lee of a rough region which yielded abundant debris to the ice. The drift so deposited was not necessarily deposited permanently. At a later time, when the ice over the same place was thicker, or when its load was less, some of the material once deposited might be moved on for lesser or greater distances. The extremely local character of much of the drift, for probably 50 per cent. of it was not moved ten miles, is conclusive evidence that much of the debris which the ice once got hold of, was not carried far. Much even of that which was not moved far was probably deposited, removed and re-deposited many times in the course of its history.

This phase of subglacial deposition was going on beneath the ice so long as there was forward motion, whether its edge was advancing, stationary or receding. On the whole, the ice, especially toward its marginal parts, had a heavier load while its edge was advancing than at other times, and so far forth subglacial deposition would have been favored during this stage rather than during others, but the strength of forward movement was probably less while the edge of the ice was receding, and the weaker movement would have favored subglacial deposition at this stage.

Along some radii of the ice field the amount of debris deposited beneath the ice remote from the edge was doubtless much greater than along others, both because the amount of drift gathered by the ice along some lines was greater than along others, and because topographic conditions favored deposition in some situations rather than others. The material which was deposited and overridden by the ice was thoroughly compacted by the pressure to which it had been subjected, and must have assumed such characterictics as pressure would develop.

All the drift deposited from the bottom of the advancing, the advanced, and the retreating ice constitutes the *ground moraine* of the ice sheet. To the material of the ground moraine the name *till* or sometimes *subglacial till,* is often applied. Where it is made up largely of clay and bowlders the term *bowlder clay* is applicable. The great body of subglacial till was basal in position while it was in transit. It became subglacial on deposition.

The great body of unstratified drift constitutes the ground moraine of the continental ice sheet.

DEPOSITION BENEATH THE EDGE OF THE ICE.

In considering the deposits made beneath the edge of an ice sheet, account must be taken of the two or three stages in the history of an ice sheet, namely, the stage of its growth, the stage of its maximum expansion, and the stage of its decline.

When the ice was advancing.—The marginal part of a growing ice sheet was probably heavily loaded all the time, wherever conditions were favorable for the acquisition of load, and beneath the margin deposition was probably always in progress. Deposits made in this position were liable to be picked up and moved on again when the ice in the same region became thicker. Much drift deposited under the edge of the advancing ice was probably picked up, re-shifted, and re-deposited many times in the course of its history. When the ice sheet had reached its maximum expansion, therefore, there had probably been lodged beneath it a considerable amount of drift, which, at the outset at least, was deposited beneath the margin of the ice. It is to be remarked that submarginal deposits made during the advance of the ice were continually overridden, and so assumed the character of subglacial accumulations made beneath the body of the ice.

When the edge was stationary.—If when the ice reached its maximum advance its edge remained stationary for any considerable period of time, the results of submarginal deposition would be changed, though the process itself remained the same. When the edge of the ice becomes stationary, it means that the advance of the ice is balanced by the waste at its edge. Forward movement therefore continues, though the position of the edge does not change. There is now, as before, a constant tendency to carry the drift to the edge of the ice, but no farther. The result is continued submarginal accumulation in the same place. The thickness of this accumulation will depend on the rate of advance, on the amount of debris which the ice brings, and on the length of time the edge remains stationary. The thick belts of submarginal drift which accumulate under stationary margins are known as *terminal moraines.* Their distinctive features will be considered later (p. 96). The edge of the ice in New Jersey remained stationary near the position of its maximum advance for some time, for it made a very considerable terminal moraine which has an irregular course between Perth Amboy and Belvidere.

In case the retreating stage of the ice succeeded the advancing, without an intermediate stage when the edge was stationary, a terminal moraine would not have been developed. The presence or absence of a terminal moraine therefore gives some data for an understanding of the history of a given ice sheet.

While the edge of the ice was receding.—During the advancing stage of the ice sheet the deposits made at the edge of the ice were soon overridden, and more or less disturbed; during the next stage, that of stationary edge, much debris was brought to the edge of the ice, and there left in a submarginal belt; but in the retreating stage of the ice, the marginal deposits are neither overridden as in the first case, nor accumulated in a definite belt, as in the second. If the ice is melted back 500 feet while it advances 400 feet, the drift carried by the 500 feet of ice which has been melted has been left on the 100 feet from which the ice has disappeared. Since in the retreat of the ice the zone of submarginal deposition passes over all parts of the area which had been covered by the ice, the submarginal deposits of the retreating stage of the ice are widespread; but for reasons already given, the amount of drift left on the surface becomes less and less, as the margin of the ice field approaches its center.

When the ice became stagnant.—One phase of loss of motion has already been noted, but it is another phase to which reference is here made. During the dissipation of an ice sheet considerable masses of ice appear to have lost, or to have essentially lost, their motion. This happened especially in mountainous tracts, where the ice in the depressions became isolated, when that on the surrounding elevations was melted. Such isolated bodies of ice doubtless preserved their motion, in many cases at least, for a time. But when they became small, or when the local topography was unfavorable to motion, they became stagnant, and all the drift they held was let down on the surface as the ice melted.

DEPOSITS FROM THE SURFACE OF THE ICE.

While the edge was advancing.—In so far as there was debris on the surface of the ice during its advance, there was deposition from this position. It is to be remembered that even the advancing ice is constantly being melted back at the edge, and that its advance is simply the excess of forward motion over marginal waste. If ice moves forward 500 feet per year, while it is melted back 400 feet, it makes a net advance of 100 feet. But the 400 feet of ice at the front last year is gone, and the superglacial material which it carried has been deposited where the ice which carried it melted, that is, *on ground now occupied by the ice.* The ice has already worked it over in part, and buried it in part. When the ice has advanced still farther it will have covered the particular superglacial drift here referred to more deeply, and will have modified it more completely. At no considerable distance from the margin the larger part of it would probably have lost its superglacial character and have been converted into subglacial drift.

While the edge was stationary.—To the submarginal accumulation of drift made while the edge of the ice was stationary there would be added such material as was carried on the surface of the ice. As the ice melted out from beneath it, it would be dropped. If the edge of the ice were absolutely stationary, the deposition of superglacial material from the stationary edge would have been at the very edge of the ice, that is, at the very outer edge of submarginal accumulation. If the edge of the ice fluctuated a little from season to season, or from year to year, as would be likely to be the case, this superglacial material would become thoroughly commingled with the basal.

While the edge of the ice was retreating.—The superglacial drift deposited during the advance of the ice was subsequently overridden and made subglacial, but that which was deposited during the retreat of the ice was not subject to further modification by the ice. The ice did not override or disturb or compact it. The superglacial drift deposited during the retreat of an ice sheet should therefore remain on the surface of the ground moraine after the ice had disappeared.

To drift which has been supposed to have this origin the name "upper till" has sometimes been applied. It is doubtful, however, if at this distance of time, "upper till" in this sense has generally been successfully differentiated from the "lower till" or ground moraine. The weathering of the surface since the departure of the ice would have done much to obliterate the original differences, even had they been great, and the study of the Greenland ice sheet and its drift seems to indicate that the chief differences between the superficial and basal material at the outset were differences in compactness, a difference which frosts, roots and boring animals would soon obliterate, and, less commonly, differences in composition, a difference not so easily effaced.

In general it seems certain that the amount of superglacial material left by the ice must have been slight, for all the superglacial material deposited during the advancing stage of the ice became subglacial after deposition. The complete absence of surface drift from the ice sheets of to-day, except at their extreme edges—usually a small fraction of a mile—tends to check all hypotheses which refer much of our drift to a superglacial origin. At a few points in northern New Jersey drift which may have been superglacial has been observed. It is distinguished from the drift which is regarded as subglacial by differences of composition, being made up more largely of debris from distant sources. Even in this case, however, it is quite as rational to suppose (1) that it was carried in the ice as on it, and (2) that in the final melting of the ice it is as likely to have reached its bottom as its top before being finally deposited.

ENGLACIAL DEPOSITS.

Since all or nearly all englacial material becomes subglacial or superglacial before it leaves the ice, the deposition of englacial drift need not be separately discussed.

EFFECTS OF UNEQUAL AND OSCILLATING ADVANCE OR RETREAT.

If during the advance of the ice the edge made a temporary halt in any position, there would have been a tendency to form a submarginal moraine where the halt took place. Subsequent advance of the ice would tend to destroy whatever moraine was made, though it might not completely obliterate it. If during the retreat of the ice its edge made temporary halts, there was likewise a tendency to form submarginal moraines, and in this case they would not have been overridden. Marginal moraines so formed are moraines of recession. Stretches of recessional moraines are found at several places in New Jersey, the largest and best marked being between Ogdensburg and Culvers Gap, in Sussex county. The edge of the ice might have halted in one place and not at another at the same time. Moraines of recession are therefore sometimes not traceable for long distances. If during the stage of extreme advance the edge of the ice oscillated back and forth within narrow limits, the zone of submarginal accumulation would be somewhat widened and perhaps made irregular.

SUMMARY.

When the ice has melted from a region which it once covered, it leaves a mantle of drift, chiefly ground moraine. The ground moraine may or may not be bordered by a terminal moraine, and there may or may not be moraines of recession. The ground moraine will have a variable thickness, dependent on topography, on the character of the formations contributing to the drift, on rate of retreat, on the amount of load the ice carried, and on various other conditions. Ridge and hill crests are likely to have little, capacious valleys through which the ice moved are likely to have little, but the valleys which were not parallel to the movement of the ice, and flats which the ice reached after passing regions which had yielded much debris, are likely to be heavily covered. On the whole, especially if the ice remained long in its advanced position, the tendency is for the drift to be thicker toward its outer edge, and thinner toward its center, and thicker on low lands than on high, when the two sorts of surface are closely associated. Whatever the effect of ice erosion in changing the amount of relief, the effect of deposition was to decrease it. Locally, however, the deposits were so disposed as to develop notable roughness of surface.

CHARACTERISTICS OF GROUND AND TERMINAL MORAINES.

All these types of morainal accumulations are found within the borders of New Jersey. The ground moraine or till (see map Plate XXVIII in pocket) is, as in all great drift sheets, the most extensive. Its southern limit is the terminal moraine which marks the stationary position of the edge of the last ice epoch which affected the State.

The ground moraine.—The ground moraine covers much of the area which the ice overspread, but is wanting, or nearly wanting, at various points especially on hill and ridge crests and on steep slopes. Its thickness is as variable as the thickness of the drift.

The general composition of the ground moraine has already been given in the description of unstratified drift (p.15). It may here be added that its composition changes from point to point, especially where traced from one formation to another. Where the ice had been moving for a long time over one formation, the till which it carried, and finally deposited on that formation, was composed largely of debris derived from it. Thus the till of the Highlands is composed chiefly of debris from the gneiss, schist, &c., found there. The till of the Kittatinny valley is made up principally of shale, slate, &c., from the underlying Hudson River formation, and subordinately of materials from the lesser formations of the valley. The till of the Triassic plain is made up largely of material worn by the ice from the sandstone and shale of that area.

Followed across the border of one formation to another, the character of the drift changes, debris from the new formation at once appearing in the till, though at first it may be in slight quantity. Thus in passing from the Highlands into the Kittatinny valley, the composition of the drift changes promptly as the underlying formations change. In passing from the Highlands east to the Triassic area the change is less sudden, for here the movement of the ice was such as to carry material from the Highlands out to the plain. But even here the red material of the plain appears in the drift, at least subordinately, but a short distance from the Highlands. The influence of the underlying rock on the drift is also shown at the many junctions of trap and sandstone.

The topography of the ground moraine does not call for extended notice at this point. In our State, the ground moraine is in general too thin to greatly change the topography of the rock surface below it. It has to some extent, though to a limited extent only, smoothed the rough surface of the rock by filling up the minor and irregular depressions.

In many parts of the drift-covered part of the United States, especially where the relief of the rock is less, the ground moraine has a distinctive topography of its own. The eastern portion of the area shown on Plate IX gives an idea of one phase of ground moraine topography, where the rock beneath has little effect on the shape of the surface. Even in New Jersey, where the relief of the rock is great, the till is locally so thick as to have a dis-

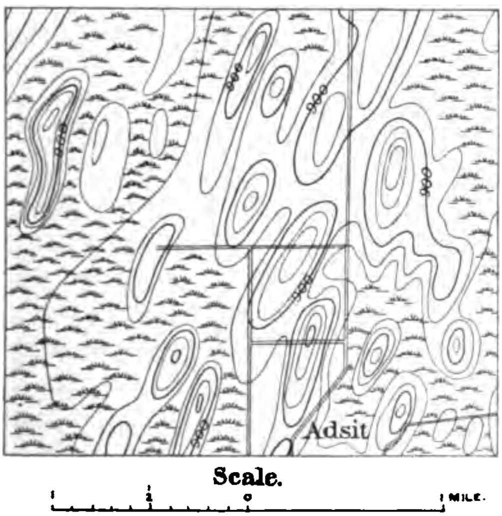


Fig. 23.

Drumlins in contour, near Sun Prairie, Wis.

tinctive topography of its own. Thus in some parts of the State, notably in the vicinity of Newark, there are considerable hills of till elongate in the direction of ice movement. Their longer axes are two to four times the shorter, and their slopes are moderately steep. Such till hills are known as *drumlins* (Fig. 23). There are few well-formed drumlins in the State, though there are several till hills (*drumloids*) which approach this form (Fig. 24.)

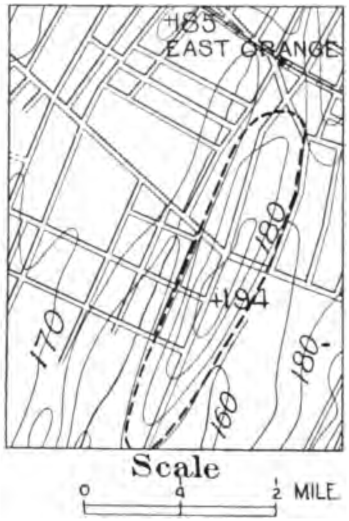


Fig. 24.

A New Jersey drumlin in contour, near Orange. The dotted line surrounds the drumlin.

Drumlins and drumloids are the result of the local accumulation or concentration of till beneath, or at the base of, moving ice. Their shapes are the shapes which sub-ice accumulations, made while the ice was still moving, would be likely to take, for they are the shapes which the ice could most easily override. Their relation to the ice has been likened, with something of truth, to that of sand bars to streams[1]. Where their forms are imperfect it may be either because the ice did not shape them well (*immature drumlins*)[2] or because, in the retreat of the ice, deposits were finally left on them which obscured their earlier and well-shaped surfaces.

Drumlins are probably formed where the ice has somewhat more load than it can carry, but where it is not heavily overloaded. In the latter case the drift is deposited in a more irregular fashion without definite shaping.

[1] Davis. Am. Jour. Sci., Vol. 28, 1884.
[2] Chamberlin. Third Annual Report U. S. Geol. Survey.

THE TERMINAL MORAINE.

Its course.—The terminal moraine of the ice sheet which left the main body of drift is generally well marked, and has already become well known. It is the thick belt of drift which extends from Perth Amboy to Belvidere by way of Metuchen, Netherwood, Summit, Morristown, Denville, Dover, Budd's Lake and Hackettstown. From Belvidere it extends in a general westerly direction far into the interior. From Perth Amboy it extends eastward across Staten and Long Islands. Its more southerly latitude in the eastern part of the State is the result of the lower surface over which the ice of this part of the State advanced. Its abrupt turn to the north, traced from Metuchen to Summit, is the effect of First and Second mountains, which retarded the ice. Its more westerly course, between Summit and Morristown, follows from the lower land which it here crosses. Its northerly course, between Morristown and Denville, reflects the influence of the Highlands, and its westward or slightly southwestward course, west of Drakesville, is in keeping with the slight decline of surface in that direction. Its most southerly point in the western part of the State is opposite the end of the Kittatinny valley. It most northerly position is between Denville and Rustic, in the lee of the Green Pond mountain belt.

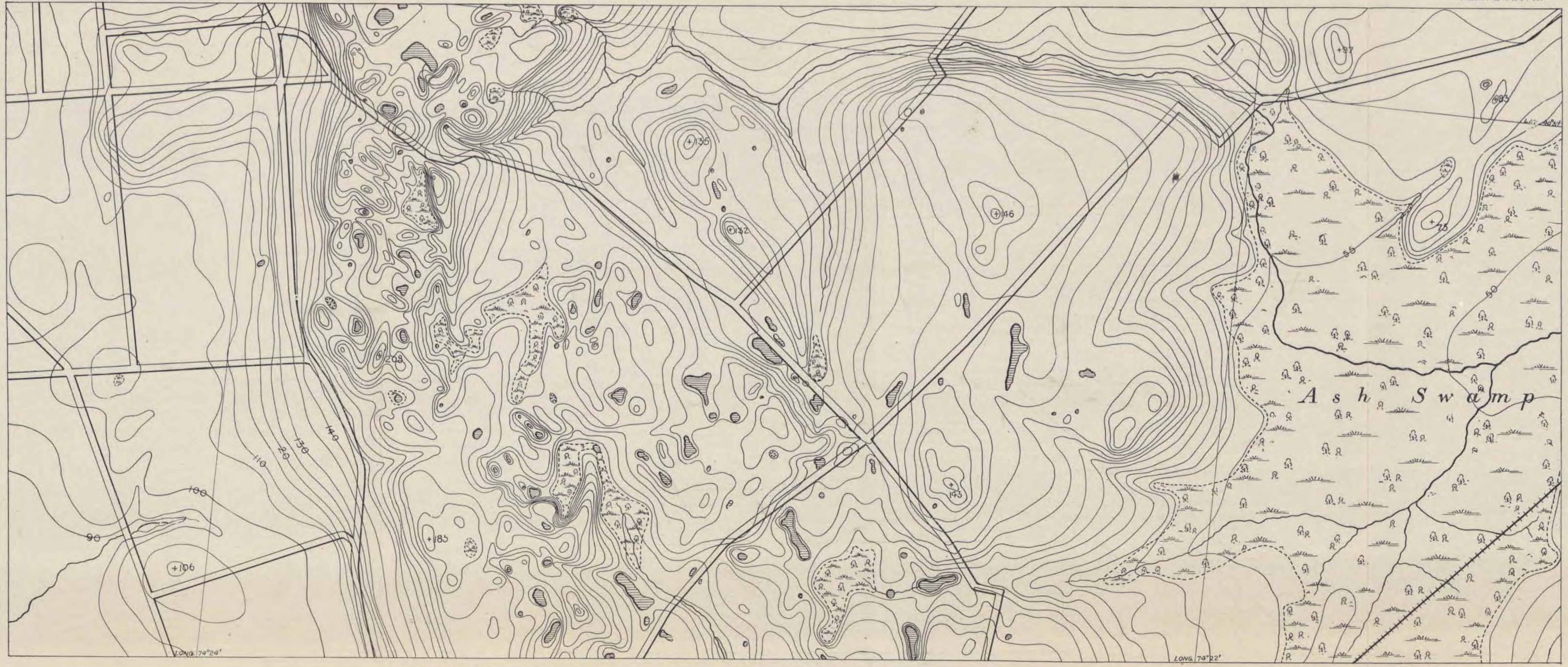
Width and thickness.—The width of the moraine varies from half a mile to something more than two miles, its average width being about a mile. The thickness of the drift in the moraine is more than 200 feet at some points, though its average is probably less than half that amount.

The terminal moraine as a topographic feature.—The thickness of the drift of the terminal moraine is so great that where the relief of the underlying rock is not great, as from Perth Amboy to Scotch Plains, and from Stanley to Morristown, it is itself an important topographic feature. Thus between Fords Corner and Scotch Plains the moraine is a conspicuous topographic feature most of the way, especially as seen from its outer (southwestern) face (see Plate IX, p. 12). Between Fords Corner and Metuchen it rises locally as much as 140 feet above the plain southwest of it. It is equally conspicuous east of Plainfield, where its juxtaposition to the plain on which that city stands makes it all the more striking.

The moraine is also a prominent topographic feature between Stanley and Morristown (Plate X), where it constitutes a part of the broad ridge on which Morristown and Madison are built. Here the moraine is quite as conspicuous from its inner (northeastern) side as from the other. Over most of the Highlands, the height of the moraine is not so great but that it is dwarfed as a topographic feature by the great relief of that region. Where it crosses considerable valleys, such as that of the Musconetcong just above Hackettstown, it seems conspicuous when compared with the valley plain to the south of it, but inconspicuous when compared with the high hills of rock between which the valley lies.

In general a terminal moraine is not a pronounced ridge with narrow crest and even slopes. Rather it is a belt of thick drift. Since its width is often a mile or two, and since its height is often no more than twenty-five to fifty feet, it is clear that its ridge-like character is not always pronounced. Its slopes are indeed so gentle in many places that the moraine as a whole is unobtrusive. It becomes altogether inconsequential as a topographic feature when its height is notably less than the relief of the country which it crosses.

Topography of the terminal moraine.—Even where the terminal moraine is not, as a ridge, an important topographic feature, it has peculiarities of surface which are distinctive, and these peculiarities are characteristic of terminal moraines in general. Its surface is often characterized by hillocks and hollows, or by interrupted ridges and troughs, following one another in rapid succession, and without order in their arrangement. The hollows and troughs are often without outlets, and are frequently marked by marshes, ponds and lakes wherever the material constituting their bottoms is sufficiently impervious to retain the water falling and draining into them (see Plate XXVII and Fig. 25). The shape and abundance of round and roundish hills, and of short and more or less serpentine ridges, often closely huddled together, have locally given rise to such descriptive names as the "knobs," "short hills," etc. The topography about



SKETCH OF MORAINE BETWEEN PLAINFIELD AND ASH SWAMP, UNION COUNTY.

FEET 600 5 4 3 2 1 0 600 1200 1800 2400 FEET
METRES 100 50 0 100 200 300 400 500 600 700 800 900 METRES

The moraine is the rough belt near the west edge of the map.

Short Hills is an illustration. But it is to be kept in mind that it is the association of the "knobs" or "short hills" with the "kettles," and not either feature alone, which is especially characteristic of terminal moraine topography.

The "knobs" vary greatly in size. From mounds but a few feet across, and elevated only enough to make them observable, they range up to considerable hills, a quarter of a mile or more in diameter and a hundred feet or so in height. If they attain such heights while their bases are small, their slopes may be very steep. Not rarely they are about as steep as the loose material of which they are composed will lie.

Fig. 25.

Sketch of moraine topography, near Hackettstown.

The "kettles" are the counterparts of the elevations. They may be a few feet, or many rods, or even furlongs in diameter. They may be so shallow that the sagging at the center is scarcely observable or they may be scores of feet in depth. Where the diameter is short and the depth great the kettles are steep-sided. If steep-sided depressions are closely associated with abrupt hillocks, the topography may become notably rough, and the total relief within a few rods may be nearly equal to the total height of the moraine above its surroundings. Where the topography of a moraine is rough, as east of Plainfield (Plate XXVII) its position is likely to be marked by a multitude of marshes, ponds and lakes.

The topography of the terminal moraine is often strongly developed, even where the moraine as a whole does not appear as a distinct ridge. It is not to be understood, however, that this peculiar topography always affects terminal moraines, or that it is strictly confined to them. The elevations and depressions of the moraine may grade from strength to weakness, and locally even disappear, while features closely simulating those characteristic of terminal moraines are sometimes found in other parts of the drift, and, very rarely, altogether outside it.

Development of terminal moraine topography.—The manner in which the peculiar topography of terminal moraines was developed is worthy of note. The first condition for the development of a terminal moraine is that the edge of the ice remain approximately stationary in position for a time sufficiently long for the submarginal accumulation to become sensibly thicker than the drift within or without. If the margin of the ice remained constant in position over a region of uniform topography during the formation of a terminal moraine, and if it bore equal amounts of material at all points along the margin, the moraine would be developed with a good deal of regularity. It would be about as high and about as wide at one point as at any other. If the margin remained constant in position, but bore unequal amounts of material at different points, the moraine would be unequally developed. Where there was much material it would be higher and probably wider than where there was but little. Irregularity of height and width would thus be introduced by virtue of the unequal amounts of material at different parts of the ice edge.

If, instead of remaining stationary, the margin of the ice moved alternately backward and forward within narrow limits, the effect would have been to spread the moraine by widening the zone of submarginal accumulation. If during the oscillation of the margin it remained stationary either during or after its minor recessions or advances, or both, subordinate ridges would be developed, marking the positions of the several halts. If the edge of the ice remained parallel to itself as it advanced and receded, these subordinate ridges would be parallel, and each a miniature terminal moraine.

If while the edge of the ice was carrying unequal amounts of material, its edge oscillated unevenly, with halts, that is, if recessions and advances were unequal at different points, the several subordinate ridges formed at the various positions of halt would not be parallel, and would not be equal in height or width, and no one of the ridges would be uniform in size throughout its course. Adjacent ridges might touch each other at some points and be separate from each other by considerable intervals at others. Let 1,1, 2,2, and 3,3, Fig. 26, represent three successive

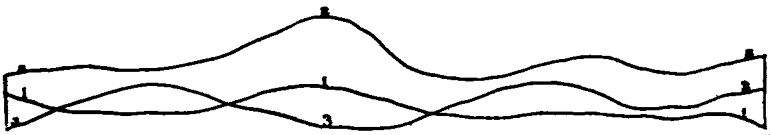


Fig. 26.
Three successive positions of the ice front.

positions of the oscillating edge of the ice, and let it be supposed that the edge stood in each of these positions successively, long enough to make something of a marginal ridge of drift. The result would be a series of interlocking moraine ridges of variable heights and widths (Fig. 27). If instead of three stands of the

Fig. 27.
Three morainic ridges of unequal height and unequal width corresponding with the successive positions represented by the preceding figure.

ice, there were more, the result would be a "tangle" of moraine ridges, with depressions of various shapes and sizes between (Fig. 28). In the development of this tangle it is to be remembered that those which were overridden after their formation

Fig. 28.
Six morainic ridges made during six successive halts of the oscillating edge of the ice.

suffered partial reduction, and sometimes perhaps complete destruction. In this way, it is believed, many of the characteristic hills and hollows of terminal moraines arose.

If at the same time that the ice margin was oscillating backward and forward at unequal rates, making frequent halts, and carrying unequal amounts of material at different parts of its margin, the topography of the country over which the marginal deposits were made was variable, a further element of complexity was introduced in the marginal moraine belt. If marginal masses of ice were detached from the main body during temporary recessions of the ice, they might subsequently be buried by deposits of drift. Later, when these buried ice blocks melted, the drift above them would sink into the space which they had occupied, and a kettle-like depression, marking the site of the buried ice block, would result. Thus would be added another element of complexity in the topography of the terminal moraine.

Mention has already been made of the fact that such surface debris as there may have been on the ice while the edge was stationary, was continually being dropped (dumped) at the edge of the ice. If the edge of the ice oscillated, this drift would have been scattered over a zone as wide as the zone of oscillation. Wherever and whenever the edge remained perfectly stationary, there was a tendency for the surface debris to be dumped at the edge along a definite line. Locally where the debris dumped was mainly bowlders, a wall-like ridge was developed in such a position. In Germany such a bowlder-wall is known as an *Endmoräne*, or *Geschiebewall*. Such bowlder-walls are nowhere well developed in New Jersey and have been reported in but few spots in North America. There are, however, narrow marginal ridges at some points, as north of Hackettstown (see geological map of Hackettstown region, Plate XLV a.), which somewhat resemble the *Endmoräne* of Germany.

Still another process, not until recently taken into account, may have entered into the development of terminal moraine topography. Mention has already been made of the fact that the recent study of Greenland glaciers and ice sheets[1] has shown that

[1] Chamberlin, Journal of Geology, Vols. II and III, 1894-1895.
Salisbury, Journal of Geology, Vol. IV, 1896.

the layers of ice at the ends of the former and the edges of the latter have a general, and often notable, tendency, to turn up (Fig. 22 and Plate XXV). This upward turning of the layers unquestionably involves upward movement of the ice along the planes between them, for drift is brought up to the surface from the bed (p. 81). In some places the amount of drift thus brought to the surface, and now resting upon it, is considerable. Plate XXIX represents the edge of the main ice cap at a point east of Bowdoin bay, North Greenland, on which there is a well-developed and unusually regular surface moraine, the material of which was brought to the surface in the manner indicated. Several such moraines, concentric with one another, are sometimes seen. These surface moraines may be very irregular in height and width, as shown by Plate XXVI.

In one locality on the main ice cap east of Gable glacier (east of Bowdoin bay), five ridges or surface moraines were to be seen in the summer of 1895. These were roughly concentric and but a few rods from each other. They varied much in width and height. Where massive, they had severally spread so as to merge into one another, and where slight, they had preserved their individuality. Their irregularities in height were so marked that a single moraine often appeared more like a lineal succession of hillocks than a ridge. Where the more massive parts merged, the resulting topography was strikingly like that of hummocky terminal moraines, the relief of which is not great in our own latitude. The same thing was seen south of North Star bay, Wolstenholme sound, latitude 76° 35′. Here eight distinct and more or less concentric moraines were seen at one locality, all within a belt half a mile wide, and all within that distance of the edge of the ice sheet. Here again the topography of the surface drift was identical in kind with that of terminal moraines. The several ridges, irregular both in height and in width, frequently spread to the extent of merging. Between their crests there were left circular or elongate depressions, comparable in shape, and dimensions to the elevations themselves. In two cases the depressions contained water, one of which was a lakelet not less than a fourth of a mile in greatest diameter.

The apparent roughness of these surface moraines in Greenland was partly due to ice. The moraines as they appeared on the ice were really ridges and mounds of ice, heavily coated with debris. The ridges came into existence because of the drift, which shielded the ice beneath from the sun's rays. Had the surface of the ice been melted down evenly, the surface of the drift would have been irregular, for its thickness was unequal, but it would have been very much less irregular than it appeared.

Superficial debris of this sort might ultimately be let down on the surface of the submarginal terminal moraine, helping to emphasize its roughness. Deposits comparable in topography to those on the ice, but much less rough, were seen at one point in Greenland near the locality last mentioned. They gave the impression of having been left on the surface as the ice melted out from beneath them.

Topographic relations of the terminal moraine.—The vertical range of the moraine between Perth Amboy and the Delaware is about 1200 feet. Its lowest point is near sea level at the former place, where the moraine reaches its most southerly point. Its highest point is a little southeast of Lake Hopatcong, about where it reaches its most northerly latitude.

Constitution of terminal moraines.—From the conditions of their development, it will be seen that terminal moraines must be made up of materials closely similar to those of the ground moraine. In keeping with this generalization, sections of terminal moraines show material indistinguishable from that of the ground moraine adjacent. Nevertheless, there are often certain recognizable differences between the two types of moraines. In general the following hold: 1) Terminal moraines have a larger proportion of bowlders; 2) the proportion of bowlders of distant origin is somewhat greater in terminal moraines, and especially on their surfaces; 3) there is more stratified drift associated with terminal moraines; and 4) there are more frequent alternations (more mixing) of stratified and unstratified drift in the terminal moraines.

Most of these characteristics are easily explained. The bowlders which are carried far are most commonly carried somewhat above the bottom of the ice. In this position they stood the best chance of getting to the edge of the ice. In the terminal moraine, therefore, and especially at its surface, they tended to concentration. It is true that as the ice receded over the ground moraine there was everywhere the same tendency to leave on the surface bowlders of distant origin, carried in the ice above its base, but since the ice stood less long in other positions than where the terminal moraines were developed, the concentration was less. Perhaps the same conditions help to account for the larger proportion of bowlders, for bowlders carried at the bottom were being continually crushed and ground (worn out), while those a little higher up in the ice, being subject to less friction, were carried farther before being reduced. The greater proportion of stratified drift in the terminal moraine is the result of the greater efficiency in this position of the water which arose from the melting of the ice. The ice probably melted faster here than elsewhere, and some of the water which came from the melting of the ice remote from its margin found its way to the edge, either over, or through, or beneath the ice. On the whole, therefore, there was more water in operation at the margin of the ice than elsewhere.

Some of these points are well illustrated in New Jersey. In many places, however, the surface of the terminal moraine has been so modified by grading and by the removal of bowlders that some of its original features have been obscured or destroyed altogether. In general, the surface bowlders have been removed to such an extent that their greater abundance on the terminal moraine than on the ground moraine is not striking. Their original abundance on the terminal moraine is sometimes to be inferred from the abundance of stone walls (fences) and stone piles in that position as compared with the ground moraine adjacent. The greater proportion of widely transported bowlders on the terminal moraine is often shown by the constitution of the bowlder walls and stone piles. Illustrations of both these points may be seen along the terminal moraine from Stanley to Morristown, and over the area of ground moraine to the northeast. Many of the more conspicuous knolls and ridges of the terminal moraine are of sand and gravel. This is sometimes seen from the nature of the soil and vegetation on them, but more surely from the sections which roads, railways and other gradings have made. The same sections show the frequent alternations of stratified and unstratified drift. Illustrations of these points are found between Summit and Morris Plains, and again in the valley of the Pequest, between Townsbury and Belvidere.

THE LIFTING POWER OF THE ICE.

From what has been said, it is clear that the ice sometimes moves up considerable slopes. Where this is the case it may carry debris from lower to higher levels. Many instances of this kind are known both in New Jersey and elsewhere. Two or three examples may be added. A fine perched bowlder of Newark sandstone (Plate XXXV) lies on the ridge east of Englewood, more than 200 feet above the highest outcrop of this sandstone along the base of the ridge in this latitude. The sandstone on the west slope may extend up above its highest outcrop, but it falls far short of the altitude of the bowlder. Again, bowlders of the peculiar elæolite syenite near Beemerville are found in positions such as show that they were carried up at least 100 feet above their source (see p. 106). The most remarkable illustration of the lifting power of the ice which the State affords is found on Jenny Jump mountain in Warren county. On the southeast side of this mountain there is a limestone bowlder 50 x 25 x 15 feet, estimated to weigh 2,000 tons, which came from the northwest side of the mountain at least two miles from its present position, and which must have been carried up over the mountain 300 feet to 400 feet above its source, and down again on the other side.

MEANS OF DETERMINING THE DIRECTION OF ICE MOVEMENT.

Incidental reference has been made in the preceding pages to the direction of ice movement in northern New Jersey, and something has been said concerning the means by which this direction is known. This question may now be looked into in greater detail.

There are several ways of determining the direction in which ice moved after it has disappeared. Its approximate course can sometimes be determined 1) by the shape of the drift hills, especially drumlins (p. 91), which it left, or by the shape of the rock hills which it has overridden (p. 69); 2) by the direction from which the drift material came; and 3) by the direction of the striæ which the ice left on the rock over which it passed. There are other criteria of local application. Thus the course of a terminal moraine tells the direction of ice movement near it, for the movement was approximately at right angles to the moraine.

The shapes of drift hills.—Of the three principal criteria mentioned above, not all are universally applicable. In some regions there are no drumlins or other drift hills significant of the direction of ice movement. In most parts of New Jersey drumlins are wanting, so that were our knowledge of the direction of ice movement dependent on them, it would be meagre indeed. The few drumlins of the State (in Essex county about the Oranges and Franklin, and in Sussex county east of Franklin Furnace) have their longer diameters parallel to the direction of ice movement; but the fact of this relationship was not established by the shape of the drumlins, but by the striæ, for it is only because the long axes of the drumlins are parallel to the striæ where they occur, that the correspondence between their longer axes and the direction of ice movement is known. Eskers (p. 136) are usually parallel to the direction of movement, but the correspondence is not exact. Furthermore, eskers are, on the whole, rare, not only in New Jersey, but in most glaciated regions. The correspondence between their courses and the direction of ice movement, so far as such correspondence exists, is established, as in the case of drumlins, only by a comparison of their directions with that of the striæ of the same regions. Belts of kames (p. 116), where such exist, are likely to be elongate in a direction parallel to the edge of the ice, and, therefore, normal to the direction of movement. Such a belt of kames extends, with some interruption, from Waverly to Springfield, in Union county, and probably marks the position of the edge of the ice at one stage of its retreat. There are, however, belts of kames elongate in directions parallel to that of ice movement, as in some of the valleys of Sussex county. Taken by itself, therefore, the position of a kame belt is not a reliable means of determining the direction of ice movement.

The shapes of rock hills.—The shapes of the rock hills overridden by the ice are perhaps somewhat more reliable for determining the direction of movement where they are free from drift or so slightly covered as not to conceal their shapes. The side of a hill against which the ice first impinges, that is the "stoss" (or struck) side, is more effectively worn than the opposite side (see Fig. 16). But to show the direction of ice movement with approximate accuracy, the rock hills must not only be nearly free from drift, but they must be sufficiently isolated to have been normally affected by the ice and sufficiently numerous and so distributed as to cover the field of study adequately. Safe conclusions can be drawn only from the shapes of many such hills, since any one might have had peculiarities of form before it was glaciated. Furthermore, as in the preceding cases, the fact that rock hills are most worn on their stoss sides was first established by the study of the striæ.

From the shapes of drift, or glaciated rock hills, therefore, the inference concerning the direction of movement is finally based on striæ, but after the relations between their forms and striæ have been established, certain drift and rock hills are locally available for determining the direction of ice movement. In some localities they are the most available means for such determination.

Constitution of the drift.—With the second mode of determining the direction of the ice the case is somewhat better. If the constitution of the drift of a given locality is known, and if the formations of rock in all directions from that locality are also known, it is safe to infer the direction of ice movement, for it is hardly probable that the series of formations which could give origin to the drift of any locality lie in more than one general direction from that locality. Thus the drift of New Jersey could not have been made by ice moving from the south to the north, because the formations which contributed to it, aside from those on which it lies, are not to the south of it. No more could it have been made by ice moving from the west or from the east, for the same reasons. The constitution of the drift, taken in connection with the distribution of the contributing formations, therefore, shows the direction whence drift came. This criterion may sometimes be depended on even for great detail, as the phenomena of various parts of New Jersey show. Thus bowlders from the Palisade ridge were not carried due south, but rather to the southeast, as shown by their occurrence on the east side of the Hudson river, and even across East river on Long Island, in longitudes considerably east of the easternmost part of the Palisade ridge. The ice therefore moved east of south. The same conclusion concerning the direction of ice movement in this region is reached from the fact that abundant debris from the Newark formation west of the Palisade ridge was carried up its western slope and even over its crest to the east side of the Hudson and East rivers.

Again, bowlders from the peculiar and distinctive Green Pond and Bearfort mountain conglomerates are easily used for determining the direction of ice movement. In general these bowlders were moved to the southward or even a little west of south, but not a few appear in the drift as far east as the Hackensack valley and south to Raritan bay. Since the formation of these mountains is continued northward into New York, some of the bowlders in the drift were probably derived from the more northerly parts of the range. In proportion as the source whence a given sort of bowlder may have come is large, the determination lacks accuracy.

The peculiar igneous rock (elæolite syenite) near Beemerville, Sussex county, affords another illustration of the determination of the direction of movement by the distribution of material. The outcrops of this rock occur at intervals along a narrow belt less than two miles long. With such limited outcrops the distribution of bowlders allows of the somewhat accurate determination of the direction of movement, which was here a little west of south (Fig. 29). The distribution of the easily identified bowlders of the Oneida and Medina formations of the Kittatinny range are easily used in the same way, though the wide extent of their outcrop makes them less serviceable than the elæolite syenite for exact determination.

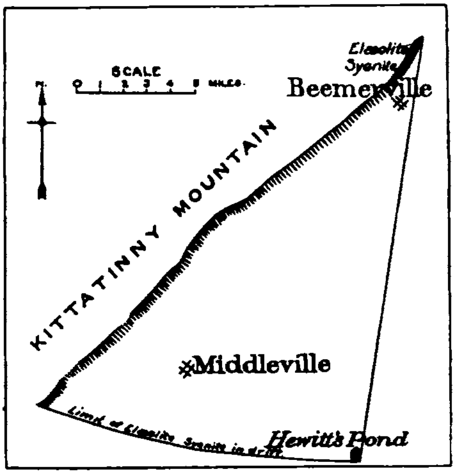


Fig. 29.
Fan of Elæolite syenite bowlders.

Striæ.—In determining the exact direction of ice movement, the greatest reliance is placed on striæ and similar markings. Glacial striæ available for this purpose[1] are nothing more nor less than the scratches on the bed rock, inflicted by the sand, the pebbles and the larger stones carried in the bottom of the ice. Glacial grooves have the same significance as striæ so far as the point under consideration is concerned.

In its simplest form a glacial scratch is simply a line on the surface of the rock. A simple line would not tell, between two, the direction of motion. If a scratch points south, it also points north. If it points S. 40° W., it also points N. 40° E. Between these two directions it is needful to decide. For decision, reliance might be placed on the direction of transport of material, but in general the rock surface itself will tell. If a lime-

[1] Striæ on the stones of the drift are of course worthless for this purpose.

stone surface be affected by a nodule of chert which rises somewhat above the general level, it will often be found that one side is worn notably more than the other. This side of greater wear is the stoss side. Or suppose the rock surface to be affected by an abrupt depression (Fig. 30) perhaps no more than an inch

Fig. 30.
Illustrates how a slight depression in the rock surface may be used to determine the direction of the ice movement.

in diameter and a fraction of an inch deep. The application of the same principle shows the side against which the ice advanced. Slight elevations or depressions adequate for this purpose may be found on almost any surface of striated rock if the exposure be so much as a square yard in extent.

In general the striæ of the United States are arranged in a series of divergent systems, illustrated by Fig. 31. Plate XVII shows that the ice sheet was, at its edge, made up of a series of great lobes, from the axes of which the ice diverged to right and left. This peculiar and systematic arrangement is less well illustrated in the east than in the Mississippi basin.

To the use of the striæ in determining the direction of ice movements there are certain limitations which must not be lost sight of. In the first place, it is to be noted that the ice of any ice sheet was in operation on the surface for a long time; that it was continually making striæ and then rubbing them out, to leave others in their place; and that the striæ which we now see are those which were *finally* left. The striæ which are finally left may have been made at any stage of the ice sheet's history. Some of them were probably made in the early stages of the ice invasion, promptly covered by drift, and never afterward disturbed; others were probably made when the ice was at its maximum, at which time they were buried, and so preserved; while still others were probably made during the final recession of the ice. It goes without saying that striæ may have been left at all intermediate stages in the history of an ice sheet.

It is to be noted in the second place that the direction of movement in any given locality may not have been the same at successive stages of glaciation. Local topographic features were

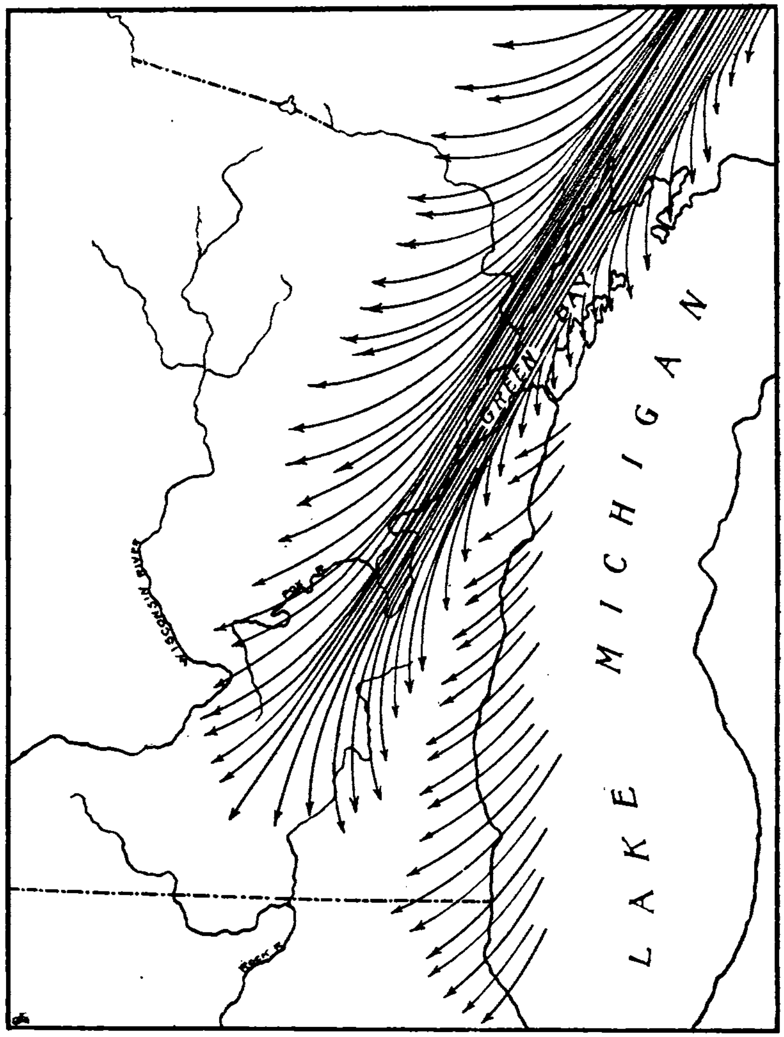


Fig. 31.
A divergent system of striæ.

much more effective in controlling the direction of motion when the ice was thin than when it was thick. The ice must have been thin in each situation at least twice in the history of an ice sheet, once while the ice was developing, and once when it was disappearing. Between these stages it was relatively thick. Furthermore, the dynamic center of movement in an ice sheet may have changed in the course of its history (p. 40), involving change in direction of movement irrespective of local topography. Striæ made in an early or in a late stage of an ice sheet's history may fall far short of recording its movement as a whole. This would be particularly true if more than one ice sheet had been operative in the region concerned.

In this connection the distribution of debris may come in to give information which the striæ do not afford. For example, bowlders from the Kittatinny mountain are distributed much farther eastward than they should be if the ice always moved in the direction of the existing striæ. The same is true of the bowlders from the Green Pond mountain. In both these cases it is to be remembered that the corresponding formations lie farther east in New York than in New Jersey, and that the bowlders which seem to be too far east may have come from these more northerly outcrops; but making due allowance for the distribution of the outcrops, it seems probable that the ice, at some time earlier than that when the existing striæ were chiefly made, moved over these mountains in a direction more easterly than that indicated by the striæ. In the case of the bowlders from the Kittatinny mountain, many of them lie far south of the terminal moraine, and are a constituent of the older sheet of glacial drift, of which there are remnants. This lends plausibility to the view that the ice of the earlier epoch moved in a southeasterly direction, and that the bowlders which it spread about were re-handled and re-distributed by the ice of the last glacial epoch. The distribution of the Green Pond mountain conglomerate bowlders is in harmony with this suggestion.

Relations of this sort, where the distribution of debris is not in harmony with the direction of observed striæ, are by no means rare in the great area of drift in America and Europe, and where this is the case the material of the drift may give information concerning the direction of movement which the striæ fail to record.

Another difficulty in determining the direction of ice movement from striæ arises from the fact that they are sometimes inharmonious among themselves. A given surface may be affected by two or more sets of striæ which cross each other at some notable angle. At the south end of the Clinton reservoir, for example, there are striæ pointing S. 45° W., S. 30° W., S. 10° W., and S. 2° W. Again, a surface may be affected by striæ pointing in all directions between certain limits, and the discordance may be great. For example, the striæ may range from S. 20° W. to S. 45° W. Where two discordant sets of striæ affect the same surface, they were made at different times, the first set failing to be erased when the second was made. They show that the ice moved in different directions at different times, but do not record the directions at intermediate stages. Where there are striæ in all or in various directions between given extremes, as between S. 20° W. and S. 45° W., we have at least a partial record of the change from one direction to another. These changes may be connected either with the thickening and thinning of the ice, with changes in the center of movement, or with changes in local topography, due to glacial abrasion.

Crossing striæ are not to be taken as proof of separate ice invasions, though it is conceivable that striæ developed during one glaciation might be preserved here and there through both the interglacial and through the succeeding glacial epoch.

Discordant striæ may be found on surfaces near each other, though the striæ on each surface may be in harmony among themselves. Discordances of this sort are often the result of local topography. The striæ on opposite sides of the stoss end of a hill, for example, are likely to show that the ice had a tendency to pass around the hill on either side. Discordant striæ are common in New Jersey and in all regions of similar relief.

Striæ are not universal in the glaciated area. They failed of development in some places, and they have since been destroyed in others. They are most common on rock of no more than moderate hardness, which has been continuously covered with drift since the ice disappeared. On exposed rock they have commonly been obliterated by weathering.

Situations in which striæ occur.—The striæ of New Jersey are found in many situations. Their occurrence is sometimes such as to show that the ice was capable, under proper conditions, of adapting itself to trivial irregularities of surface. They are found on plane surfaces; on gently and steeply inclined surfaces, pointing up slope; on gently and steeply inclined surfaces, pointing down slope; on vertical faces; on rounded angles, between horizontal and vertical surfaces; on vertical surfaces with horizontal curvature; and in glacial grooves. Striæ in these various positions are demonstrative of a great degree of pliancy on the part of the ice.

Other glacial marks.[1]—Aside from the striæ and grooves, which are only striæ on a large scale, there are various other markings. There are marks which are best designated as *bruises,* and still others which are known as *chatter marks,* but they are of such exceptional occurrence that they are only mentioned in this connection.

[1] For an exhaustive discussion of glacial markings, see Chamberlin, 7th Ann. Rept. U. S. Geol. Surv.

CHAPTER IV.

THE WORK OF WATER ACCOMPANYING THE ICE.

CONTENTS.

Since all the ice of the continental glacier which was not evaporated was ultimately converted into water, it is evident that water must have had an important influence on the drift.

Much of the water from the ice ran off as surface streams, and these streams carried much drift beyond the place where the ice left it. Some of the stream-borne drift was carried to the sea, and some of it was left on land. With the latter only have we here to do.

The deposits made by glacial waters are often called *modified drift,* to indicate that they are not, like the rest of the drift, deposited by the ice itself. The principal difference between the drift deposited by water and that deposited by ice is that the former is assorted, or stratified.

In tracing the history of the deposits of stratified drift it is still more important than in the case of the unstratified, to keep in mind the three principal stages of an ice sheet's history, namely, stage of advance, the stage of stationary edge and the stage of retreat.

GLACIAL DRAINAGE.

The body of an ice sheet during any glacial period is probably melting more or less at some horizons all the time, and at all horizons some of the time. Most of the water which is produced at the surface during the summer sinks beneath it. Some of it may congeal before it sinks far, but much of it reaches the bottom of the ice without refreezing. It is probable that melting is much more nearly continuous in the body of a moving ice sheet than at its surface, and that some of the water thus produced sinks to the bottom of the ice without refreezing. At the base of the ice, so long as it is in movement, there is doubtless more or less melting, due both to friction and to the heat received by conduction from the earth below. Thus in the ice and under the ice there must have been more or less water in motion throughout essentially all the history of an ice sheet.

If it be safe to base conclusions on the phenomena of existing glaciers, it may be assumed that the waters beneath the ice, and to a less extent the waters in the ice, organized themselves to a greater or less degree into streams. For longer or shorter distances these streams flowed in the ice or beneath it. Ultimately they escaped from its edge. The subglacial streams doubtless flowed, in part, in the valleys which affected the land surface beneath the ice, but they were probably not all in such positions, and their courses were probably subject to continual change.

The courses of well-defined subglacial streams were tunnels. The bases of the tunnels were of rock or drift, while the sides and tops were of ice. It will be seen, therefore, that their courses need not have corresponded with the courses of the valleys beneath the ice. They may sometimes have followed lines more or less independent of topography, much as water may be forced over elevations in closed tubes. It is not to be inferred, however, that the subglacial streams were altogether independent of the sub-ice topography. The tunnels in which the water ran probably had too many leaks to allow the water to be forced up over great elevations. This, at least, must have been the case where the ice was thin or affected by crevasses. Under such circumstances the topography of the land surface must have been the controlling element in determining the course of the subglacial drainage.

When the streams issued from beneath the ice the conditions of flow were more or less radically changed, and from their point of issue they followed the usual laws governing river flow. If the streams entered standing water as they issued from the ice, and this was true where the ice edge reached the sea or a lake, the standing water modified the results which the flowing waters would otherwise have produced.

As they now exist, the deposits of stratified drift made at the edge of the ice while the latter was stationary, present the simplest, and at the same time, most sharply defined phenomena, and are therefore considered first.

DEPOSITS MADE BY EXTRAGLACIAL WATERS AT THE STATIONARY EDGE OF THE ICE.

The deposits made by the water at the time of the maximum extension of the ice and during its final retreat, were never disturbed by subsequent glacier action. So far as not destroyed by subsequent erosion, they still retain the form and structure which they had at the outset. Such drift deposits, because they lie at the surface, and because they are more or less distinct topographically as well as structurally, are better known than the stratified drift of other stages of an ice sheet's history.

AT THE EDGE OF ICE, ON LAND.

Kames.—If the subglacial streams flowed under "head," the pressure was relieved when they escaped from the ice. With this relief, there was diminution of velocity. With the diminution of velocity, deposition of load would be likely to take place. Since these changes would be likely to occur at the immediate edge of the ice, one class of stratified drift deposits would be made in this position, in immediate contact with the edge of the ice, and their form would be influenced by it. At the stationary margin of an ice sheet, therefore, at the time of its maximum advance, ice and water must have coöperated to bring into existence considerable quantities of stratified drift.

The edge of the ice was probably ragged, as the ends of glaciers are to-day, and as the waters issued from beneath it, they must frequently have left considerable quantities of such debris as they were carrying, against its irregular margin, and in its reëntrant angles and marginal crevasses. When the ice against which this debris was first lodged melted, the marginal accumulations of gravel and sand often assumed the form of hillocks, or, less commonly, of short ridges of stratified gravel and sand. Such hills and ridges are known as *kames.*[1]

So far as the superficial streams which flowed to the edge of the ice carried debris, this was subject to deposition as the streams descended from the ice. Such drift tended to increase the body of marginal stratified drift derived from subglacial sources. Several or many kames are sometimes associated, giving rise to groups and areas of kames. The topography of kame areas is very similar to that of terminal moraines. Kames are

[1] Kames are referred to and more or less fully described in many publications on the drift. In the earlier literature they were not separated from eskers. For references, see footnote under eskers, p. 136.

indeed often associated with terminal and recessional moraines, a relation which emphasizes the fact of their marginal origin.

The stratification of the sand and gravel of the kames was often irregular at the outset, and was subject to disturbance with every movement of the edge of the ice, so long as the ice and kames were in contact. The effects of the crowding of the ice are often distinctly seen in the disturbed and crumpled condition of the lines of stratification of the gravel and sand. The stratification was subject to still further disturbance when the ice melted, for in many cases the kame material was deposited against steep faces of the ice.

Much of the material entering into the make up of kames had not been carried far, and was, therefore, not well water-worn. Not rarely its constituents retain glacial striæ. These characteristics of the material kames gave rise to the descriptive designation "hillocks of angular gravel and disturbed stratification."[1]

Kames abound in New Jersey. They occur along many parts of the terminal moraine, and constitute many of its sharpest knolls. They are also present in the moraines of recession, and at numerous other points, many of which mark halting places of the edge of the ice during its retreat. Striking examples occur near Demarest, Highwood, north of New Orange (four miles west-northwest of Elizabeth), a mile east-northeast of Rivervale (Fig. 32), two miles west-northwest of Oradell, and near Hamburg (see plates XXX and XXXI).

The highest of the group of kames near Hamburg (just south of west of the village) is more than 100 feet high, and is in immediate proximity to a depression, the bottom of which is 127 feet below the top of the kame. The kames in Bergen county are generally not so high, but are conspicuous in their surroundings. Most of those mentioned both in this county and in Union have something of a morainic habit. This is conspicuously true of those near Rivervale. This group of kames gave rise to the name ***kame moraine.***[2]

---

[1] Chamberlin, Am. Jour. Sci., Vol. XXVII, 1884, p. 378.
[2] Report of the State Geologist of New Jersey for 1892, p. 93.

The kames of the State may be grouped into three classes, which at their best are somewhat distinct, though between them there are all gradations. Kames of the first class, which may be called *moraine kames,* have the topography, the relations, and

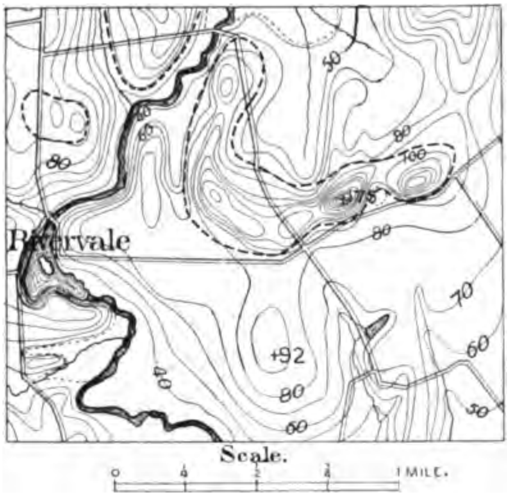


Fig. 32.
Rivervale kames. Dotted lines surround the kames.

something of the constitution of terminal moraines. They differ from terminal moraines primarily in being in groups rather than in long continuous belts, and in being more largely of stratified drift. Bowlders are often abundant on their surfaces. They were formed in the position of terminal moraines, and have the same general significance. To this class belong the most conspicuous kames of the State, including most of those mentioned above. The second class of kames occur in areas or groups, less likely to have a linear arrangement. They are less high, their topography less pronouncedly moraine-like, their material less heterogeneous and more clearly stratified. Their material was probably deposited a little in advance of the active edge of the ice, but on ground which was still encumbered with ice, the melting of which gave rise to many of the irregularities of the present surface. The third class of kames includes individual hillocks of stratified drift.

EXPLANATION OF PLATES

XXX and XXXI.

Plate XXX is a contour map embracing the Hamburg kames and their surroundin[g]. The conspicuous hills are the kames.

Plate XXXI shows the surface geology of the area shown on Plate XXX.

Large and small, the kames of the State are to be numbered by scores and hundreds. Small ones are far more numerous than large ones.

Kame terraces.—Another phase of stratified drift, known as kame terraces, finds abundant illustration in the State. Kame terraces are like kames in that their material was deposited by water at the edge of the ice.

In mountainous regions, where the friction of movement was great, it sometimes happened that considerable masses of ice became stagnant during the dissolution of the ice sheet. After surface-melting had proceeded so far as to bring the upper surface of the ice below the crests of the inter-valley ridges, allowing them to project through the ice, great bodies of ice still occupied the valleys. In some cases, this ice in the valleys doubtless retained movement after the ridges were laid bare, in which case it constituted valley glaciers. Ultimately some of the valley ice lost its motion, but even after it became stagnant, it exerted an

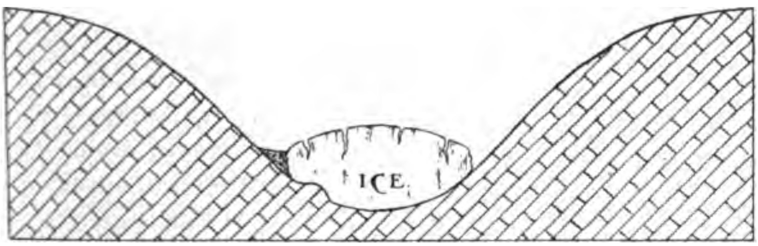


Fig. 33.

Cross-section of a valley with stagnant ice in its bottom, illustrating deposition of gravel as described in text. A stream has flowed down one side of the valley between the ice and the rock face, and has deposited gravel and sand between it and the irregular face of the ice.

important, though passive influence in determining the position of stratified drift deposits, and the forms which they assumed.

Suppose a mass of stagnant valley ice, lying near the edge of the ice sheet, but beyond its main body. The melting ice to the north discharged its waters along the lowest accessible lines. These lines, under the conditons assumed, were the valleys, but not the bottoms of the valleys, as they now exist. The bottoms of the valleys were occupied by the ice, as indicated in Figure 33.

Under these conditions the ice did not rest snugly against the slopes on either hand, for, warmed by the sun, the slopes melted back the ice, leaving miniature valleys between the rock slope and the edge of the ice, as represented in the figure. The junction of the ice and the bluff would, therefore, be the position along which such glacial drainage as found its way through the valley would be likely to flow. Streams might flow down one or both sides. Along their courses they would deposit more or less of the gravel and sand they were transporting. After the ice had melted, these deposits of stratified drift constituted a sort of constructive terrace against the valley slope.

The edges of these stagnant ice masses against which the deposits of sand and gravel were made were irregular. The deposits were limited on one side by the irregular ice face, and the forms they assumed were the exact counterparts of the irregularities of the ice. After the ice melted, the slope of the terrace would retain some of the irregularities impressed on it by the ice, but many, if not most of them, would have been lost, as the gravel and sand assumed slopes of equilibrium after the ice melted. In assuming these new slopes, there must have been extensive slumping, giving rise to other irregularities in place of those destroyed. Terraces formed in this way would have as their unique feature hummocky kame-like slopes, distinguishing them sharply from terraces formed in the usual way.

The deposition of gravel against the stagnant ice might go so far as to bury considerable parts of the sides of the ice. When the ice melted there would be unequal settling of the gravel which overlay it. This also would give rise to irregularities of surface on the valleyward face of the terrace.

The irregularities of slope produced in these ways is often striking. Standing on one side of the valley and looking across to the opposite terrace face, the latter may be seen to be marked by few or many depressions, hummocks, ridges, etc., a part or all of which may be gentle or abrupt; that is, the face of the terrace, in its general topography, closely resembles the topography of a terminal moraine, or of a group of kames (Plate XXXII).

Kame terrace topography. The water shown at the left is Drakes pond, near Newton.

Such terraces constitute a type and deserve a special name. They have been called ***kame terraces***,[1] a name which is appropriate both because of the topography of their slopes and their mode of origin. A kame terrace, then, is a terrace of sand and gravel, deposited by a glacial stream between valley ice (generally stagnant) and the rock slope of the valley. More or less isolated kames are sometimes associated with kame terraces.

If drainage came down both sides of such a valley, kame terraces would be developed on both sides (Fig. 34). If it came

Fig. 34.
Diagrammatic section of a valley containing kame terraces.

down on one side only, the terrace deposits would be confined to that side (Fig. 35). The ice might be so disposed as to

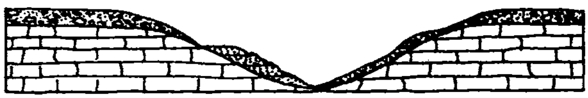


Fig. 35.
Kame terrace on the left side of a valley, and till on the other.

allow of continuous deposition along either side, or of interrupted deposition only. Kame terraces may, therefore, have been discontinuous at the outset. The irregularities of the ice might also give the stream at its side an unequal gradient. There might have been rapids and falls along its course, and as a result the surface slope of the terraces might have been interrupted at the time of their development. These and other irregularities of drainage gave the kame terraces different heights at different points, and unusually frequent alternations of coarse and fine material.

Where a mass of stagnant valley-ice was affected by gaping crevasses, leading from the edge of the ice toward its center, they would be likely to be filled with sand and gravel. After the ice had melted, the filling of such crevasses would stand out as ridges,

[1] Ann. Rept. of the State Geologist for 1893, p. 156.

wide toward the valley bluff and narrower toward the cent of the valley, just as the crevasse was. The present slopes such a crevasse-ridge were assumed after the ice melted, a have essentially the angle at which the loose material will li The great embarkment of stratified drift which lies athwart tl valley at Ogdensburg (Plate XXXIII) is believed to have be formed in this way.

Since the valley bottom was occupied by the ice it would protected from deposition at the stage represented by Fig. 3 If the ice endured longer than the glacial drainage through t valley, the deposits made by the drainage would be confined the sides of the valley, at a greater or less height above its bo tom, their exact position on the slope depending on the volu of the ice at the time of deposition. With the melting of t ice, the deposits were made at successively lower levels, and glacial drainage through the valley continued after the disa pearance of the ice, the bottom of the valley would be aggrad and the deposits of stratified drift would not be limited to t sides of the valley above the bottom.

Kame terraces are developed on a large scale in New Jerse They occur along most of the valleys of the Appalachian provinc and appear to be the normal thing in regions of topography con parable to that of northwestern New Jersey.[1] They are mo conspicuous in Sussex county. Good examples occur in the va leys of Flatbrook, Paulinskill, Papakating creek and the Wallkil and in Vernon valley. Farther east in the Highlands they occu in the Pequannock and Rockaway valleys. East of the Higl lands the topography is not generally such as to favor their pro nounced development, but deposits of this class are well develope between First and Second mountain between Verona and Ceda Grove, in the valley of the Ramapo, and less distinctly at numer ous other places.

BEYOND THE EDGE OF THE ICE, ON LAND.

Valley trains.—As the waters flowed out from the ice, deposit of stratified drift were made beyond its edge. The form

[1] Details concerning the kame terraces of these localities will be given i the second part of this report.

THE DRIFT EMBANKMENT AT OGDENSBURG

assumed by such deposits are various, and depended on various conditions. Where the waters issuing from the ice found themselves in valleys, and where they possessed sufficient load and not too great velocity, they made deposits in the valleys, developing fluvial plains of gravel and sand, which often extended far beyond the ice. Such fluvial plains of gravel and sand constitute the *valley trains*[1] which extend beyond the unstratified glacial drift in many of the valleys of the United States. They are found especially in the valleys leading out from the stouter terminal moraines of late glacial age, a relation which shows that they are deposits made by water beyond a stationary ice margin. Valley trains have all the characteristics of alluvial plains, built by rapid waters carrying heavy loads of detritus. Now and then their surfaces present slight variations from planeness, but they are minor. Such elevations or depressions as affect these surfaces are generally more or less elongate in a direction corresponding to the axis of the valley. Like all plains of similar origin they decline gradually, and with diminishing gradient, down stream. They are of coarser material near their sources, and of finer material at a distance from them. Such stratified drift constitutes a distinct topographic as well as genetic type.

The building up of a valley bottom by deposition is called *aggradation*. The surface of the valley plain thus developed is the *aggradation plain*. Its slope is down stream, and its gradient is higher where the material is coarse, and lower where it is fine. It follows that the gradient is highest and the material coarsest

Fig. 36.
Profile of a valley train.

at the head of the valley train, where it joins the moraine. The profile of the valley train and its relation to the moraine is shown in Fig. 36, which at the same time gives some suggestion of the constitution of the train.

[1] For fuller definition and illustration of valley trains, see Chamberlin, 3d Ann. Report U. S. Geol. Surv., p. 302; Journal of Geology, Vol. I, p. 534. Salisbury, Report of the State Geologist of New Jersey, 1892, pp. 102-105.

The aggradation of the valley below the ice is the result of the excess of load carried by the stream. The excess of load causes the stream to deposit in its channel, the coarse material being deposited first and the finer later. The result is the more rapid aggradation of the valley and with coarse material near the ice, and its slower aggradation with finer material below. Presently the channel becomes too small to hold the water, part of which then breaks out on one side or the other into new channels. The several channels thus produced are aggraded by the waters flowing through them, and the waters again break their bounds, finding new channels, which in turn are aggraded and abandoned. The depositing stream then gives off *distributaries,* and as the distributaries themselves break up into minor streams, some of

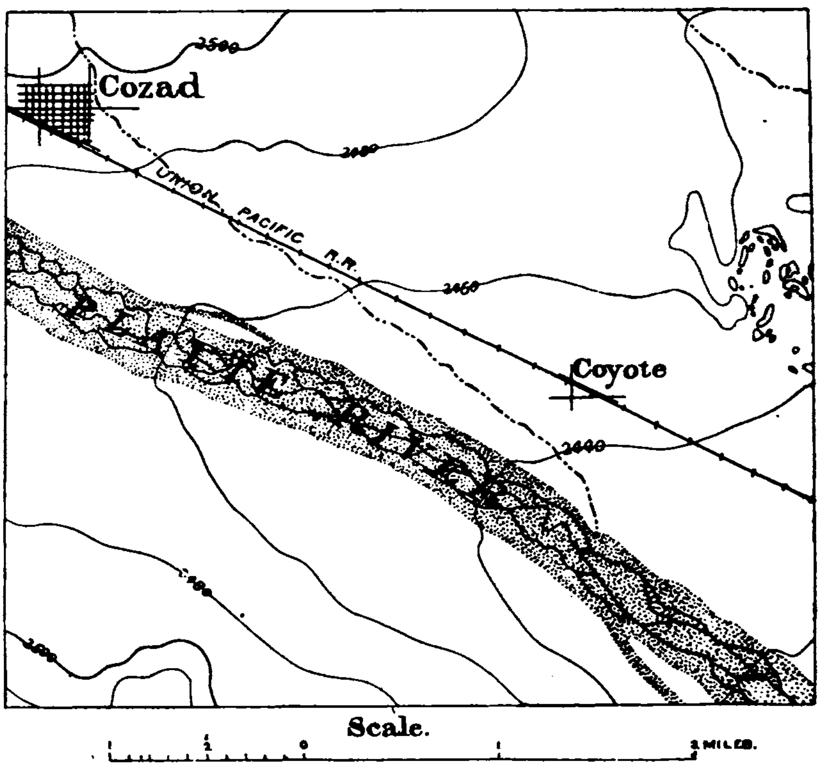


Fig. 37.

Aggradation plain of Platte River, Neb.

the minor streams again unite. The result is that when a stream is actively depositing it is broken up into a multitude of anastomosing streams which are constantly changing. This condition of things is illustrated by numerous streams issuing from glaciers in valleys where the gradient is not steep. It is also illustrated by all streams which are actively depositing, whether glacial or not (Fig. 37).

The result of the above process is the building up of the bottom of the valley. The more it is built up, the wider the valley plain becomes, for the valley walls are, as a rule, farther apart at any level than at any lower one. With the edge of the ice remaining constant in position for a sufficiently long period of time, such a valley train as is suggested in Fig. 9 is the result.

As the ice retreated from any given position, the stream issuing from it tended to aggrade their valleys, but no distinct aggradation plain resulted, except below the places where the edge remained constant in position for some considerable period of time. In the valleys below recessional moraines, plains similar to those below the terminal moraine, may be developed.

It follows from the above that the disposition of valley trains in valleys north of the terminal moraine may be made to throw much light on the history of the recession of the edge of the ice. Thus if the stratified drift of the valley above the terminal moraine have the surface slope shown in Fig. 38, it clearly means

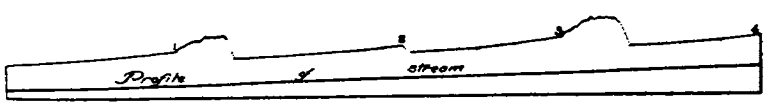


Fig. 38.

Valley train in longitudinal section from terminal moraine north through region of successive belts of deposition.

that after the ice withdrew from the terminal moraine, 1, it halted at the position 2 long enough for a valley train, with a distinctly developed aggradational slope, to be developed, below 2. The ice did not stay at 2 long enough for the lower end of this aggradation plain to be built up to the level of that just below 1. Similarly the ice, after retreating to 3, halted again, and another valley train was developed between that point and 2, but its lower end was not built up to the level of the upper end of the train heading at 2.

In the northwestern part of the State several halting places of the ice can be distinguished by the study of the successive aggradation plains in the valleys, on the principle illustrated by Fig. 38.

After a valley train has been developed, and after glacial drainage has ceased to flow through the valley in which it lies, a part or all of the material which has been deposited may be removed. When a part only has been removed, the remainder may constitute terraces (Fig. 10, p. 14). Terraces of this sort are unlike kame terraces, both in the manner of their origin and in the configuration of their slope.

Valley trains are not extensively developed in New Jersey. There was a notable one down the Delaware from the crossing of the moraine below Belvidere, extending down to Trenton, but much of it has since been carried away by the river. There was a lesser valley train down the Musconetcong from the moraine at Hackettstown. The valleys of the Black, and of the North and South Branches of the Raritan received glacial waters, but for reasons which will appear later, did not develop notable valley trains. There are also numerous small valley trains heading in the recessional moraines, or in other positions where the edge of the ice halted in its retreat. They will be mentioned in Part II.

Moraine plains.—Where the subglacial streams did not occupy subglacial valleys, they did not always find valleys at hand when they issued from the ice. Under such circumstances, each heavily loaded stream coming out from beneath the ice tended to develop a plain of stratified material (a sort of alluvial fan), near its point of issue. Where several such streams came out from beneath the ice near one another for a considerable period of time, their several plains, or fans, were likely to become continuous by lateral growth. Such border plains of stratified drift differ from valley trains particularly (1) in being much less elongate in the direction of the drainage; (2) in being much more extended parallel to the margin of the ice; and (3) in not being confined to valleys. Such plains stood an especially good chance of development where the edge of the ice remained constant for a considerable period of time, for it was under such conditions that the issuing waters had opportunity to do much work.

Thus arose the type of stratified drift variously known as *overwash plains, outwash plains, morainic plains,* and *morainic aprons*[1]. These plains sometimes have a width of several miles. Like the valley trains, they are topographically and genetically distinct, and their relations are well known.

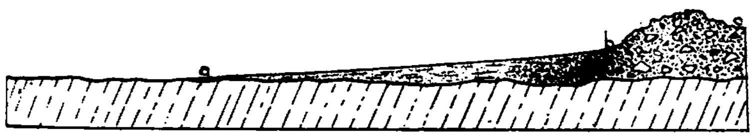


Fig. 39.
Profile of morainic plain.

There is but a single normal overwash or outwash plain in the State, namely, that at Plainfield (Plate IX). The great plain of sand and gravel bordering the moraine from Scotch Plains to South Plainfield and beyond, and extending southwestward to Bound Brook and beyond, is covered with stratified drift carried out by running water from the moraine. A lesser example is found in the Succasunna plain.

Gradational types, pitted plains.—Outwash plains may sometimes depart from planeness by taking on some measure of undulation of the sag and swell (kame) type, especially near their iceward edges. The same is often true of the heads of valley trains. The heads of valley trains and the inner edges of overwash plains, it is to be noted, occupy the general position in which kames are commonly formed, and the undulations which often affect these parts of the trains and plains, respectively, are probably to be attributed to the influence of the ice itself. Valley trains

[1]This type is described in the following places, among many others: Chamberlin, 3d Ann. Report U. S. Geol. Surv., p. 303; Journal of Geology, Vol. II, p. 533. Salisbury, Ann. Report of the State Geologist of New Jersey, 1892, p. 97.

and overwash plains, therefore, at their upper ends and edges, respectively, may take on some of the features of kames, and either may head in a kame area.[1]

Occasionally a morainic apron, or stratified drift in the general position of a morainic apron, is affected by numerous sags without corresponding elevations. This topographic type has received the name of *pitted plain*. The sags, in many cases at least, appear to be intimately connected with the ice edge, and so to be marginal phenomena.

Not only may morainic plains and valley trains grade into kame areas at their heads, but they may grade into each other. A wide valley train and a narrow overwash plain may closely simulate each other, and in individual cases it is not easy to say whether the deposits are more properly referred to the one or the other of the two classes.[2] This is especially true where an overwash plain is developed in a valley.

At many points near the edge of the ice during its maximum stage of advance, there probably issued small quantities of water not in the form of well-defined streams, bearing small quantities of detritus. These small quantities of water, with their correspondingly small loads, did not develop considerable plains of stratified drift, but small patches instead. Such patches have received no special designation.

When the waters issuing from the edge of the ice were sluggish, whether they were in valleys or not, the materials which they carried and deposited were fine instead of coarse, giving rise to deposits of silt, or clay, instead of sand and gravel.

In the deposition of stratified drift beyond the edge of the ice, the latter was concerned only in so far as its activity helped to supply the water with the necessary materials.

AT AND BEYOND THE EDGE OF THE ICE IN STANDING WATER.

Deltas and subaqueous morainic plains.—The waters which issued from the edge of the ice sometimes met a different fate.

---

[1] Ann. Report of State Geologist of New Jersey, 1892, p. 94.

[2] Ann. Report of State Geologist of New Jersey, 1891, p. 97.

The ice in its advance often moved up river valleys. When at the time of its maximum extension it filled the lower part of a valley, leaving the upper part free, drainage through the valley was likely to be blocked. Where this happened a marginal valley-lake was formed. Wherever the ice spread over a land surface sloping toward it, there was the possibility of the development of a lake basin between the ice on one hand and the land surface on the other. Marginal lakes and ponds arising in these and other ways were probably not rare at the time of the maximum extension of the ice, and more or less drainage from the ice must have found its way into them. Wherever this occurred, stratified deposits of drift were made in the lakes, the materials for which were borne into the standing water by the streams which issued from the ice. *Deltas* must have formed where well-defined streams entered the lakes, and *subaqueous outwash* or *morainic plains,* where deltas became continuous by lateral growth. These subaqueous moraine plains differ from subaërial moraine plains in their steep delta fronts (Compare Figs. 39 and 40). The accumulation of stratified drift along the iceward shores of such lakes

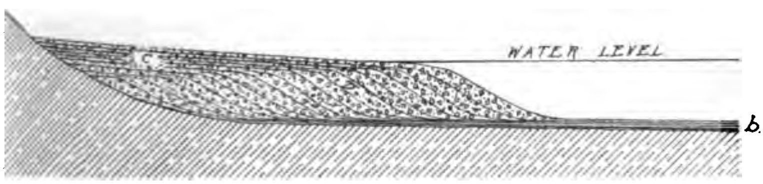


Fig. 40.
Profile of delta plain.

must have been rapid, because of the abundant supply of detritus. These materials were probably shifted about more or less by waves and shore currents, and some of them may have been widely distributed. Out from the borders of such lakes, fine silts and clays must have been in process of deposition, at the same time that the coarse materials were being laid down near shore.

Excellent examples of this class of deposits are found in New Jersey, the most conspicuous of which are those associated with the shores of the extinct Lake Passaic.[1] The best known plain

[1] Details are to be found in the Annual Report for 1893 and in Part II of this volume.

of this sort, now more or less modified by human agency, is that which skirts the moraine, with some interruptions, from Morristown to Summit. Other equally well marked, but less extensive developments of subaqueous moraine plains, some of them more properly deltas, are found farther north, about the shores of the same lake, as at Montville, one and three-fourths miles north of Glenview (Whitehall), at Upper Preakness, southwest of Caldwell, etc. Several of them are shown on Plate XXXIV.

Similar plains or deltas are also known at other points where lakes existed for longer or shorter intervals during the glacial period. An example is the North Church plain in the Wallkill valley near Franklin Furnace.

Deposition must have taken place in a similar way along the shores of the sea wherever the ice reached it. The silt, sand, gravel, etc., carried to the sea by running water was either deposited at once, or worked over and transported greater or less distances by waves and littoral currents. Such deposits still remain beneath the sea, unless changes of level have brought them above the surface. Under these circumstances, however, it is probable that the ice of the sea had an important influence in restraining the activity of waves, and therefore of shore currents.

During the maximum extension of an ice sheet, therefore, there was chance for the development, at its edge or in advance of it, of the following types of stratified drift: (1) kames and kame belts, at the edge of the ice; (2) fluvial plains or valley trains, in virtual contact with the ice at their heads; (3) border plains or overwash plains, in virtual contact with the ice at their upper edges; (4) ill-defined patches of stratified drift, coarse or fine, near the ice; (5) subaqueous moraine plains and deltas, formed either in the sea or lakes at or near the edge of the ice; (6) lacustrine and marine deposits of other sorts, the materials for which were furnished by the waters arising from the ice.

PLATE XXXIV.

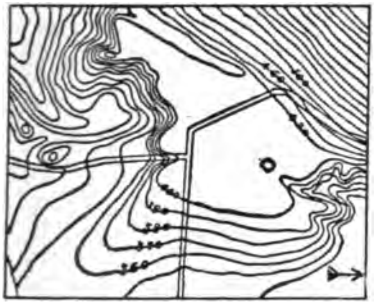


Fig. A.

Delta near the Jacksonville schoolhouse, one and three-fourths miles north of Whitehall. (Scale, three inches to the mile.)

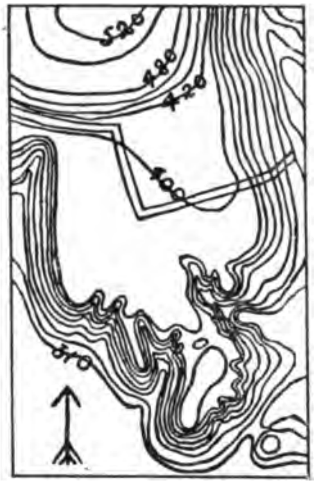


Fig. B.

The Montville delta. (Scale, three inches to the mile.)

Fig. C.

Subaqueous overwash plain, from Madison to Morristown (southwest of the railway), with a part of the moraine (mainly northeast of the railway).

DEPOSITS MADE BY EXTRAGLACIAL WATERS DURING THE RETREAT OF THE ICE.

During the retreat of any ice sheet, disregarding oscillations of its edge, its margin withdrew step by step from its position of extreme advance to its center. When the process of dissolution was complete, each portion of the territory once covered by the ice, had at some stage in the dissolution found itself in a marginal position. At all stages in its retreat the waters issuing from the edge of the ice were working in the manner outlined in the preceding paragraphs. Two points of difference only need to be especially noted. In the first place the deposits made by waters issuing from the retreating ice, were laid down on territory which the ice had occupied, and their subjacent stratum was often glacial drift. So far as this was the case, the stratified drift was super-morainic, not extra-morainic. In the second place, the edge of the ice in retreat did not give rise to such sharply marked formations as the edge of the ice which was stationary. The processes which had given rise to valley trains, overwash plains, kames, etc., while the ice edge was stationary, were still in operation, but in so far as the line or zone of activity (the edge of the ice) was continually shifting, the foregoing types, more or less dependent on a stationary edge, were rarely well developed. As the ice withdrew, therefore, it allowed to be spread over the surface it had earlier occupied, many incipient valley trains, overwash plains, and kames, and a multitude of ill-defined patches of stratified drift, thick and thin, coarse and fine. Wherever the ice halted in its retreat, these various types attained more considerable development. They are often found in association with recessional moraines, as already noted.

Such deposits would not cover all the surface discovered by the ice in its retreat, since the issuing waters, thanks to their great mobility, concentrated their activities along lines which favored their flow. Nevertheless the aggregate area of the deposits made by water outside the ice as it retreated was great.

It is to be noted that it was not streams alone which were operative as the ice retreated. As its edge withdrew, lakes and ponds were continually being drained, as their outlets, hitherto choked by the ice, were opened, while others were coming into existence as the depressions in the surface just freed from ice filled with water. Lacustrine deposits made while the edge of the ice was retreating are identical in kind with those made in similar situations while it was stationary, but for the development of the topographic forms characteristic of deposits in standing water, such as deltas, a moving ice edge was not favorable. It may be noted that a favorite place for the deposition of stratified drift during the retreat of the ice, and especially during the early stages of its retreat, was just inside the moraine, where the moraine was massive. In this case it served as a barrier to drainage. So extensive are stratified deposits just inside the moraine in some places that they are comparable, so far as amount of material is concerned, to the morainic plains on the other side of the moraine. Some of the stratified drift in this position may have been deposited beneath the ice while the moraine was making.

Disregarding oscillations of the ice edge at these stages, the deposits made by extra-glacial waters during the maximum extension of an ice sheet and during its retreat, were always left at the surface, so far as the work of that ice sheet was concerned. The stratified drift laid down by extra-glacial waters in these stages of the last ice sheet which affected any region of our continent still remain at the surface in much the condition in which they were deposited, except for the erosion they have since suffered. It is because of their position at the surface that the deposits referable to these stages of the last ice sheet of any given region have received most attention and are therefore most familiar.

DEPOSITS MADE BY EXTRA-GLACIAL WATERS DURING THE ADVANCE OF THE ICE.

During the advance of an ice sheet, if its edge moved steadily forward, the waters issuing from it, and flowing beyond, were attempting similar results. They were continually starting valley trains, overwash plains, kames and small ill-defined patches of stratified drift, over which the ice then advanced, shoving forward the zone of the water's activity. If the ice halted in its advance, there was at such times and places opportunity for the better development of extra-glacial stratified drift.

Lakes as well as streams were concerned in the making of stratified beds of drift during the advance of the ice.

Unlike the deposits made by the waters of the retreating ice, those made by the waters of the advancing ice were laid down on territory which had not been glaciated, or, at least not by the ice sheet concerned in their deposition. Marginal lakes were restricted and then obliterated by having their basins filled by the advancing ice; but new ones were formed, on the whole, as rapidly as their predecessors were destroyed, so that lacustrine deposits were making at intervals along the margin of the advancing ice.

All deposits made in advance of a growing ice sheet, by waters issuing from it, were subsequently overridden by the ice, and in the process suffered destruction, modification or burial, in whole or in part, so that they now rarely appear at the surface.

DEPOSITS MADE BY SUBGLACIAL STREAMS.

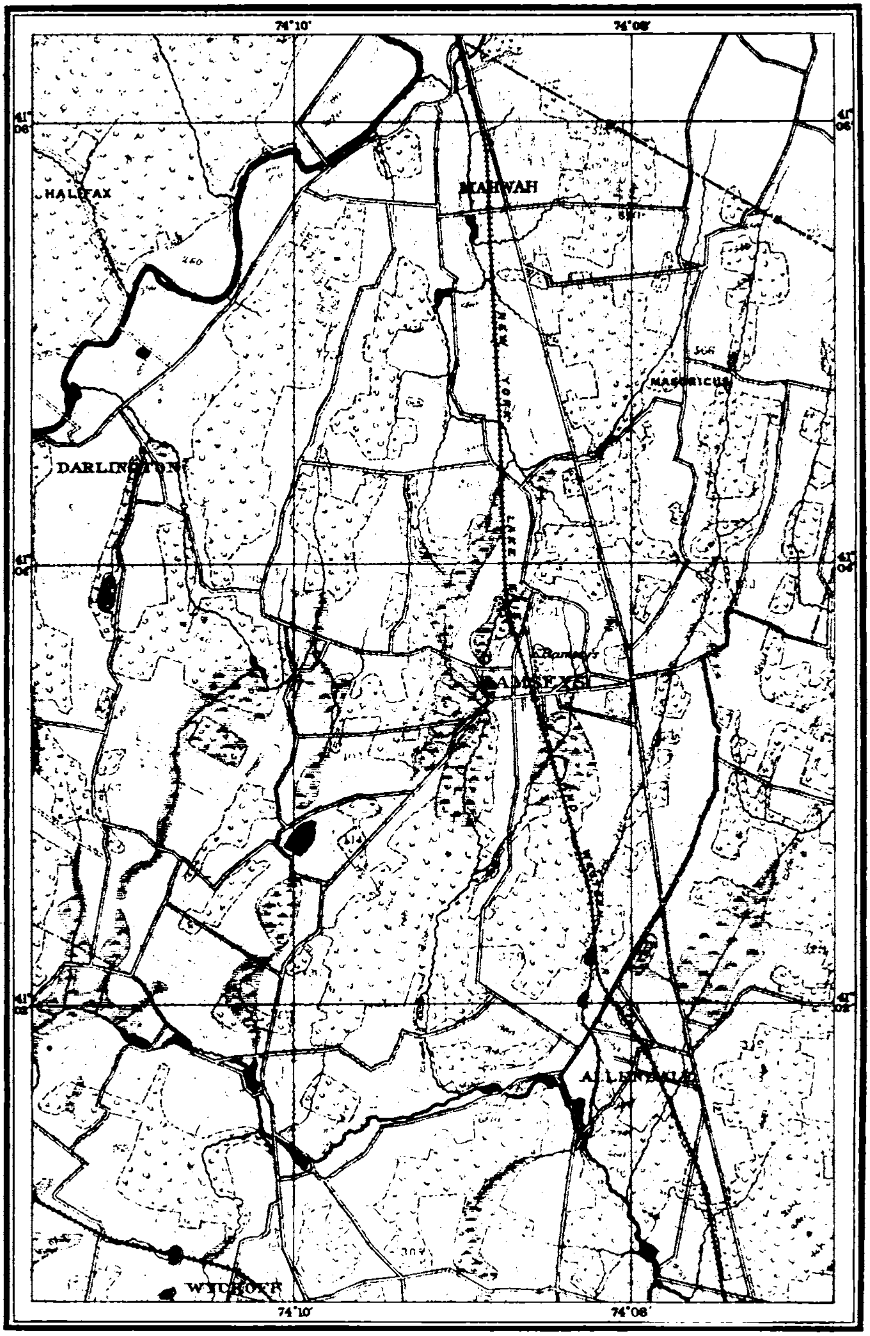
Before their issuance from beneath the ice, subglacial waters were not idle. Their activity was doubtless sometimes erosive; but where the subglacial streams found themselves overloaded, as seems frequently to have been the case, they made deposits along their lines of flow. Where such waters were not confined to definite channels, their deposits probably took on the form of irregular patches of silt, sand or gravel; but where depositing streams were confined to definite channels, their deposits were correspondingly restricted. Such channels may have been constant in position, or may have shifted more or less from side to side. In the latter case there was a tendency to the development of a belt or strip of stratified drift having a width equal to the extent of the lateral migrations of the under-ice stream.

Eskers.—Where the depositing subglacial stream remained fixed in position, the deposition was more concentrated, and its channel was aggraded. If the stream held its course for a long time, the aggradation may have been considerable. In so far as these channel deposits were made near the edge of the ice during the time of its maximum extension or retreat, they were likely to remain undisturbed during its melting, after which the channels stood out as ridges. These ridges of gravel and sand are known as osars or eskers. It is not to be inferred that eskers never originated in other ways, but it seems clear that this is one method, and perhaps the principal one, by which they came into existence[1].

Eskers early attracted attention, partly because they are relatively rare, and partly because they are often rather striking topographic features. They are often conspicuous, not so much because of their height as because of their abrupt slopes and their even and narrow crests. They may be ten, or several times ten feet high, but their crests are generally no more than a few feet wide. They are, for example, often so narrow, and their slopes so steep, that two wagons could with difficulty pass each other on their tops. The angle of their slopes is about the angle at which the drift will lie. Where they cross marshes and swamps, as is sometimes the case, they are most conspicuous, sometimes resembling railway grades. Eskers no more than a fraction of a mile in length are more common than longer ones, but eskers scores of miles long are known. Long eskers sometimes wind up and down over low elevations and valleys, showing that the

---

[1] Eskers or osars are described and discussed in the following places, often under the name of kames or serpentine kames: Chamberlin, 3d Ann. Report U. S. Geol. Surv., p. 299; Compte Rendu. 5th session of the International Congress of Geologists, Journal of Geology, Vol. I, p. 255; *Ibid.*, Vol. 2, p. 529. Stone, Proc. Bost. Soc. Nat. Hist., Vol. XX, pp. 430-69. Upham, Geol. of N. Hampshire, Vol. 3, p. (under kames); Proc. A. A. A. S., Vol. XXV, p. 216; Report Minn. Geol. Survey, Vol. 1, p. 545; Am. Jour. Sci., Vol. CXIV (1877), p. 459; Shaler, Proc. Bost. Soc. Nat. Hist., Vol. XXIII, p. 36; 7th Ann. Report U. S. Geol. Surv., p. 314; 9th Ann. Report U. S. Geol. Surv., p. 549; Davis, Proc. Bost. Soc. Nat. Hist., Vol. XXV, p. 477-492. Geikie, Great Ice Age, 3d edition, chap. XIV. Holst, Am. Nat., Vol. XXII, pp. 590-711. Salisbury, Ann. Rep. State Geologist of New Jersey, 1892, pp. 41, 79.



MAP OF
ESKERS NEAR RAMSEYS, BERGEN COUNTY

Scale 1 inch to a mile

water which made them must have been under great head, if they are of subglacial origin. They often lie along the lower slope of a valley, though distinctly above its bottom. Long eskers are likely to be interrupted at intervals, probably at points where the depositing waters failed of confinement to definite channels. The best developed eskers in the United States are in Maine.[1]

Eskers are made up primarily of stratified gravel and sand. As in kames, the stratification is often much distorted, probably as the result of ice pressure. Bowlders are often present in them and on their surfaces, showing the help of the ice in their building. The bowlders might be crowded in from the sides, or let down from the ice above. As in kames, the gravel is often not well rounded. Eskers often end in kames, and where they are interrupted the interval is often occupied by kames. Occasionally they end in a delta, where the constructing stream issued from the ice into a lake.

New Jersey has a few eskers, mostly rather small, inconspicuous, and of rather imperfect development. The best examples are in the vicinity of Ramseys (Plate XXXV), in Bergen county, and near Afton in Morris.

Kames.—Kames have been referred to as phenomena of the edge of the ice, but it is very probable, too, that they are sometimes developed beneath the ice, especially near its edge, after vigorous movement had ceased. The fact that the breaks between the parts of an interrupted esker are sometimes occupied by kames points to this conclusion, as do certain other phenomena, not susceptible of equally brief statement.

Subglacial drainage was operative during the advance of an ice sheet, during its maximum extension, and during its retreat, and during all these stages it was effecting its appropriate results. It will be readily seen, however, that all deposits made by subglacial waters were subject to modification or destruction or burial through the agency of the ice, and that those made during the advance of the ice were less likely to escape than those made during its maximum extension or retreat. Most existing eskers were probably made just before the disappearance of the

[1] Stone, Monograph, XXXIV. U. S. Geol. Surv.

ice from the region where they occur. Subglacial deposits of stratified drift were sometimes made on unstratified drift (till) already deposited by the ice before the location of the stream, sometimes on other phases of stratified drift, and sometimes on rock surfaces on which no covering of drift had been spread.

DEPOSITS OF SUPERGLACIAL AND ENGLACIAL STREAMS.

Superglacial and englacial streams have been supposed to make deposits in their channels. It has even been conceived that this was the principal mode of origin of eskers. Against this view, and against the view that superglacial stream deposits are of consequence quantitatively, stand two facts. (1) So far as known, the surfaces of ice sheets are free from drift (apart from wind-blown dust) except for a fraction (and generally a small one) of a mile from their edges; and (2) superglacial streams are in general much too swift to allow of the accumulation of drift in their channels. The channels of most superglacial streams in North Greenland, *even near the edge of the ice where surface debris is abundant,* are absolutely free from drift. Judging from the force with which they issue from the ice, englacial streams are likewise much too swift to allow of deposition along their channels, as a general rule.

Such trivial accumulations of drift as may be made in superglacial or englacial channels would ultimately reach the land surface. During the advance of the ice they would be delivered onto the land, as the ice which sustained them melted from beneath. They would then be overriden by its further forward motion. During the retreat of the ice, such deposits, once they reached the land surface, would not be subsequently destroyed or overridden by it.

SUMMARY.

Such are the main phases of water action in connection with a single ice sheet, on the assumption that the edge of the same did not oscillate backward and forward during the period of its advance or retreat. Were this the complete history of an ice sheet, the stratified deposits, as they now exist, would be (1) in part extra-glacial—those made by waters beyond the extreme advance of the ice; (2) in part super-morainic (super-till)—especially those made by extra-glacial waters during the retreat of the ice; and (3) in part submorainic (sub-till)—chiefly those made by extra-glacial waters during the advance of the ice, and subsequently buried. The actual relations of the stratified drift to the unstratified are, however, far less simple.

RELATION OF STRATIFIED TO UNSTRATIFIED DRIFT.

Deposits made by extra-glacial waters during the advance of the ice, edge not oscillating.—At all stages of the glacial period extra-glacial streams were depositing gravel, sand, or silt in the valleys through which they flowed. So, too, the waters which did not concentrate themselves in valleys as they issued from the edge of the ice, made deposits in the form or in the position of outwash plains of gravel, sand, or silt. The marginal lakes which came into existence during the advance of the ice, and there were many, likewise gave rise to stratified deposits of glacio-lacustrine origin. Deposits formed in the margins of seas at the edge of the ice would, if subsequently overridden by the ice, be subject to the same changes as those formed in lakes. The deposits made at the immediate edge of the ice, such as kames, were subject to the same changes as those made in advance of it.

If it be supposed that the edge of the ice did not oscillate as it advanced, all the deposits of extra-glacial and marginal waters made during its first advance, whether of the valley train, outwash plain, lacustrine, kame or other types, were made *on surfaces free from drift.* All of them were liable to destruction by the farther progress of the ice, and in so far as they were not destroyed they were liable to be buried beneath unstratified drift deposited by the ice itself. So far as not destroyed, therefore, the existing deposits of stratified drift *made during the first advance of the ice* are likely to occupy *the basal position* (submorainic) in the drift series, in all the territory subsequently overspread by the ice.

Effect of edge oscillation.—Hitherto the assumptions have been made, for the sake of simplicity, that the advancing edge of the ice moved steadily forward, and that the retreating edge was subject to no temporary advances. It is probable that neither of these assumptions is true. It is believed rather that the advance of the ice was interrupted by many minor oscillations of its edge, both seasonal and periodic, though the sum of the advances was greater than the sum of the retreats, up to the time when the ice reached its greatest extension. When the ice advanced to a certain line, and then receded temporarily, incipient outwash plains, valley trains, lacustrine beds; kames and ill-defined patches of gravel and sand, were doubtless deposited on the territory from which the ice had temporarily receded. In this case the gravel and sand would, in general, not lie on a driftless bed, but on deposits made by the ice before its temporary recession. The subsequent advance of the ice would be likely to bury these deposits of stratified drift so far as it did not destroy them. Thus by oscillations of the edge of the ice during the general period of its advance, *stratified sand and gravel came to be enclosed between beds of till.* The extent of the area where this interbedding was effected at any one time, depended on the extent of the oscillation which the ice underwent. The process may have taken place at so many times and places and at so many stages in the development of an ice sheet, that the interbedding of the two types of drift effected during the advance of the ice, may have been somewhat general.

Deposits made by extraglacial waters during the retreat of the ice.—Stratified deposits made by extraglacial streams during the retreat of the ice of any epoch would remain at the surface (supermorainic) so far as the ice of that epoch was concerned, except in so far as forward oscillatory movements intervened in the general period of retreat. So far as such movements intervened, their tendency would be to bury or destroy such stratified deposits as were overridden by the temporary advances of the ice, making them intermorainic (inter-till). In a complex body of drift deposited by a single ice sheet, the edge of which was subject to oscillation, it would not always be possible to tell which beds of intermorainic stratified drift were deposited during the advance of the ice and which during the retreat, though the latter would of course overlie the former.

Deposits made by subglacial streams.—The deposits of subglacial streams, whether concentrated along sharply limited channels (eskers), or more widely spread, were sometimes made on the surface of the rock, but more commonly on till which the ice had already deposited, or on stratified drift deposited at an earlier time. Because of the ever-changing conditions at the bottom of moving ice, it is probable that the ice frequently came to occupy beds which streams had temporarily commanded. Wherever this happened, the stratified deposits were likely to be destroyed in whole or in part, or buried. In the latter case *they became intermorainic,* if they rested on till, or *submorainic,* if on rock. It is believed that very large numbers of beds of stratified drift, of limited extent, became in this way interbedded with till. Subglacial waters which did not organize themselves into regular systems of drainage, must have done a similar work on a smaller scale.

Deposits made beneath the ice during the time of its maximum extension or during its retreat, and especially those made near its edge, stood least chance of being buried by later glacial deposits, and were likely to remain at the surface.

Deposits made by superglacial and englacial streams.—As already stated, the deposits of superglacial and englacial streams were probably unimportant. Such deposits as were made in the channels of superglacial streams during the final recession of the ice sheet were delivered on the land as the ice melted, and should remain at the surface to the present time, so far as the ice of that epoch was concerned. Such deposits as were made by superglacial streams during the advance of the ice must likewise have been delivered on the land surface as the ice melted from beneath them, but were subsequently destroyed or buried, becoming in the latter case, submorainic. This would be likely to be the fate of all such superglacial gravels as reached the edge of the ice up to the time of its maximum advance. As a result of edge escillation, superglacial deposits, after they reached the land surface, might become inter-morainic.

Streams descending from the surface of the ice into crevasses carried down sand and gravel, where such material existed on the ice. These deposits may have been made on the rock which underlies the drift, or on stratified or unstratified drift already deposited. In either case they were liable to be covered by till, thus reaching an inter-till or sub-till position.

Englacial streams probably do little depositing, but it is altogether conceivable that they might accumulate such trivial pockets of sand and gravel as are found, not infrequently, in the midst of till. The inter-till position would be the result of subsequent burial after the stratified material reached a resting place.

Complexity of relations.—From the foregoing it is clear that there are diverse ways by which stratified drift, arising in connection with an ice sheet, may come to be interbedded with till. It is evident that stratified drift may alternate with unstratified many times in a formation of drift deposited during a single ice epoch. The extent of individual beds of stratified drift, either beneath the till or interbedded with it, may not be great, though their aggregate area and their aggregate volume is very considerable. It is to be borne in mind that the ice, in many places, doubtless destroyed all the stratified drift deposited in advance on the territory which it occupied later, and that in others it may have left only patches of once extensive sheets. This may help to explain why it so frequently happens that a section of drift at one point shows many layers of stratified drift, while another section close by, of equal depth, and in similar relationships, shows no stratified material whatsoever. It also makes it clear that the inter-relations of the two types of drift are, on the whole, less complex than they might have been had all the deposits once made by the ice and its accompanying waters escaped destruction.

After what has been said, it is hardly necessary to add that two beds of till, separated by a bed of stratified drift, do not necessarily represent two distinct glacial epochs.

In any region which has been affected successively by two or more ice sheets, the complication of stratified and unstratified drift may be even greater. While the ice of one epoch is likely to destroy in part the deposits of earlier epochs, it is not likely to obliterate them altogether. In some regions, indeed, the full series of one epoch is buried beneath the deposits of a second, as the soil between shows. In addition therefore to the complicated series of stratified and interstratified deposits of a first epoch, the ice of a second developed a full series of its own. A prolonged series of ice epochs might bring about most complicated relations, the complete unraveling of which would be an arduous task.

CLASSIFICATION OF STRATIFIED DRIFT ON THE BASIS OF POSITION.

On the basis of position stratified drift deposits may be classified as follows:

1. *Extraglacial deposits,* made by the waters of any glacial epoch if they flowed and deposited beyond the farthest limit of the ice.

2. *Supermorainic deposits* made chiefly during the final retreat of the ice from the locality where they occur, but sometimes by extraglacial streams or lakes of a later time. Locally, too, stratified deposits of an early stage of a glacial epoch, lying on till, may have failed to be buried by the subsequent passage of the ice over them, and so remain at the surface. In origin, supermorainic deposits were for the most part extraglacial (including marginal), so far as the ice sheet calling them into existence was concerned. Less commonly they were subglacial, and failed to be covered, and less commonly still (if ever) superglacial.

3. *The submorainic (basal) deposits* were made chiefly by extraglacial waters in advance of the first ice which affected the region where they occur. They were subsequently overridden by the ice and buried by its deposits. Submorainic deposits, however, may have arisen in other ways. Subglacial waters may have made deposits of stratified drift on surfaces which had been covered by ice, but not by till, and such deposits may have been subsequently buried. The retreat of an ice sheet may have left rock surfaces free from till, on which the marginal or extramarginal waters of the retreating ice or of the next advancing ice may have made deposits of stratified drift. These may have been subsequently covered by till during a re-advance of the ice

in the same epoch or in a succeeding one. Still again, till left by one ice sheet may have been exposed to erosion to such an extent as to have been completely worn away before the next ice advance, so that stratified deposits connected with a second or later advance may have been made on a driftless surface, and subsequently buried.

4. *Intermorainic stratified drift* may have originated at the outset in all the ways in which supermorainic drift may originate. It may have become intermorainic by being buried in any one of the various ways in which the stratified drift may become submorainic.

TOPOGRAPHIC CONSIDERATION.

Topographic distribution of stratified drift.—The accompanying map, Plate XXVIII, showing the distribution of the stratified and unstratified drift shows that the larger part of the former is on the lower lands. In the Appalachian province it is mainly in the Delaware valley, the Flatbrook-Clove river valley and in the sub-valleys of the Kittatinny valley. In the Highlands, likewise, it is chiefly along the water courses, while in the area of the Piedmont plain it is mostly in the depressions between the ridges, though its disposition in this province is often somewhat anomalous. It fails to conform strictly to the laws governing river deposits. The extra-morainic stratified drift is likewise mainly in valleys and on lowlands. This distribution is the necessary result of the laws controlling the flow of water.

But although the stratified drift is abundant in valleys and on lowlands, it is not confined to these positions for reasons which the preceding discussion has made evident. Kames are measurably independent of topography, as they should be if their mode of origin is correctly understood. Eskers also are not confined to valleys as valley trains are, although they have a disposition to avoid hills and ridges. There is no reason, however, why they might not be developed on an upland of moderate relief. A morainic plain might be developed in a similar position, though good examples are not found in New Jersey. Though the deposits along stagnant ice (kame terraces) are usually in valleys, they sometimes lie well up on the slopes, while the bottom of the valley is covered with till. The stratified deposits made in glacial lakes are always surrounded, or partially surrounded, by higher land. It sometimes happened, however, that one side of a lake basin's rim was ice, by means of which the lake was held up to a high level. The deposits of stratified drift were then made at the same level.

Effect of the stratified drift on relief.—Since the deposits of stratified drift are mostly in valleys and on low lands, they tend, on the whole, to build up the low places, and, therefore, to reduce the relief of the surface. While this is the rule, many of the conspicuous kame groups constitute notable exceptions to the general rule.

Topography of stratified drift.—The topography of the several phases of stratified drift has been mentioned, in connection with the discussion of the several phases which this drift assumes. By way of summation it may be said that valley trains and outwash plains tend toward a plane topography, with an increasingly gentle slope away from the moraine, and an increasing tendency to unevenness near the moraine; that delta and subaqueous morainic plains have gently sloping tops, but abrupt fronts; that kame terraces tend toward flat tops, but have steep and irregular slopes; that kames are often pronounced hillocks, or short ridges, which locally roughen the surface notably; and that eskers, so far as New Jersey is concerned, are low ridges, though sometimes so narrow and steep-sided as to attract attention. Plains of stratified drift, either extra or intra-morainic, are sometimes affected by depressions. The topography of extraglacial water deposits tends to flatness; the topography of deposits made by marginal and by some subglacial waters tends to roughness.

CHAPTER V.

CHANGES IN DRAINAGE RESULTING FROM GLACIATION.

CONTENTS.

The topographic changes effected by the ice in northern New Jersey have been referred to, but the effect of these changes on drainage deserves consideration. The modifications of drainage produced while the ice was here, and those which persisted after it disappeared, may be considered separately.

CHANGES WHILE THE ICE EXISTED.

As the continental ice sheet invaded a region, its valleys were filled with ice, and drainage was thereby deranged. Different streams were affected in different ways. When the entire basin of a stream was filled with ice, the streams of that basin were, for the time being, obliterated. Where basins were but partly filled, several distinct cases arose. 1) Where the ice covered the upper part of a valley or river basin, but not the lower, the lower portion was flooded, and though the river held its position, it assumed a new phase of activity. 2) Where the ice occupied the lower portion of a valley, or river basin, but not the upper, the ice blocked the drainage, giving rise to a lake. 3) Where the ice occupied the middle part of a stream's valley first, a lake was likely to be formed above, while the part below was flooded. 4) Where a stream flowed parallel or approximately parallel to the edge of the advancing ice, it was sometimes shifted in the direction in which the ice was moving, its new course often remaining parallel to the front of the ice.

Most of the larger valleys of the glaciated part of New Jersey are roughly parallel to the direction of ice movement and through most of those having this course, the drainage is now to the southward. In this respect the present drainage does not depart widely from that of preglacial times.

1) As the ice reached the head waters of the southward flowing streams, they became avenues of discharge for the glacial waters. Their swollen currents started out from the ice with gravel, sand and mud, and these materials were deposited, partly successively, and partly contemporaneously along the lower course of the stream. Such was the condition of things along the Delaware, Paulinskill, Beaver, Pequest, Musconetcong, Wanaque, Ramapo, Saddle and Hackensack valleys, as well as along the valleys of many smaller streams.

2) Where the ice invaded the lower part of a stream's basin instead of the upper, giving origin to a lake, the water in the lake above the ice probably rose until it found an outlet (darkest area, Fig. 41). As the ice advanced farther up the basin or valley, it displaced the water, and tended to contract the lake. In its advance, the ice may have reached and blocked the first outlet of the lake, and the waters may then have risen to a new and higher level, namely to the lowest remaining point in the rim (lined area, Fig. 41). In this way, the increase of the area of the lake resulting from the rise of its surface, might counterbalance the decrease of area resulting from the advance of the ice. So the changes went on until the ice reached its limit. If it reached the divide separating the ponded stream from the drainage which flowed the other way, the lake was obliterated.

The Wallkill valley offers an example of this sort. This valley now drains to the northeast, and it did so in preglacial time.

The ice must have occupied the lower part of the valley before it reached the upper, and the water must have been ponded above, forming a lake. As the ice advanced up the valley to the south, it continually diminished the area of the lake, until the ice reached the divide separating the head waters of the Wallkill from the drainage flowing southwest to the Delaware. The lake was then obliterated. The deposits made in such lakes were generally

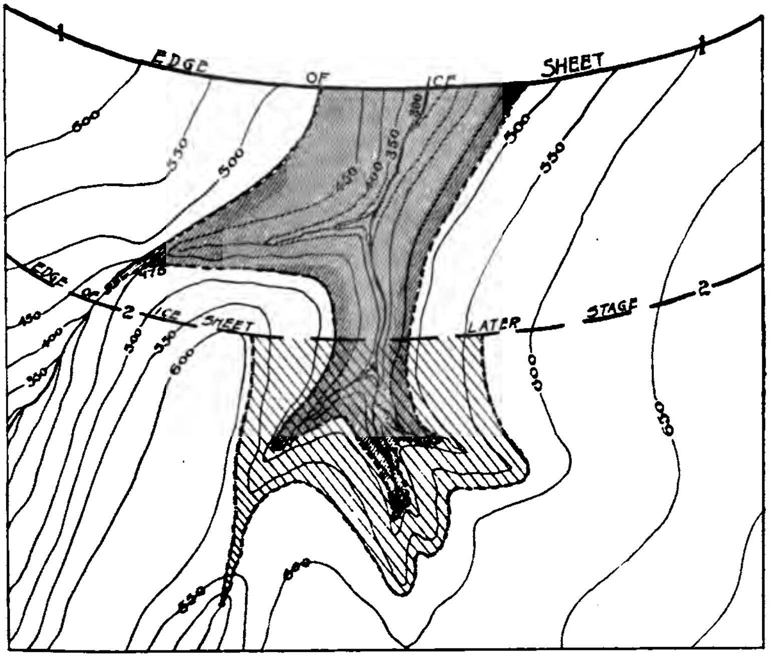


Fig. 41.

Illustrates how the ice, by advancing up a valley, may give rise to a lake, and how by farther advance, 2, the lake is diminished in area (area of light lining), at the same time rising in level and acquiring a new outlet.

obliterated or buried by the later deposits of the ice, so that the details of its history are not easily ascertained.

An example of a lake formed in a similar way, but not obliterated by the advance of the ice is found in the upper course of the Black river, which, in preglacial time, flowed to the north. The lake in this valley occupied the area of the Succasunna plains, and may be called the *Succasunna lake*. Succasunna lake was probably obliterated by having its shallow basin filled with drift washed out from the ice; but a considerable part of its basin was not occupied by the ice. The drainage of this valley is believed to have been reversed, while the ice was on, and to have since persisted in the reversed course.

The general sequence of events represented by these examples, the sequence in the Wallkill on the one hand, and in the Black on the other, must have been repeated in all the valleys which sent their waters northward, except in so far as they found outlets under the ice; and this was probably not often the case.

Applying the same principles to the retreating stages of an ice sheet's history, there was a similar sequence of events, but in reverse order. So soon as the ice retreated from a water divide, a lake may have come into existence just north of it. As the ice retreated farther and farther, the area of the lake expanded. It may have found new outlets as the retreat went on, and when this occurred, the level of the water may have been so drawn down as to decrease the area of the lake, in spite of the fact that the recession of the ice allowed of its expansion northward.

It is to be borne in mind that the outlets of a lake during the retreating stages of the ice were not necessarily the same as those of the lake occupying the same basin during the advancing stages, for the erosion of the ice may have lowered the rim of the basin at some points, and the deposits of the ice may have built it up at others. There is especial likelihood that the ice filled with drift the gaps which served as outlets for the lake of the advancing stage of the ice. Thus if sufficiently heavy drift deposits were made in the position of the first outlet shown in Fig. 41, to raise the surface above the level of the later outlet, the latter would remain its outlet as the ice receded. It is probable indeed that many lakes come into existence in the retreating stages of the ice, where there were none in the advancing. Suppose, for example, that the ice moves down a valley. In this case it does not pond the stream and does not make a lake. But it may make so massive a moraine, at the limit of its advance, as to effectively dam the valley. When the ice retreats, the moraine barrier serves to hold back the water. Such a lake was formed in the valley of the Pequest above the terminal moraine.

3) *Lake Passaic.*

An example of the third case cited, on page 148, is found in the basin of the Passaic. The lake formed in the upper part of the basin of this stream, was the most important of all the lakes formed at the edge of the ice in the State. It illustrates so many of the principles just outlined, that its history will be summarized at this point. The details on which this summary is based have been published in earlier reports.[1]

The peculiar course of this river is well known (Plate XXXVI). After reaching a point (near Summit) but 12 miles from tide water, it turns northward, and after a devious course finally reaches Little Falls and Paterson, where it crosses First and Second mountains. Below Paterson it again turns toward the sea.

The preglacial drainage of the Passaic basin was notably unlike that of the present time. This is known from the existence of a deep, drift-filled gap in Second mountain, at Short Hills (Fig. 6, p. 10). Were the drift in this gap removed, its bottom would be lower than the gap across Second mountain at Little Falls, where the Passaic now flows. Consequently it is concluded that all the drainage of that part of the Passaic basin which lies southwest of the moraine, and probably a considerable part which lies between the moraine and Little Falls, flowed to the sea through the Short Hills outlet, before the ice filled it with drift.[2] It is altogether possible that the Rockaway flowed southward from Pine Brook, and joined the waters which flowed through the Short Hills pass. The size of the gorge through the moun-

[1] Rept. of the State Geologist for 1893.

[2] The sequence of events outlined above is based on the assumption that all the drift in the Short Hills gap was deposited by the last ice sheet, and that until the ice reached the line of the moraine, drainage escaped through this gap at the level of the rock bottom. It is possible that the history of the lake was somewhat more complicated, but the facts which seem to suggest the more complex history do not illustrate the principles under discussion, and their consideration is omitted.

tain at Little Falls makes it probable that the Pompton, or the drainage from the basin of the Pompton, followed its present course, before the glacial period. The map, Plate XXXVII, indicates some such system of drainage as is believed to have existed before the disturbing influence of the ice was felt.

For a time after the ice sheet reached Little Falls and Paterson, the river which had flowed through the valley across the trap ridges may have been able to keep its channel open beneath the ice. So long as this was true, no lake was formed in the Passaic basin. But there came a time when such a sub-ice outlet, if it existed at all, was closed. When this happened, the drainage which, but for the ice-blocking, would have escaped to the sea *via* Little Falls, must have accumulated in front of the ice in the northern drainage basin referred to above (Plate XXXVIII). Any lake which formed here at this time must have been small and shallow, for it would soon have overflowed the low divide separating the drainage basin which had its outlet at Little Falls, from that which had its outlet through the Short Hills gap. This divide was quite certainly low, much below 303 feet, the height of Great notch (a pass in First mountain a few miles south-southwest of Paterson), which, in this event, could not have served as an outlet at this time. As the ice advanced, it encroached upon this hypothetical early lake, displacing its water, diminishing its size, and finally obliterating it altogether (Plate XXXIX).

No lake could have formed in the drainage area of the river system which flowed through the Short Hills gap (unless in the upper courses of such tributaries, as were obstructed at their lower ends) until after the ice reached that gap, and filled it. Then, and not until then, could a lake have existed in the basin south of Morristown. Once formed, the level of the lake rose until it found an outlet. For a time it may have overflowed through the narrow notch across Second mountain at Summit (height 320 feet), but this notch is so close to the Short Hills gap that it was doubtless filled with ice soon after the Short Hills gap was occupied. After the ice blocked the Short Hills gap, the lake level rose to the next lowest outlet. This was at Moggy hollow, near Liberty Corner, some twelve miles southwest of Morristown

EXPLANATION OF PLATES

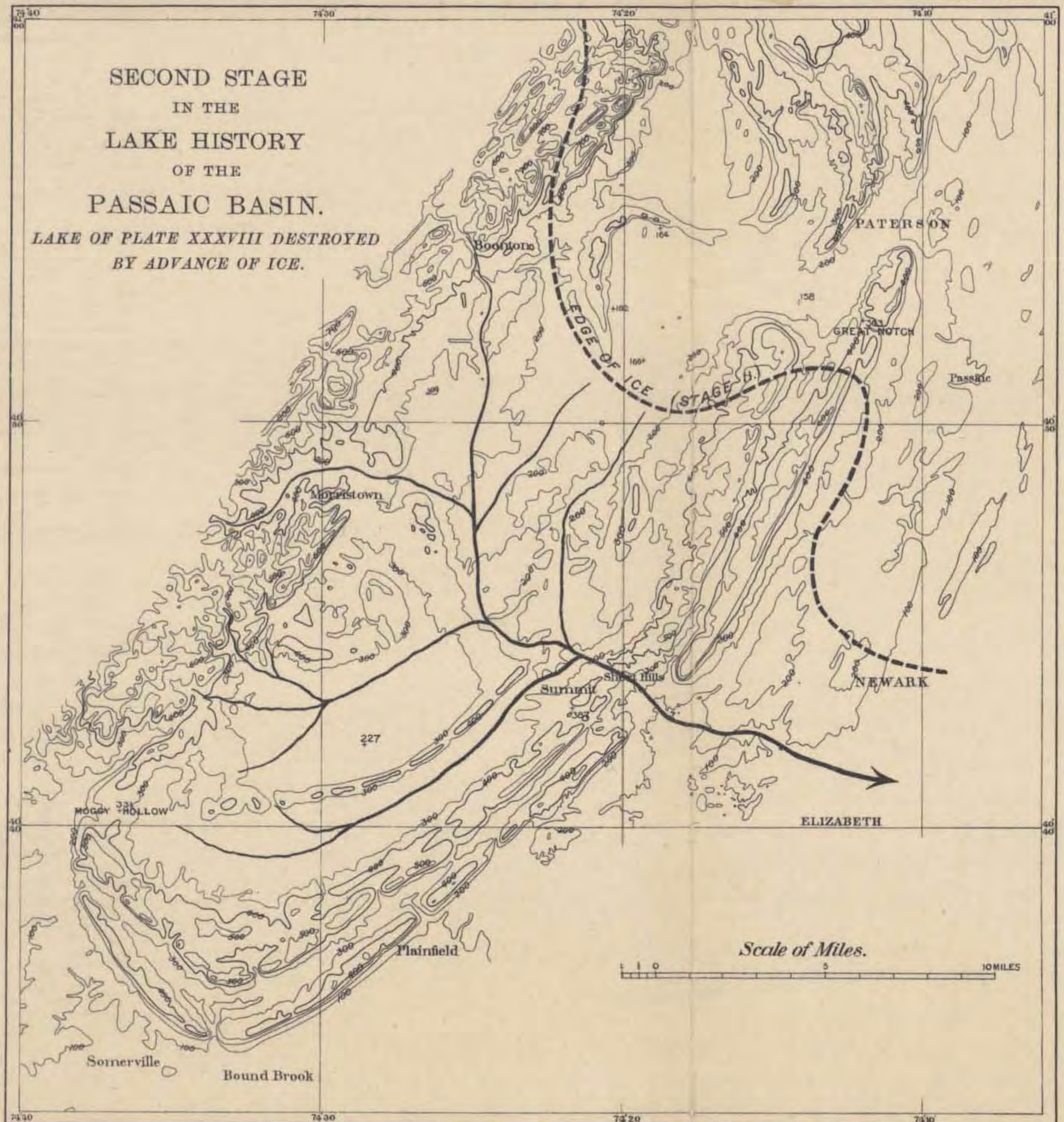
XXXVI, XXXVII, XXXVIII, XXXIX, XL, XLI and XLII.

Plate XXXVI represents the present drainage system of the Upper Passaic basin.

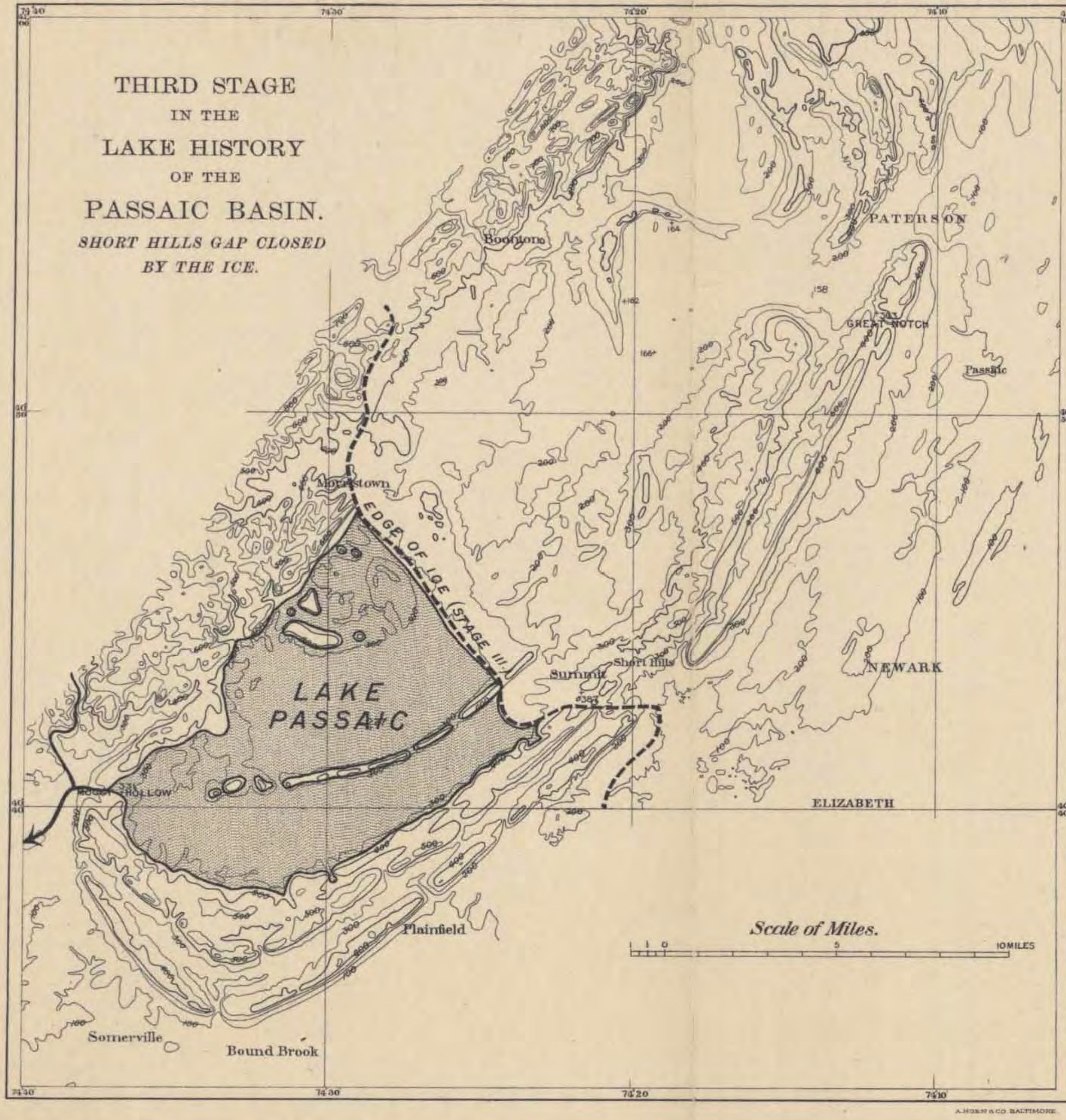
Plate XXXII represents the general plan of the drainage of the Upper Passaic basin as it is conceived to have been before the last glacial epoch.

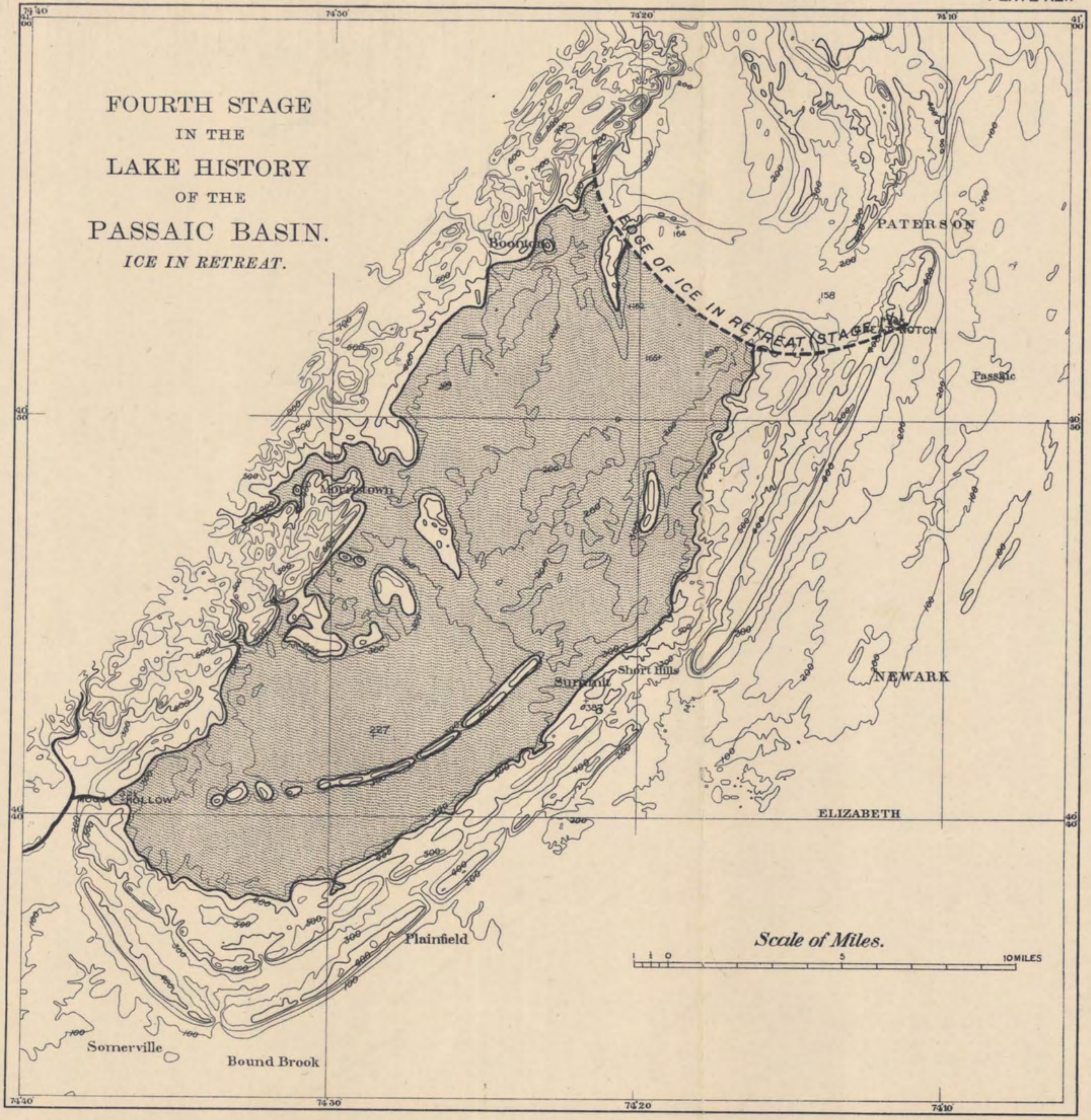
Plates XXXVIII-XLII represent successive stages in the lacustrine history of the Upper Passaic basin during the last glacial epoch.

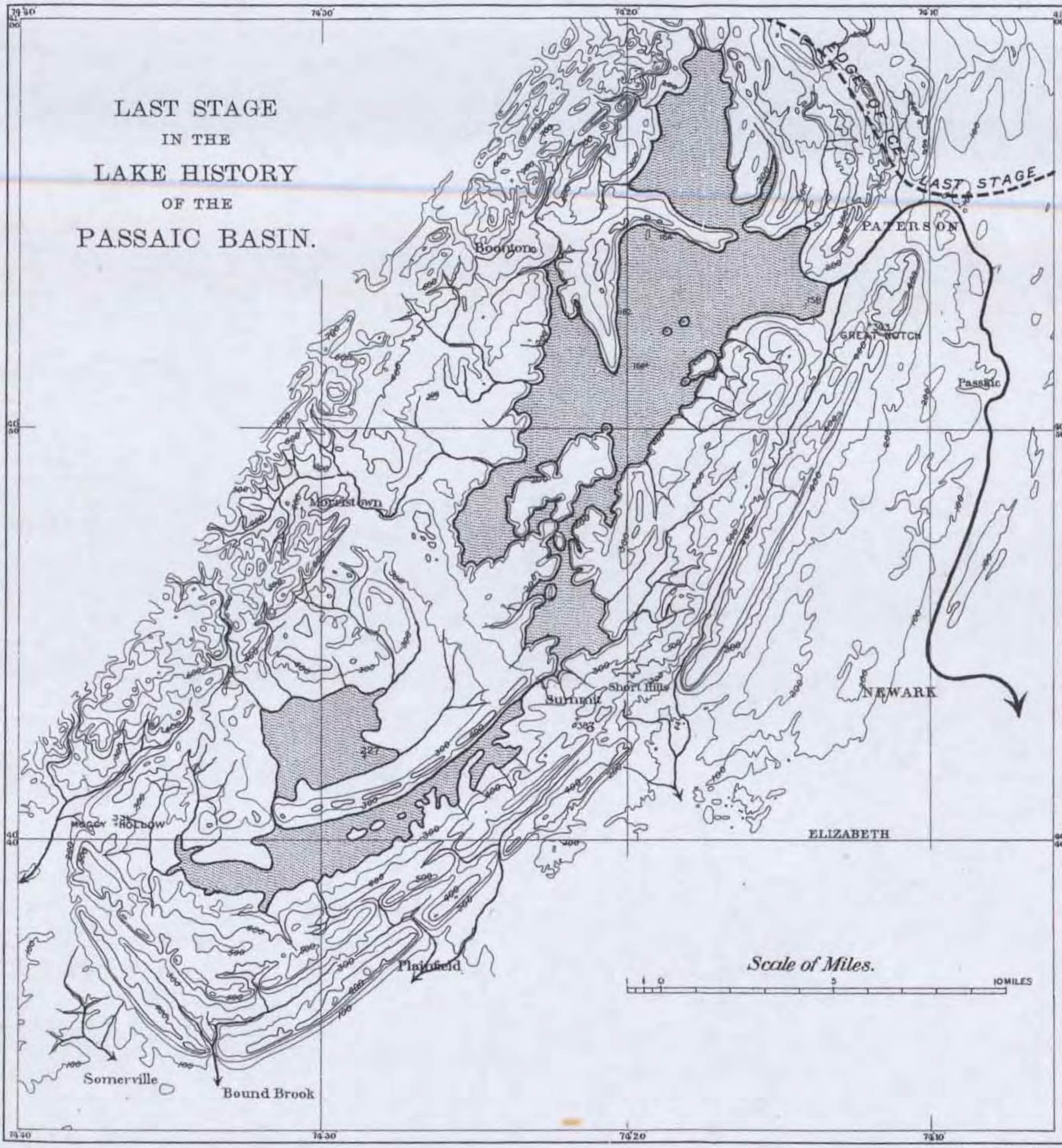

THE
PRESENT DRAINAGE
OF THE
LAKE PASSAIC BASIN.
PATERSON
GREAT NOTCH
Passaic
Boonton
Whippany River
Passaic River
Morristown
GREAT SWAMP
Summit
Short Hills
NEWARK
ELIZABETH
NEWARK BAY
MOGGY HOLLOW
Dead River
Plainfield
Somerville
Bound Brook
Scale of Miles.
10 MILES
A. HOEN & CO. BALTIMORE.



A. HOEN & CO. BALTIMORE.


THIRD STAGE
IN THE
LAKE HISTORY
OF THE
PASSAIC BASIN.
SHORT HILLS GAP CLOSED
BY THE ICE.
Boonton
PATERSON
GREAT NOTCH
Passaic
Morristown
EDGE OF ICE (STAGE III)
LAKE
PASSAIC
Short Hills
Summit
NEWARK
ELIZABETH
MOGGY HOLLOW
Plainfield
Scale of Miles.
10 MILES
Somerville
Bound Brook
A. HOEN & CO. BALTIMORE.


FOURTH STAGE
IN THE
LAKE HISTORY
OF THE
PASSAIC BASIN.
ICE IN RETREAT.
EDGE OF ICE IN RETREAT (STAGE IV)
Boonton
PATERSON
NOTCH
Passaic
Morristown
Short Hills
Summit
NEWARK
ELIZABETH
HOLLOW
Plainfield
Somerville
Bound Brook
Scale of Miles.
10 MILES
74°40'
74°30'
74°20'
74°10'
A. HOEN & CO. BALTIMORE.


LAST STAGE
IN THE
LAKE HISTORY
OF THE
PASSAIC BASIN.
EDGE OF ICE
LAST STAGE
PATERSON
Boonton
GREAT NOTCH
Passaic
Morristown
Summit
Short Hills
NEWARK
ELIZABETH
Plainfield
Somerville
Bound Brook
Scale of Miles.
10 MILES
A. HOEN & CO. BALTIMORE.

(Plate XL). There is at this point a current-swept pass in Second mountain, the bottom of which is 331 feet A. T. (Fig. 42). When the lake first began to discharge through Moggy

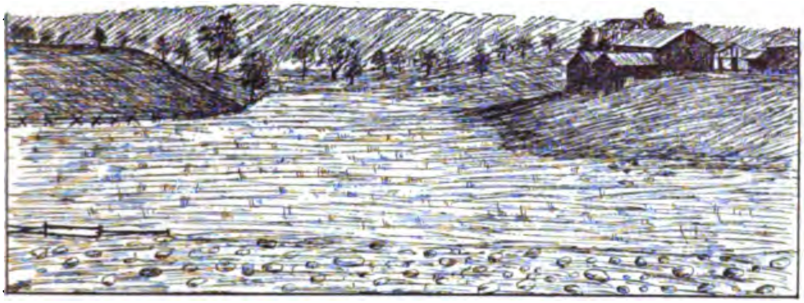


Fig. 42.
The Moggy hollow outlet.

hollow, the bottom of the pass was somewhat higher, but it was cut down by the erosion of the outflow. From the evidence of old shore lines in the immediate vicinity of the outlet, it appears that the outlet was not lowered more than twenty-five feet by the outflowing waters, and perhaps somewhat less. Since the ice made little advance after occupying the passes around Second mountain, near Short Hills, neither the area nor the level of the lake was subject to much variation, while the edge of the ice stood where the moraine was made. During this interval, feeble, but sometimes distinct shore lines were developed about the lake. With these shore lines are to be correlated the broad sub-aqueous moraine plain extending from Chatham to Morristown, and perhaps also the somewhat lower plains near West Summit, as well as many minor features.

As the ice melted back from the moraine, the former outlet of the basin *via* Short Hills was closed, and the Moggy hollow pass remained the outlet. The lake therefore increased in area by filling that part of the basin from which the glacier withdrew. During this period, the lake was more or less completely divided into two parts by the moraine, which, for part of its course across the basin, rises above the highest level which the water reached

(Plate XLI). This moraine barrier probably prevented icebergs from reaching the extra-morainic part of the basin, limiting the time in which berg deposits could have been there made, to the period of ice advance.

It is easy to conceive of a very simple subsequent history for the lake. The northern border of the lake might have followed up the southern border of the ice in its retreat, until the latter had passed Great notch. The lake should then have discharged its waters through this outlet, its level falling to 303 feet, and stopping the outflow *via* Moggy hollow. Though there is no positive evidence of outflow through Great notch, it must have taken place, unless a sub-ice outlet was opened along the course of the present stream. A little later, as the ice retreated farther, the Little Falls and Paterson gaps in Second and First mountains were opened, and the lake must then have discharged its waters through the Passaic. Once this outlet was opened, the lake would soon have been chiefly drained. But the actual course of the history seems to have been less simple.

At a number of places more or less well-defined shore features of the lake are found, at altitudes sixty-five to seventy-five feet lower than those formed when the water stood at the level of the Moggy hollow outlet. At a still later time, the waters of the lake seem to have stood again at a level corresponding with the Moggy hollow outlet. These facts have been interpreted[1] to mean that the level of the lake fluctuated to some considerable extent during the course of its history. It is probable that these changes of level were connected with oscillations of the edge of the ice, which alternately opened and shut some outlet, possibly Great notch (303 feet A. T.), or a sub-ice outlet, along the course of the present Passaic. A mile northwest of Little Falls, till overlies lacustrine clay, showing that the ice subsequently advanced over an area from which it had retreated, and over which the lake had spread. It is possible that the outlet *via* Little Falls was opened and closed again by the oscillation of the ice, though of this there is no positive evidence.

[1] Kümmel, Rept. of the State Geologist for 1893.

Whatever the effects of the oscillation of its edge about Little Falls, the ice was finally melted back beyond the present course of the Passaic, and when this happened, the intra-morainic part of the lake was drained to the level of the outlet at Little Falls. This was at about 185 feet. If drift overlay the rock in the valley at this point, the outlet was a little higher than 185 feet at the outset, but the great volume of the outflow would shortly have swept away whatever of drift there was in the valley at this point. The drainage of the intra-morainic part of the lake must have been rapid, since on the many hills within the basin, rising to heights of 200 to 300 feet, there are no shore lines, though many of the hills are of loose sand and gravel, in which terraces could have been easily and quickly cut.

The remaining stages in the history of the draining of the basin of Lake Passaic, belong not to the time when the ice was in the basin, but to the time after it had withdrawn. For completeness, however, they are added at this point.

When the intra-morainic part of the lake was chiefly drained by the opening of the Little Falls outlet, shallow bodies of water occupied the lowest lands along the Passaic between Little Falls and the moraine (Plate XLII). While the outlet was at 185 feet, the water over Great Piece meadows and Hatfield swamp was fifteen to twenty feet deep. As the outlet was lowered, this shallow body of water was drawn down. Since the outlet is over resistant rock, it was probably cut slowly, so that the shallow lake may have endured for a considerable time. A small lake more or less independent of that which covered the Great Piece meadows remained over the low belt between Second mountain and Long hill and southwest of the moraine along the courses of the present Passaic and Dead rivers. At the outset, its level was at about 230 feet where it was held by the moraine dam at Stanley, west of Summit. The greatest depth of this lake, which may be called *Dead* lake, was not much more than twenty feet. The outflow soon cut down the dam, lowering the lake and finally draining it altogether. If any considerable portion of the Millington gorge in Long hill, through which the Passaic now flows, is post-glacial, the area of the Great swamp was also occupied by a shallow lake after the Little Falls outlet opened. If the bottom of this gorge was then higher than now by so much as ten feet, as seems not unlikely, the lower part of Great swamp was covered by water, and the limits of the swamp considerably extended.

Other extinct lakes.—Aside from the cases already mentioned, lakes were temporarily formed in other ways while the ice was present. The ice itself sometimes helped to make the basin in which the waters were held. In its retreating stages, its edge was sometimes markedly irregular. Furthermore, masses of ice became detached from the main body as the latter receded. These irregularities of edge, and these isolated masses of ice were sometimes so disposed as to call into existence local lakelets or ponds. Temporary lakes were also sometimes developed between the ice to the north and a barrier of drift to the south. The former existence of these *ice barrier* basin lakes is often known by the existence of deltas built into them. So soon as the obstructing ice melted, the bodies of standing water disappeared. In general, their duration was slight. Probably but a fraction of the lakes of this sort which existed are known, since only those which received copious drainage developed deltas.

An excellent example of a delta built in a lake bordered by ice is that at North Church, near Franklin Furnace (Fig. 43). The

Fig. 43.

The North Church delta, sketched from a photograph. The elevated flat near the background is the delta.

lake, which may be called North Church lake, was held in between the ice at the north, and the huge embankment of drift across the valley at Ogdensburg on the south. The delta was built from the ice at the north.[1] Another example of the same significance, though the delta form is not now seen, is the delta plane about Franklin lake in Passaic county.[2]

There were other lakes, not dependent on the presence of the ice for their basins, which came into existence as the ice retreated, and persisted for a time. Lakes of this sort were formed where dams of drift were left in the valleys, and where the outflow was over the dam. In this case the loose material of the obstruction was easily removed. More than one such lake has become extinct by the lowering of its outlet. The best example of this sort is Pequest lake. As the ice retreated, the terminal moraine formed a great dam across the valley of the Pequest at Danville. The water above the dam formed a shallow lake, which may have attained a length of eight miles and a width of two. The outlet needed to be cut down no more than thirty feet or so to drain the lake, and this result was probably accomplished quickly. Other minor lakes of the same type had a temporary existence, but were long since drained.

Through lakes of this sort which persisted somewhat after the ice retreated from them, the drainage changes produced while the ice was here, pass over into those which lasted after it had disappeared.

CHANGES WHICH PERSISTED AFTER THE ICE DISAPPEARED.

Changes in the Courses of Streams.

Though glaciation often entailed notable changes in the courses of the streams in the area which it covered, and in the area adjacent to it, yet most of the larger streams of the glaciated area of New Jersey follow approximately the drainage lines established before the advent of the glacial period, or at least before the advent of its last epoch. The single notable exception is the Passaic system. As already stated in connection with the history of Lake Passaic, the drainage of this basin bears

[1] For details, see Chapter X.
[2] For details, see Chapter XII.

little resemblance to that which existed before the disturbing influence of the ice made itself felt.

The reasons for the general immunity from change in the case of most of the streams of northern New Jersey may be readily pointed out. In the first place, most of the valleys of the glaciated portion of the State were parallel, or essentially parallel, to the direction of ice movement. In this position, glacial erosion tended to emphasize them, rather than to make them less marked. Had their courses been at right angles to the direction of ice movement, or oblique to it, the disturbing influence of the ice would have been greater. In the second place, most of the streams flowed through their valleys in the directions in which the ice was moving. Had their flow been in the opposite direction, the derangement would have been more considerable. In the third place, most of the valleys were deep, and deep valleys are less readily obliterated, or obstructed, than shallow ones. In the fourth place, the rock in which they were cut is, on the whole, hard, and hard rock yields to the erosion of glaciers much less readily than soft. In the fifth place, the thickness of the drift over most of northern New Jersey is rather slight, far too slight to fill the valleys which preglacial and glacial erosion had excavated. Lastly, the terminal moraine—the thickest belt of drift in the State—crosses few of the important drainage lines. When the ice had disappeared, therefore, most of the preglacial valleys still remained, and along them drainage re-established itself, much as before.

The changes in drainage in the upper Passaic basin have already been indicated in connection with the history of Lake Passaic. The changes in the lower part of the basin were not less considerable. After escaping from Second and First mountains, the lower course of the pre-glacial stream was eastward to the sea, probably somewhere south of Newark; but so completely is its valley effaced, that it cannot be accurately located. To it, all the minor streams of the southern part of Essex county, and of most of Union county, were tributary. Their valleys were largely effaced by the drift, and the drainage of Union and southern Essex counties probably has little resemblance to that of preglacial times.

Apart from the Passaic system, the most obvious change in drainage within the glaciated area is that of the Black river, the present course of which is believed to be in some sense postglacial, for while the valley is preglacial, the drainage through a part of it has been reversed. The preglacial flow from the upper part of this valley was to the north, into the valley of the present Rockaway, somewhere near Kenville. Just above the junction, the ice, and later its moraine, obstructed the drainage, and the waters were ponded above. They rose until they found escape over the low divide to the south. When the ice disappeared, the drift filling at the moraine and south of it had raised the surface there above the level of the channel leading south, and the stream has therefore continued to flow in that direction.

Several other minor changes in the courses of streams, occasioned by the ice or by the drift, are known, but they are not of great importance, and illustrate no further general principles.

Changes in drainage were sometimes effected by the drift, even beyond the position of maximum ice advance. This was likely to be the case where the ice occupied a part of a drainage basin, but not the whole of it. The derangement in the part which the ice did cover often entailed changes throughout the remainder of the drainage basin. There is perhaps one notable example of this in New Jersey, though the case is not demonstrable.

There is reason to believe that at some early time, the Raritan river, following its present course to a point midway between Somerville and Bound Brook, turned thence southward up the present valley of the Millstone, which it followed to its junction with Stony brook; thence up the valley of Stony brook to its sharp turn near Port Mercer; thence across the low divide to the Shipetaukin, and thence down the Shipetaukin and Assanpink valleys, to the Delaware. The exact date of the reversal of this drainage has not been determined, and is not easily determinable. It may have been as late as the last glacial epoch, or it may have been somewhat earlier. Quite certainly it occurred within the Pleistocene period. The reason for thinking that the change may have taken place at this time, is the fact that gravels of fluvio-glacial origin, and dating from the last glacial period, occur at intervals along this route; but whether it was river water or ocean water that deposited them, may be questioned.

The principles involved in the change of this river are general ones, and might appropriately be discussed in this part of the report; but so many details concerning the extra-morainic drift of various areas are involved, that the consideration of the case is postponed until the details have been presented (see Chapter XIII).

Lakes.

It has already been stated that the drift was so disposed as to give rise, after the ice melted, to many depressions without outlets, in which the surface waters collected, forming ponds and lakes. So abundant are lakes and ponds in recently glaciated regions, and (except in special situations) so rare elsewhere, that they constitute one of the more easily recognized characteristics of a glaciated region.

The lake and pond basins of the glaciated part of the State belong to several distinct classes. There are 1) limestone sinks; 2) rock basins produced by glacial erosion; 3) basins produced by the obstruction of river valleys by means of the drift; 4) depressions in the surface of the drift itself; 5) basins produced by a combination of two or more of the foregoing; and 6) lakes and ponds produced by artificial means. The fourth class, as specified above, may be subdivided into (a), depressions in the surface of the terminal moraine; (b), depressions in the surface of the ground moraine; and (c) depressions in the surface of the stratified drift. Since the stratified drift in which the lakes of this last sub-class lie is largely in valleys, it would not be altogether inappropriate to class them with the group 3) specified above. With lakes and ponds of the first and last of these classes, we are not here concerned.

In some cases it is not possible to say with absolute certainty to which of the foregoing classes a given lake or a pond belongs, for the available data are too insufficient for a positive determination. Nevertheless, most of the lakes and ponds of northern

New Jersey can be classified in one or another of the foregoing groups, with a reasonable degree of certainty.[1]

For the fuller illustration of lakes of glacial origin, a few details concerning the lakes of the State are added.

Rock basins produced by glacial erosion.—It cannot be affirmed that there is more than a single representative of this class of lake basins in New Jersey, though there may be several. The lake thus distinguished is Sand pond on Hamburg mountain.

Drift dammed valley basins.—The basins of the larger number of lakes in the glaciated part of New Jersey were formed by the obstruction of river valleys, and to this class belong several of the largest bodies of standing water in the State. A few of the most important are White pond (near Marksboro) in Warren county; Swartswood lake, Long pond (Franklin township) and Culvers pond, in Sussex county; Green pond, Budds lake, Split Rock pond and Lake Hopatcong, in Morris county; and Macopin and Green lakes in Passaic county.

The drift which blocks the valleys, giving origin to the lake basins, is sometimes stratified and sometimes unstratified. Many of the valleys are blocked at one end of the lake only, while others are blocked at both. North of the moraine, one lake only appears to owe its existence to the blocking of a river valley by the moraine itself. This is Green pond, in Warren county. Outside the moraine there is likewise a single lake which owes its origin to the damming of the valley. This is Budds lake, in Morris county. Though this lake now drains to the south, its site is believed to have drained to the north, before the glacial epoch. Blocked by the moraine just above the lake, water accumulated in the valley above until it overflowed the divide to the south. The northern shore of the lake does not reach the moraine, though it does reach the stratified drift just outside it.

Lakes in drift depressions.—The number of lakes and ponds in New Jersey occupying depressions in the surface of the unstratified drift (4 (a) & (b), above), is not large. The only ones which can be referred with confidence to this class are a few unnamed ponds.

There is a very much more considerable number of lakes occupying depressions in the surface of stratified drift, which might,

[1] See Annual Report of the State Geologist for 1894.

with equal propriety, be put into the preceding class. They lie for the most part in the bottoms of valleys, and are believed to represent the sites of huge blocks of stagnant ice, which lingered in the valleys after the edge of the main ice sheet had retreated some distance to the north. Gravel and sand were deposited in about and over these ice blocks while glacial drainage still coursed through the valleys containing them. After fluvio-glacial deposition had ceased, the ice blocks melted, leaving the depressions now occupied by the lakes.

Examples of this class of lakes are, Stickle pond, Hewitt's pond, Long pond (Andover township), Iliff's pond, Howell's pond, White lake (Sparta township), and Lake Grinnell (Lane's pond) in Sussex county, and Franklin lake, in Passaic county.

Combination types.—A very considerable number of lakes occupy depressions which do not fall into one or other of the foregoing classes. The basins are partially bounded by drift and partially by rock. They are due to the disposition of the drift with reference to rock elevations, though not necessarily with reference to the walls of valleys. If their basins are the result of the obstruction of valleys this fact does not appear. To this class belong several ponds, mostly small, in Sussex, Passaic and Morris counties.

Number, size and altitude.—The total number of lakes and ponds in New Jersey which owe their existence to the ice is about seventy, but their aggregate area is only about sixteen square miles. Of the total area, lake Hopatcong occupies about one-fourth, and Greenwood and Swartswood lakes nearly another fourth. The average depth of the lakes is not great. Morris pond is said to have a depth of 110 feet. Long pond (Andover township) and Wawayanda lake are reported to have maximum depths of about 100 feet each, but their average depths are considerably less. By far the larger number of lakes are less than 50 feet deep, and many of them much less.

In altitude the lakes vary greatly. Aside from the artificial lakes and ponds, and aside from some very small ponds which have not individual names, the lowest lake is Cedar lake, in Sussex county, with an altitude of 384 feet. The highest is lake Marcia, with an elevation of 1,574 feet. The lakes of northern New Jersey, therefore, have a vertical range of nearly 1,200 feet.

CHAPTER VI.

THE HISTORY OF THE GLACIAL PERIOD.

CONTENTS.

THE PERIOD.

When the glacial origin of the drift was first demonstrated, it was customary to speak of the glacial period as a unit. It soon became evident, however, that the drift was not deposited at one time and by one ice sheet, but at different times, and by different ice sheets which were more or less distinct from one another. So soon as this was clearly seen, the custom arose of referring the drift to two glacial epochs, and in the literature of the subject published between 1880 and 1890, two drift formations are commonly spoken of, and attributed to a first and second glacial epoch, respectively. Continued investigation of the drift developed the fact that the plurality of glaciation was more than dual. When this first became evident, the attempt was then made to refer the drift to three more or less distinct epochs; but it is now believed that this number is too small, and that there were perhaps as many as five epochs of glaciation, separated by more or less considerable intervals of deglaciation.

The conception of these epochs of glaciation and deglaciation is that after a given advance, the ice was melted back some considerable distance from its previous position, and advanced again at a later time. How far the ice receded and how long it stayed in retreat during the interval of deglaciation has not been determined, and probably cannot be, with exactness; but certain lines of indirect evidence testify that some of the recessions were great, —hundreds of miles at least—and that the duration of the retreats was long.

The lines of evidence which have led to this conclusion are various. Old soils, sometimes with the vegetation which grew on them, are found in many places on the surface of one sheet of drift, and beneath another. This shows that after one formation of glacial drift had been made, the ice receded, and that during the interval of deglaciation, the surface of the drift from which the ice had melted became clothed with vegetation. In its next advance, the oncoming ice overrode the surface, burying its soil and its vegetation, where the local conditions were not such as to favor erosion.

In other places, the remains of land animals are found in similar situations, showing that they lived on the surface of one formation of drift after the ice had departed, and that their bones were subsequently buried by the drift of the next ice sheet. Again, inorganic products, such as bog iron ore, which accumulate slowly, are sometimes found between sheets of till, showing that after the till on which it lies was deposited, it was exposed for a long period of time before being buried by the drift of the next advancing ice sheet. Beds of marine and lacustrine sediment and beds of subaerial gravel, sand, etc., are found in the same stratigraphic position, and have a similar significance. Furthermore, it has been found in many places that the surface of the lower body of drift, where two are distinguishable, was deeply weathered before the deposition of the one above, and that both the underlying sheet of drift, and the rock formations beneath it, sometimes suffered extensive erosion after the deposition of the lower formation of drift, before the deposition of the upper. It is found too that the direction of movement of the ice during the deposition of superposed formations of drift was sometimes very different, and that superposed formations are often of unlike constitution. It has been found also that the attitude and altitude of the land in various parts of the glaciated region were different during different epochs of glaciation. For example, a given region was high during one epoch of glaciation, causing the streams from the ice to flow rapidly, while it was low during another epoch of glaciation, causing the drainage from the ice to be sluggish. This is known from the character of the deposits made by the outflowing waters. These and other phenomena show that the drift was not deposited by a single ice sheet in a single advance and retreat, but that the movements of the ice were complex, that protracted intervals of deglaciation intervened between times of ice advance, and that the time between the beginning and the end of the glacial period was very long.

The measure of distinctness of the various epochs of glaciation has been much discussed, but the general facts of great retreats, followed by great re-advances of the ice, is now admitted on all hands. There is still some difference of opinion as to whether the several advances should be regarded as distinct glacial epochs, or whether they should be regarded merely as great oscillations of the edge of the ice. In order to answer this question it is necessary to have a common understanding as to the meaning of the term *epoch*, as applied to the glacial period.

WHAT CONSTITUTES A GLACIAL EPOCH?

If an ice sheet once in existence disappeared, and if subsequently another ice sheet developed in the same region, the second ice sheet would be taken to mark a second glacial epoch. Theoretically, indeed, the successive ice sheets might be so related to each other in time, in position, and in the general sequence of geological events, as to be regarded as distinct epochs of the same glacial period, or as distinct glacial periods. If instead of entirely disappearing, the first ice sheet suffered great reduction of volume and area, and if this reduction were followed by a second great expansion of the ice, such expansion might be regarded as a second glacial epoch, or merely as an oscillation of the edge of the ice sheet during a single epoch. An answer to the question as to how much of an oscillation is necessary, and under what attendant circumstances it must take place, in order that the recession of the ice edge shall mark an interglacial, and its re-advance a distinct glacial epoch, must, in the nature of the case, be more or less arbitrary.

Four elements seem to enter into the idea of a glacial epoch as distinct from other glacial epochs. These are 1) the distance to which the ice retreated between successive advances; 2) the duration of the retreat, or of the interval of deglaciation; 3) the temperature of the region freed from ice during the time of deglaciation; and 4) the intervention, between successive advances, of changes interrupting the continuity of geological processes.

1) It would be arbitrary to name any definite distance to which the ice must recede in order to constitute its re-advance a distinct glacial epoch, nor would it be so much a question of miles as a question of proportions. Considering this point alone, it would probably be agreed that an ice sheet should have suffered the loss of a very considerable proportion of its mass, and that it should have dwindled to a size very much less than that subsequently attained, before its re-advance could properly be called a separate glacial epoch. In this statement the fact is not overlooked that a northerly region—as Labrador or Greenland—might be continuously covered with ice throughout the time of

the two glaciations of more southerly regions. In this case, Labrador and Greenland had but one glacial epoch, though New Jersey might have had two. Continuity of glaciation at the centers of glaciation is, therefore, not regarded as a sufficient reason for discarding the notion of duality elsewhere. In general, the greater the recession, and the greater the advance following, the more the reason for looking on the second advance as a separate glacial epoch.

2) The time element is hardly susceptible of numerical statement, but with a given amount of recession of the ice, its re-advance would be more properly regarded as a distinct glacial epoch if the interval which had elapsed since the retreat were long.

3) The third element is perhaps somewhat more tangible than the second. If in the time between the glaciations of a region which was twice covered by the ice, the climate became genial, the tendency would be to regard the successive glaciations as distinct glacial epochs. This would be especially true if the intervening recession was great and its duration long.

Unfortunately for simplicity and ease of determination, there are difficulties in determining with precision how far the ice retreated between successive maxima of advance, how long the interval during which it remained in retreat, and the extent to which the climate was ameliorated, as compared with that which went before and that which followed.

4) If changes of the sort which interrupt the continuity of geological processes intervened between successive maxima of advance of the ice, the recognition of the earlier and later advances as a distinct ice epoch would be favored. For example, orographic movements, resulting either in continental changes of altitude or attitude, are among the events which might come in to separate one ice epoch from another. Changes of this sort have often furnished the basis for the major and minor divisions of time in other parts of geological history, so that there can be no question as to their adequacy, if they were of sufficient magnitude.

From the foregoing discussion, brief as it is, it will be seen that within certain narrow limits, the definition of a glacial epoch, as distinct from other glacial epochs, must be more or less arbitrary. There are various criteria for determining how far the ice receded after an advance, and how far it subsequently advanced over the territory from which it had receded. Such criteria are several in number. Some of them have already been referred to in the preceding paragraphs, but a fuller statement concerning their meaning is necessary.

CRITERIA FOR THE SEPARATION OF GLACIAL EPOCHS.

1. *Forest beds.*—Beds of vegetable deposits, such as peat bogs, or old soils are frequently found between layers of glacial drift. Such deposits are collectively known as *forest beds,* and may have much or little significance in the interpretation of the history of the glacial period.

During the advance of ice in any epoch, its edge probably oscillated more or less, somewhat as suggested by Fig. 44. Vegetation sometimes grows up to the edge of the ice. If it grew up to the edge of the ice during a temporary retreat, it might grow on drift, and a slight advance might bury the vegetable matter beneath more drift. The mere presence of vegetable material *in situ* between beds of drift is therefore in itself no proof of distinct glacial epochs; but this does not destroy the significance of such beds as a criterion for the recognition of distinct glacial epochs, though it makes caution necessary in their interpretation. It does not follow that since *some* inter-drift forest beds do not prove interglacial epochs, *none* do. In their use as a criterion for interglacial epochs, two points are to be noted: First, the distance from the edge of the overlying drift at which the soil, etc., occurs; and second, the character of the vegetation represented. Concerning the first of these points it is to be said that the farther back from the edge of the overlying drift the buried

Fig. 44.

Figure to illustrate the oscillation of the ice edge during one epoch of advance.

soil occurs, the stronger the evidence of extensive deglaciation. Concerning the second point it is to be said that if the species of plants found in the forest beds indicate a temperate climate, extensive deglaciation during the growth of the vegetation is certain, for temperate vegetation does not grow up to the edge of continental ice sheets, although it may grow up to the end of a mountain glacier which descends far below the snow line. If, then, a forest bed is found far back from the edge of an overlying drift sheet, and if at the same time the species of plants in it show that the climate of the region was temperate when the plants grew, the evidence of great recession of the ice, and of the existence of genial conditions in the deglaciated area, is conclusive.

Forest beds in such situations, and containing such plants, are found at various points in the United States, though they have never been found in New Jersey. Their absence here is easily explained. In general the advancing ice wore off the soil (and its vegetation) from the surface which it over-rode. The soil with its vegetation would be buried only where conditions for erosion were not favorable. As already pointed out (p. 61) these conditions are most likely to be realized on extended flat surfaces, for here there is nothing for the ice to take hold of. The known interglacial forest beds are found where theory demands, namely, in the flat tracts of the Mississippi basin. The glaciated part of New Jersey presented no such surfaces of any considerable extent. Its surface was rough, and its soils were worn away and mixed with the rest of the drift. Though they have not been found, it is possible that buried soil exists in some of the flatter areas covered by the ice. The areas where they are most likely to be found are in the southeastern part of the glaciated tract, either west of Second mountain or east of First.

Among the most remarkable of the interglacial forest beds are those near Toronto.[1] Among the identifiable plant remains are those of the pawpaw, the ash, the elm, the oak and the yew. Most of these species now range as far north as Toronto, but most of them have their greatest development farther south. The pawpaw is not known so far north. It flourishes in the latitude of the Ohio

[1] Coleman, Jour. of Geol., Vol. IX, p. 285, and Am. Geol., Vol. XIII, p. 85.

river, ranging thence north to Lake Erie. At the present time, these species as a whole seem to belong to the climate of a latitude somewhat lower than that of Toronto. Their testimony is that the climate of Toronto, during the interval of deglaciation when they grew, was somewhat warmer than that of the present time in the same locality. Toronto is 800 miles or more from the center of the Labrador ice sheet. The temperate climate which the plant remains prove, makes it clear that any ice sheet which existed north of Toronto at that time must have been small, for with no ice sheet there at the present time, the climate is less warm than during the interval of deglaciation when these plants grew.

It is of significance to note that the phenomena of America are in keeping with those of Europe on this point.[1]

Other interglacial products.—The remains of land animals are often found in the forest beds or at corresponding horizons. Their significance is similar. At Toronto, for example, animal remains are found, and, like the plants, they indicate a temperature warmer than that of the same region at the present time.

Bog iron ore often accumulates in marshes. The process of accumulation is a slow one, especially where the climate is cold. Bog iron ore deposits at the horizon of the forest beds are not common, and none have been reported from localties where their presence is of great significance. Thick beds of such ores would indicate that the ice was absent from the region where they occur for a very long time after the deposition of the underlying drift, and before the deposition of that above.

Beds of gravel, sand and silt, of lacustrine, or marine origin, are found between beds of glacial drift at many places within the areas of glaciation, both in Europe and America. Their presence indicates the absence of ice when they were made. If they be far back from the edge of the overlying and underlying drift sheets, they indicate a great recession of the ice. If at the same time they contain fossils of temperate species, they are evidence of extensive deglaciation. Deposits of this class containing such species are not known in America, though they are known in Europe.

---

[1] Geikie. "The Great Ice Age," 3d edition.

Beds of subaërial gravel, sand and silt formed by rivers in the intervals of deglaciation, have a like significance. The farther back from the edge of the overlying drift they lie, the greater the recession of the ice which they indicate. Though not found, or at least not recognized, in New Jersey, deposits of this class are well known both in America and in Europe. Such, for example, is the wide-spread loess of the Mississippi basin—a formation of silt, of non-glacial origin, which often lies on one sheet of drift and beneath another. Sometimes beneath the loess, and sometimes at its surface, beneath a younger formation of drift, buried soils are found.

Differential weathering and erosion.—Where one sheet of drift fails to completely cover a lower one, the projecting edge of the latter may show much greater weathering and erosion than the one above. The relative amounts of weathering they have suffered, may serve as a rough measure of the length of time during which they have been exposed.

The projecting edge of a lower formation of drift is in general notably more eroded than the overlying formation. This in itself might not be especially conclusive of much greater age for the older of the two formations involved, since it is conceivable that the superior erosion of the exposed part of the older formation might have been accomplished while the margin of the ice stood at the edge of the upper formation; but it has been found that the weathered surface of the lower formation of drift often passes back beneath the upper, and that it was not only weathered but sometimes deeply eroded (Fig. 45) before the deposition of

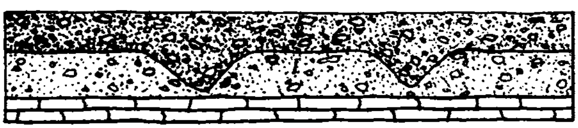


Fig. 45.

Eroded surface of lower sheet of drift, 1, beneath upper.

the drift above. The weathering is shown by the condition of the material. The stones of the upper part of the lower drift formation are often much decayed, and the soluble constituents have been more or less completely leached out, while the overlying formation has not been similarly affected. The farther back beneath the surface of the overlying sheet the weathering extends, the greater was the recession of the ice between the deposition of the successive sheets of drift. The deeper the weathering of the surface of the lower sheet of drift, the longer the interval of time during which the ice was in retreat.

In the United States this criterion of differential erosion and weathering has extensive application. The surface of a lower formation of drift, often far back from the edge of the overlying sheet, is sometimes weathered and its constituents decomposed to depths considerably exceeding those to which the surface of the overlying drift has been similarly affected; that is, the indications are, in many cases, that the lower of two formations of drift was exposed to weathering longer before being covered by the upper, than the upper has been since.

Superposed formations of drift have not been seen in section in New Jersey, though they probably exist. The ice sheet which deposited the body of drift bounded on the south by Perth Amboy-Belvidere moraine, did not reach so far south as an earlier one, and some of the drift deposited by the earlier sheet is exposed (Chapter XIV.) This old drift occurs up to the moraine at Hackettstown, and at some other points in the western part of the State. Sections of the old drift have been seen within a few yards of the moraine and in such relations as to leave no doubt that the older formation passes beneath the younger. The outer and older drift is deeply weathered from top to bottom, even where it has a thickness of thirty feet, the greatest thickness it is known to possess. Its stones, so far as they are of decomposable rock, are decayed. From it, most of the calcareous matter has been leached. The difference in constitution between the drift of the moraine and that of the extra-morainic drift is expressed by the following analyses:

The following analyses[1] of the matrix of old and new drift taken from points about five miles apart, illustrate the difference in composition. The old drift was from a point a little north of Washington; the new from the moraine to the north. In each

[1] By Prof. Albert H. Chester, Rutgers College.

case the material was taken from a depth of five feet from the surface.

	Moraine near Oxford.	*Old drift near Washington.*
Insoluble,	72.90	77.55
Fe_2O_3,	3.43	6.16
FeO,	2.46	0.62
Al_2O_3,	5.08	8.63
CaO,	3.99	0.23
MgO,	3.36	0.58
CO_2,	4.75	0.04
Moisture (by diff.),	4.03	.19
	100.00	100.00
SiO_2 (in insoluble),	52.30	56.35

Another partial analysis of similar material near Hackettstown, the two samples being less than a mile apart and at equal depths below the surface, showed the drift of the moraine to contain 17.18 per cent. of CO_2, while the old drift contained none.

In addition to its deep weathering, the extra-morainic drift now exists in patches only. From most of the surface south of the moraine which it once covered, it has been removed by erosion, and since the erosion of the moraine and the drift north of it has been slight, it follows that the great erosion of the extra-morainic drift antedated the deposition of the moraine. Judging from the physical condition of the older drift, and from the erosion it has suffered, it is inferred that its age is at least several, and perhaps many, times as great as that of the drift of the moraine.[1]

Differences in direction of movement.—It has been found that the ice moved in different directions in the same locality at different stages of the glacial period. This is shown especially by the varying constitution of the superposed beds of drift. Differences in the directions of movement of successive ice sheets do not necessarily call for the disappearance of the first, and the

[1] It should perhaps be noted that locally the ice pushed out some little distance beyond the moraine, during the last glacial epoch, so that there is here and there a little extra-morainic drift of the same age as the moraine.

development of a second from a different center. The dynamic centers of movement may be different at different stages in the history of the same ice sheet, but the differences in direction of movement both in Europe and America, at different stages of the glacial period, are so great that it is clear that the general situation must have been notably different at different times.

It has already been noted that differences in the direction of striæ in a given locality, or in contiguous localities, has little significance in this connection, for the ice of a given locality may move in essentially different directions at different stages in the history of the same ice sheet. The reasons for these changes have already been noticed.

Varying attitudes and altitudes.—More important, perhaps, is the fact that the attitudes and altitudes of various parts of the glaciated area were different at different stages of the glacial period. At one time the conditions of a given region were such as to occasion vigorous drainage, and at another such as to give sluggish drainage. In some cases it is demonstrable that between the vigorous drainage and the sluggish drainage there were intervals of deglaciation, and that the changes in attitude and altitude took place during such intervals. Such changes take place slowly, and usually involve long intervals of time.

APPLICATION OF THE FOREGOING CRITERIA.

All the foregoing criteria find illustration within the glaciated area of North America. They are of unequal value. In some instances a single one of them might be quite sufficient to establish the fact of two ice epochs. In other cases, single criteria which might not be in themselves demonstrative, have great corroborative weight, when found in association with others. In all cases much discretion must be used in their application. They find their readiest application in regions where a later sheet of drift, suspected of belonging to a later ice epoch, failed to reach the border of an earlier sheet of drift, suspected of belonging to an earlier epoch. While within this general area they may be looked for at any point, they are likely to be of rare occurrence except along a somewhat narrow belt, say fifty to one hundred miles, adjacent to the border of the lesser ice advance. The conditions for their occurrence and detection are greatly favored if the lesser drift sheet be the later. Some of the criteria find readiest application along a narrow zone on either side of the margin of the later drift sheet. It is along this zone that the types of surface are thrown into sharpest contrast, both as to material and topography. A few of the criteria have still wider limits of application, both within and without the border of the lesser ice advance.

The application of the above criteria have made it clear that there were several distinct advances of the ice, separated by protracted intervals of deglaciation during which the ice receded far to the north, and during which the vegetation of temperate climate clothed the land where the ice had been. The recognition of these great recessions and advances of the ice is of much more importance than the question whether they are to be regarded as distinct glacial epochs.

THE SUCCESSION OF GLACIAL FORMATIONS OUTSIDE OF NEW JERSEY.

Relations of successive drift formations.—Remembering that the drift deposits of a single glaciation may be very complex (pp. 142-3), attention is now directed to the relations of the deposits of the several glaciations to one another.

It has been conjectured that the history of the glacial period[1] as a whole will be found ultimately to be something as follows for each continent: 1) A succession of ice sheets each of which exceeded its predecessor, until the maximum was reached, followed by 2) a succession of ice sheets each of which fell short of its predecessor, until the ice sheets finally disappeared. This general conception is illustrated by Fig. 46, which is but a graphic expression of the above statement.

Ignoring for the moment the disturbing and destroying effects of each ice sheet on the earlier drift formation which it overrode, there should be as many formations of drift as there were

[1] James Geikie. The Great Ice Age, 3d Ed.

ice sheets, and these formations of drift should stand to one another in the relation of the several lines in Figure 46, in which

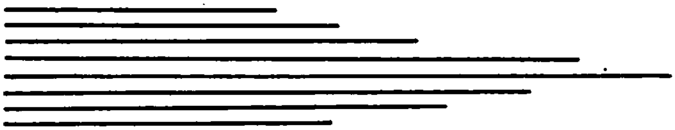


Fig. 46.

Diagram illustrating the conception that the glacial period consisted of several glacial epochs; first an increasing series, and then a decreasing series. The lowest line stands for the earliest glacial epoch, and the top line for the latest.

the lowest line represents the oldest formation of drift, the next the second, and so on; that is, the successive drift formations are imbricated.[1] This relation is indicated, for two sheets of drift, by Fig. 47. These relations would still hold, even though each

Fig. 47.

Two sheets of superposed drift.

ice sheet of the increasing series, in passing over the formation of its predecessor, destroyed it in part, and buried it in part. In so far as the second ice sheet destroyed the formation of the first, the material of the first became a part of the second. When the second drift formation had been completed, therefore, there may have been little of the first one left (Fig. 48). Back beneath the

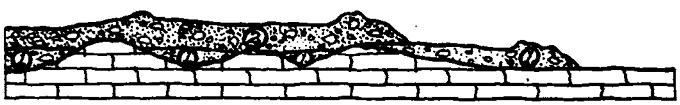


Fig. 48.

Two sheets of drift, the lower largely destroyed by the ice sheet which made the upper.

center of the ice field in the region from which the ice did not melt between the two epochs of ice extension (if there was such a region), the two formations were never separated.

[1] Chamberlin, in Geikie's The Great Ice Age, 3d Ed., p. 736.

In like manner the third ice sheet of the increasing series over-rode, and destroyed or buried the formation of the second. It may even have destroyed such remnants of the first, as the second ice sheet had spared. So the process of destroying or burying the successive formations of drift went on through the whole of the increasing series (Figs. 49 and 50).

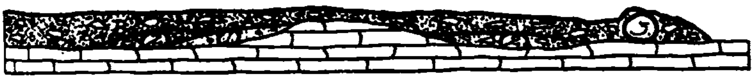


Fig. 49.

Three sheets of drift, the first and second having been largely destroyed by later glaciation.

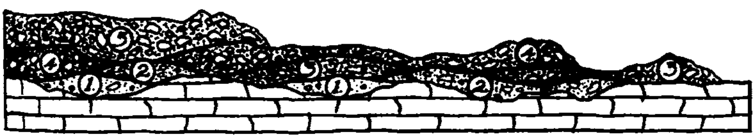


Fig. 50.

Five sheets of drift, the larger part of the older sheets having been destroyed by subsequent glaciation.

Whatever part of a drift formation was not destroyed by the next succeeding ice sheet, was probably buried, and is therefore not easily accessible; and even where exposed it may not be recognizably different from associated formations. Wherever it was overridden without being eroded, the old soil at its surface, and the greater weathering of the drift below the soil, as compared with that above, might betray the existence of the two formations. It is to be remembered, however, that the soil and the surface of the drift passed over by later ice were rarely preserved, and that even if remnants of the soils of each interglacial epoch were preserved, all of them would hardly be found in the same vertical section. For example, a buried soil at A (Fig. 49) which we will suppose to be the oldest interglacial soil, might not be distinguishable in age from a soil at B, which belongs to the second epoch of deglaciation. It follows that the separation of the successive formations of the advancing series of ice sheets would be a most difficult, if not an impossible task, though the recognition of drift older than that of the most extensive formation might not be difficult. Concerning this point it has been well said that "We know very little about the advancing stages of the ice invasion. Theoretically, the stages of incursion should be as prolonged, complex and important as the stages of retrocession. Indeed, if we may trust to the analogy of our annual episodes of glaciation, the incoming of the great Pleistocene winter should have been rather more prolonged than its outgoing, and the struggle between the conflicting forces, and the consequent oscillations of its front, more pronounced. This appears all the more probable if we draw an analogy from the arctic seasons in which the oncoming of the winter is prolonged; while the onrush of summer, after the tide of the season has once turned is surprisingly rapid."[1]

With the formations of the decreasing series of ice sheets, the case is different, for each of these failed to cover the marginal portion of its predecessor. Practically it is the series of formations made by the diminishing series of ice sheets with which we have to deal. "We must content ourselves for the present, therefore, with merely recognizing the probability of a long and important history of glacial aggression, which is largely lost to us. The known history of glaciation practically begins when the farthest ice incursion had reached its limits. The stages which can be worked out are chiefly those of its retreat and its reduplications. Without neglecting the lost half of the history of glaciation, it is still convenient and customary to speak of the earliest known stages as though they were in reality the oldest."[2]

The known drift deposits, therefore, are to be looked on as "a series of sheets overlapping each other in imbricate fashion, the outermost disappearing beneath the next inner, and this, in turn, dipping beneath the succeeding, and so on. The outer uncovered zone of each sheet retains its original form, except as modified by superficial agencies; but the inner buried zone was much modified by the overriding ice during the later advances. In a

[1] Chamberlin. Geikie's The Great Ice Age, 3d Ed., p. 753.
[2] Loc. cit.

general view of the drift, it is important to grasp clearly this conception of the overlapping of the sheets, and to distinguish this imbricate structure from the simple stratigraphical superposition of marine sediments on the one hand, and of simple morainic corrugations following each other in concentric recessional lines on the other." * * * * * * *

"The extent to which the imbrication of the glacial deposits was developed, obviously depended not only upon the extent of the oscillations of the ice-margin, but also upon the intensity of the ice-action. If, with every advance, the ice pushed all loose debris in front of it, imbrication or overlapping would entirely disappear, and a series of concentric moraines would be all that would be left. From these, only the history of the retreat, and that partially, could be worked out. It is obvious, therefore, that the morainic habit and the imbricate habit stand in antagonistic relations.

"As a matter of observation, both of these habits found large expression in the glacial deposits of America. The imbricate habit was predominant in the earlier stages, as found represented in the Mississippi basin, and the morainic habit predominated in the later stages. This was so notably true that the earlier known drift-sheets show but very slight morainic ridgings, and were not greatly disturbed nor abraded by the superposition of the borders of the succeeding deposits. The margins overlap for considerable distances without great disruption of the underlying bed. In the region of later drift, where the morainic habit prevailed, very considerable overlapping of the sheets may be demonstrated; but the abrasion and disturbance of the overridden sheets was much more marked, and the under sheet only retains its integrity for a comparatively narrow zone."[1]

It has now become customary to describe the deposits of a given ice advance as a formation, and in so far as inter-glacial deposits are recognized, they also have received formational names. The succession of deposits which is now recognized in the Mississippi basin, where the fullest glacial succession has been worked out, is as follows[1]—the formations being numbered in the order of age, the oldest being 1:

---

[1] Loc. cit., pp. 736-8.

10. Postglacial deposits.
9. Wisconsin formation (subdivided into an earlier and a later); glacial.
8. Interglacial deposits (Peorian,[1] Toronto beds?).
7. Iowan formation; glacial.
6. Interglacial deposits (Sangamon beds).[1]
5. Illinois formation; glacial.
4. Interglacial deposits (Yarmouth soil, etc.).[1]
3. The Kansan formation; glacial.
2. Aftonian beds; interglacial.
1. The Albertan formation (Dawson); glacial.

A few words concerning these formations are here in place, since they throw light on the general history of the glacial period.[2]

The Albertan formation.—Concerning the oldest formation of drift mentioned in the preceding paragraph, it may be said that practically all that is known of it is that such a formation of drift exists beneath the most widespread formation (the Kansan). Of the glacial origin of the beds (in Alberta) to which this name was first applied, there is some question.

The Aftonian formation.—Subsequent to the formation of the Albertan drift there was a very notable retreat of the ice, though its extent has not been determined. During this stage of retreat there were accumulations of vegetable matter reaching a reported depth in some places of twenty-five feet. This inter-drift formation is best known in Iowa.

The Kansan formation.—Subsequently the ice advanced over the vegetable beds which had been accumulating in the interval of deglaciation, and the Kansan formation was deposited. This is the formation of drift which marks the greatest extension of ice. It was during this epoch that the ice reached its greatest southerly extension west of the Mississippi river. The Kansan formation consists essentially of a sheet of till, with which is associated a relatively small amount of stratified drift. The outermost edge of this drift sheet is not usually marked by any

---

[1] Leverett, Monograph XXXVIII U. S. Geol. Surv.

[2] The following notes are taken from Chamberlin, Journal of Geology, Vols. III and IV.

notable ridging of the nature of a terminal moraine. In this respect it is in contrast with some of the younger formations of drift, especially the Wisconsin formation.

The Kansan formation is usually thin, especially in the marginal zone. Where favorably situated for erosion it has been largely worn away.

The underlying rock surface appears to have been only slightly modified by ice abrasion. Striæ occur beneath the Kansan drift in Kansas, Nebraska, southwestern and southeastern Iowa; but scored surfaces are not abundant.

The distribution of the Kansan formation outside the Mississippi basin, has not been worked out. The extra-morainic glacial drift in eastern Pennsylvania and in New Jersey (see accompanying map Plate XXVIII) may be of Kansan age.

It is worthy of special note that the ice sheet which made the Kansas formation advanced to the southwest, toward the great arid plains, much farther than the others. In the teeth of the southwesterly winds from what are now hot, dry plains, the ice extended 1,600 miles from the center of radiating striæ in Labrador. If the ice of this region came from the center west of Hudson bay instead, it is scarcely less remarkable, for the extremity of the drift in Kansas is about 1,500 miles from that center.

The Post-Kansas (Yarmouth, Buchanan) interval of deglaciation.—The Kansan formation is overlapped by a later drift sheet of similar nature, but between the two sheets there are interglacial deposits. Such deposits have not been widely recognized, but they are known in Iowa and Illinois where they have been called the Buchanan and Yarmouth gravels, respectively.

The Illinois drift sheet.—Following the deposits and the modifications of the drift of the post-Kansan interval of deglaciation, the ice again advanced, making deposits which covered most of the Kansan formation in the Mississippi basin, east of the Mississippi river. The drift deposited during this advance of the ice is known as the *Illinois* formation. This sheet of drift has not been distinctly recognized except in Illinois, Indiana and Iowa. Whether this formation represents a local or a general advance of the ice is undetermined.

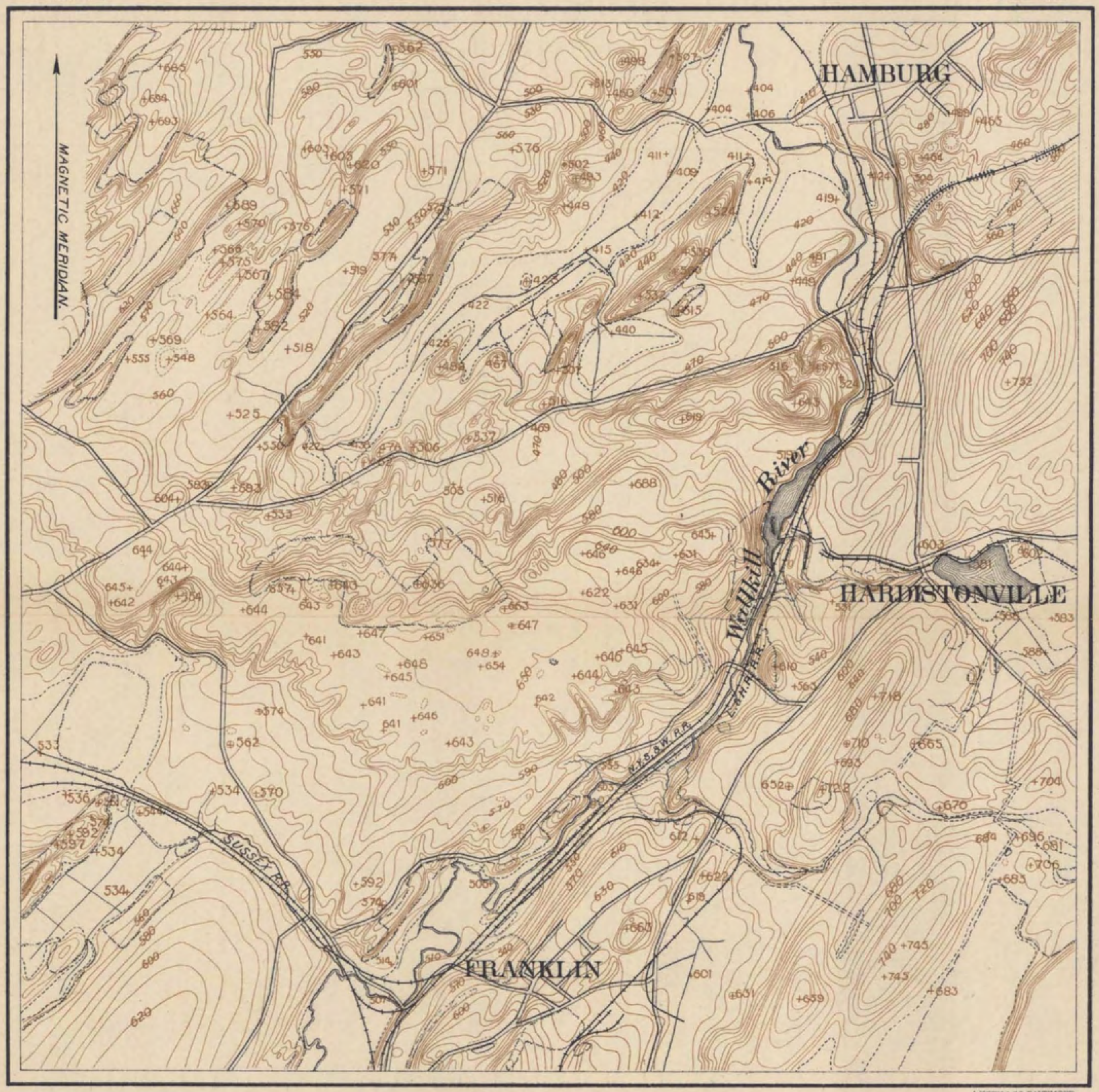
The post-Illinois (Sangamon)[1] *interval of deglaciation.*—Following the deposition of the drift just mentioned, there was another interval of deglaciation during which soil was developed on the surface of the Illinois drift from which the ice had retreated. Remnants of this soil have been recognized in Iowa and Illinois, and it is very possible that some of the similar beds of other localities belong to this interval.

The Iowan drift.—At a later time the ice again advanced over considerable areas from which it had melted, depositing a sheet of drift now known as the Iowan formation. The Iowan till sheet, like its predecessors, is not usually bordered by a very definite terminal moraine. It is a rather homogeneous, more than usually clayey, sheet of till, containing many bowlders, a large proportion of which are of distant origin. In Iowa the granitic types predominate. Immense bowlders are freely scattered over the surface. As greenstones prevail in the till below, there is a constitutional as well as a stratigraphical basis for separating the two formations. This difference seems to imply more than a simple recession and re-advance of the ice. It is best explained by a notable change of direction of movement in the Archean and Algonkian regions to the north, for it is from these regions that the greenstones and granites were derived. The Iowan formation is, on the whole, rather thin, and more uniform in thickness than most of the other drift sheets.

One of the notable features of the Iowan formation is its connection with the main deposits of loess. While loess is associated with other sheets of drift, that associated with the Iowan formation is of exceptional extent. At its edge the Iowan till graduates into loess that spreads far away from its border. In places also it passes by gradations upwards into loess.

Interval following the Iowan formation. The Toronto interglacial beds?—Between the Iowan formation and the overlapping sheet of till presently to be described, there is another horizon marked by soils, vegetal accumulations, oxidation, ferrugination, erosion, and other indications of a notable interval. These are not traceable so far back beneath the upper formation

[1] Leverett. Jour. of Geol., Vol. VI.

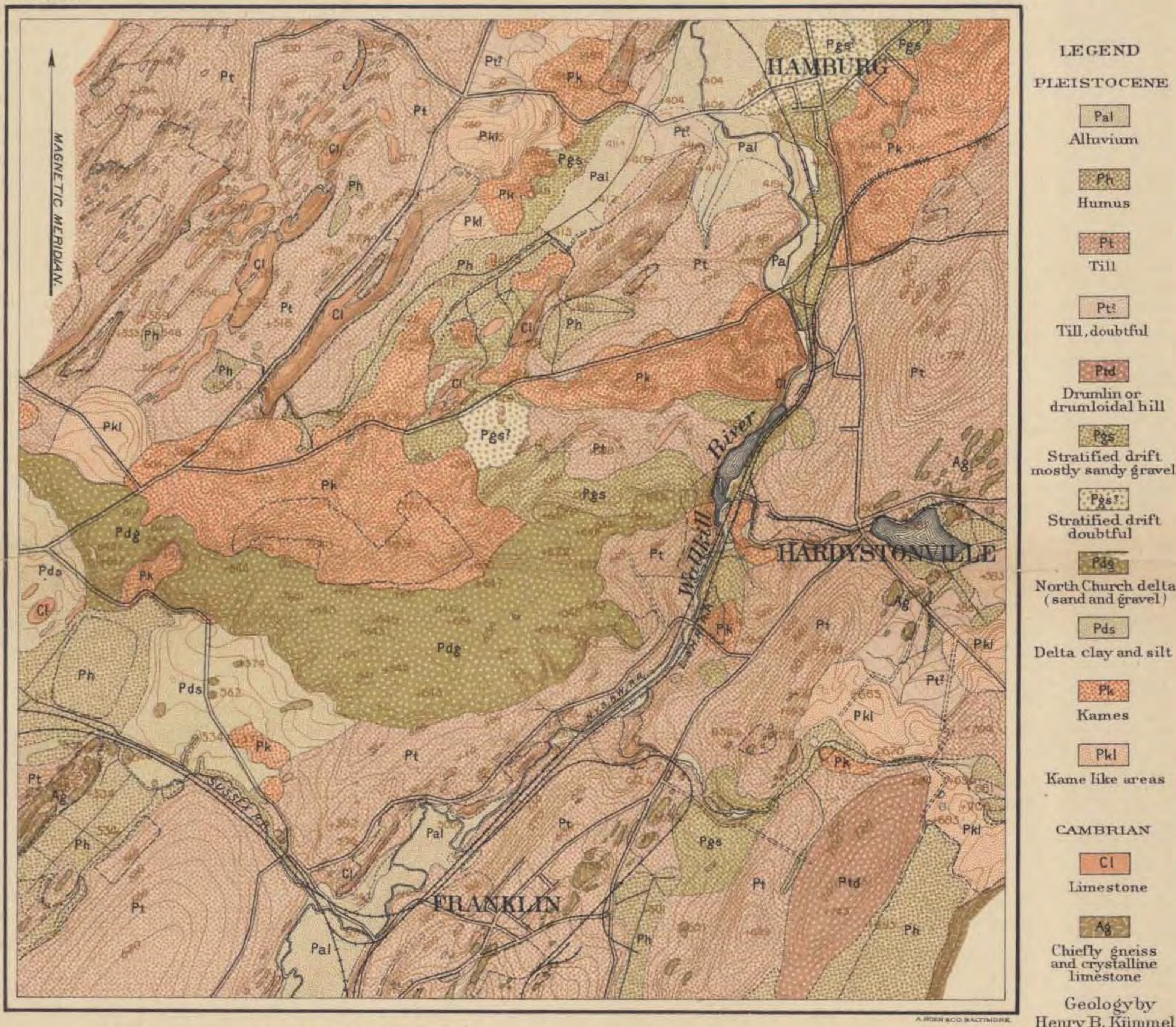


A. HOEN & CO. BALTIMORE.

THE TOPOGRAPHY NEAR HAMBURG

Scale of feet.

1000 0 1 2000 FEET.



THE SURFACE GEOLOGY NEAR HAMBURG

Scale of feet.

1000 0 1 2000 FEET.

as in the preceding instance. This may, with good reason, be attributed to the more energetic action of the ice in the succeeding stage, as indicated by the formation of massive terminal moraines, and by other tokens of intensity of action. Nevertheless, even under great depths of morainic debris, soils, beds of peat, and remains of trees are found at many localities. The interval, however, is best shown by the marked differences between the erosion of the preceding and succeeding surfaces. On the one side, the surface is carved into a well-developed erosion topography; on the other, the irregularities natural to glacial deposits have been scarcely modified. On the one side, the drainage is well established, and lakes are wanting or extremely rare; on the other, drainage is very imperfect, and lakes and undrained basins are numbered by tens of thousands. Broad valleys were cut in the older formation before the newer was formed, as is shown by the fact that the outermost terminal moraine of the latter descends into and rises up out of them where their courses cross. There is further evidence of separation in the different conditions of the surface before and after the interval of deglaciation. Just before it, conditions suitable for the deposition of the loess prevailed widely over the interior, implying low altitude and very gentle slopes. Just after it, there was free drainage, and trains of gravel took the place of widespreading silts, implying steeper slopes. This argument is of force only in so far as the loess is of aqueous origin.

It would thus appear that the interval between the deposition of the Iowan, and the next succeeding formation of glacial drift was sufficient to permit of notable changes in the configuration and conditions of the land, the development of capacious valleys; the general carving of the surface into an erosion topography; the production of vegetal beds and soils, and the deep penetration of weathering. Perhaps to this interval of deglaciation belong the important series of fossiliferous beds in the vicinity of Toronto.[1] These beds occur at somewhat different localities and their testimony is not altogether harmonious. This is perhaps

[1] A. P. Coleman, Toronto Glacial and Interglacial Deposits, Journal of Geology, Vol. III, p. 622.

because they belong to different periods of time rather than to one. While some of the fossils indicate a cool, moist climate, others (those of the Don valley) tell a very different story. They point to a climate as warm as that of Toronto at the present time, if not considerably warmer.

The Wisconsin formation.—A very notable feature of the Wisconsin formation is presented by the loops of its terminal moraines, which indicate strong lobation of the ice sheet. This lobation was greatly influenced, and perhaps even controlled, by the broad, open valleys. Narrow valleys, though deep, appear to have had little effect, but broad, open basins, especially those whose axes lay in the general direction of ice movement, and which reached considerable distances back from the margin of the ice, seem to have been very effective in determining the form of the edge of the ice. The accompanying map presents to the eye something of the extent and nature of this lobation (Plate XVII). It is in connection with this formation that the drumlins, the kames, and askers have their most pronounced development. Along the outer side, not only of the outermost moraines, but of some of the later ones, there are extensive aprons of overwash, and in the valleys great trains of gravelly drift. These phenomena indicate a free and vigorous drainage quite in contrast with the slack drainage implied by the loess and silts of the preceding formation. From this it is inferred that the altitude and slope of the land were at least as great as at present; perhaps at the maximum of vigorous action, somewhat greater. The fluvial deposits do not, however, imply a great altitude. On the surface of this formation, in favorable localities, there are extensive sand-plains indicating vigorous drainage during the recessional stages of the ice sheet.

The Belvidere-Perth Amboy moraine and all the body of drift which lies north of it, is correlated with the Wisconsin formation. Here also belongs the uppermost drift formation (the only well-known drift formation) of Staten Island, Long Island, and New England.

THE SUCCESSION OF GLACIAL FORMATIONS IN NEW JERSEY.

Extra-morainic Drift.

In the preceding chapters (I to V) account has been taken only of that formation of glacial drift which is bounded on the south by the Belvidere-Perth Amboy moraine, and of such stratified drift lying south of the moraine as was contemporaneous in origin with the moraine itself. But there is in New Jersey a formation of glacial drift older than that which has been chiefly considered in the preceding pages. This formation was described in some detail in an earlier report,[1] and the facts concerning it are summarized in the second part of this volume, but it is of so much importance to the true conception of the glacial period and of the drift formations as a whole, that a brief statement concerning it is here introduced.

Distribution.—The distribution of the extra-morainic drift of glacial origin is shown on the accompanying map (plate XXVIII). In the western part of the State, it is found between the moraine on the north and a line running from the Delaware a little south of Riegelsville, to First mountain north of Somerville, on the south. Farther east its southern limit is ill-defined. It is found to some extent in the basin of the Upper Passaic, but here its relations are obscured by the deposits of Lake Passaic. The southern limit is, however, as far south as Second mountain in the latitude of Scotch Plains or Plainfield. From this point eastward its limit cannot be determined for the ice which produced it was probably limited in its advance by the sea, which is believed to have stood 120 or more feet higher than now, relative to the land in this part of the State, and to have covered the lowlands between Plainfield and Raritan bay. Had the ice which reached this water been thick, it might have advanced into or even across the sound, but if it was only the thin edge of the ice which reached the water, its farther advance would have been stayed. Within the area of its occurrence, that is, between the

[1] Ann. Rept. of the State Geologist for 1893, pp. 73-123.

moraine on the north and a line drawn from Rieglesville to Scotch Plains on the south, the drift is by no means continuous. It is, indeed, more commonly absent than present, and where it is found, its amount is often slight. Locally, however, there are beds of it thirty feet or more in thickness. In its lack of continuity it is in striking contrast with the drift north of the moraine. It can hardly be doubted that at the time of its origin, it was essentially continuous over the whole of the area within which patches only are now found.

The topographic distribution of this extra-morainic drift is significant. It has the same disregard of altitude as the drift within the moraine, but it has a marked preference for certain topographic situations. It is most commonly found on broad uplands of slight relief. It occurs also in cols, sometimes on gentle slopes, and in capacious valleys. It is absent from steep slopes and from narrow valleys and ridges. That is, it is absent from situations where erosion has been great, and present in situations where erosion has been little. The fact that no such distinction holds in the case of the drift north of the moraine is strong evidence of the relatively great antiquity of that to the south.

While the extra-morainic drift sometimes occurs in beds of considerable thickness, scattered bowlders of imperishable rock, such as quartzite, are often the only parts of it which remain. The scattered bowlders are much more common than the beds of drift.

Constitution.—The constitution of the drift is in a general way, comparable to that of the younger drift. It contains materials of all grades, from huge bowlders to fine clay. Among the stones many sorts of rock are represented, especially those which are not easily decomposed. Quartzite (sandstone, conglomerate) bowlders are much more common than others, though bowlders of gneiss are abundant in some places, and slabs of shale in others. Limestone is rarely present. When the drift occurs in quantity, glaciated stones are by no means rare. Locally they are as abundant as in the younger drift. Where the drift is represented by scattered bowlders only, they rarely show striæ.

Physical and chemical condition of the drift.—One of the most distinctive features of the old drift is the physical and chemical condition of its constituents.[1] In many places all pieces of decomposable rock have disappeared, or have become so rotten that they crumble readily. In many sections, not a piece of gneiss or other crystalline rock can be found which is not decayed to its core. In other places, however, this is not true. The largest bowlders of the formation were derived from the crystalline formations of the Highlands. Again, the old drift has been leached of its soluble constituents, generally to its base, even where it is very thick. Its materials also have been much more completely oxidized than those of the newer drift, giving it a notably higher color. In the condition of its decomposable rock constituents, in its absence of soluble matter, especially lime carbonate, and in its oxidation, the old drift is in striking contrast with that of the moraine, and of the region north of the moraine.

Conclusions.—The foregoing facts are sufficient to make it clear that this extra-morainic drift is glacial, and that it is much older than the main drift formation to the north. This conclusion is based on the incomparably greater weathering and erosion which it has suffered. There is also some reason to think that the movement of the ice was more easterly when the old drift was deposited than when the younger formation was made. No sufficient reason has been found for regarding the extra-morainic glacial drift as belonging to more than one glacial epoch.

From the condition and relations of the old drift formation of New Jersey, it is thought to correspond with the Kansan formation of the Mississippi basin, though the correlation of drift formations at such great distances is necessarily open to question.

From the foregoing it appears that the only glacial formations which have been distinctly recognized in New Jersey are those of the Kansan (?) and Wisconsin formations. Whether the State was glaciated during the intermediate epochs is unknown. If so, the ice of the Wisconsin epoch overrode the deposits, and either destroyed them or mutilated them beyond recognition in so far as they are exposed.

CONTEMPORANEOUS DEPOSITS IN WATER.

As already indicated, it is believed that when the ice which deposited the older drift was at its maximum, the land along its

[1] See p. 175.

edge was 120 feet or more lower than now. Under these conditions a large part of southern New Jersey would have been submerged. A great sound would have existed across the State from Newark and Raritan bays on the northeast to the Delaware at Trenton on the southwest. South of this sound there were some islands, but their aggregate area was relatively small. The relations of land and water which would result from the sinking of the land 100 feet, are shown on the accompanying map (Plate XLIII). The submerged area was probably somewhat greater than that shown by this map. Under these conditions, the drift carried by that part of the ice which reached the sound was delivered over to the water, which distributed it after the manner of waves and currents, assisted by floating ice.

If this be true, there should be a widespread marine formation in southern New Jersey, contemporaneous in origin with the extra-morainic glacial drift. Such a formation is believed to exist. The materials which enter into its make-up were contributed partly by the ice which came down from the north, partly by the islands of the southern part of the State, and partly by the formations which were submerged; for the water was shallow, and the surface material of the submerged formations may have been somewhat extensively re-worked and re-deposited. This re-working may have taken place chiefly during the period of sinking which inaugurated the conditions here sketched. The formation believed to have been made at this time has been called the *Pensauken* formation.[1] It is not to be understood, however, that all of this formation is marine. Some of it, perhaps much of it, was probably deposited by streams on the land during, and perhaps preceding, the subsidence which resulted in the submergence, and some of it after emergence, while the land was still low.

At the northeast, in Middlesex county, the Pensauken formation often resembles till, containing the same elements, in similar proportions. Striated stones and bowlders, though rare, are not altogether wanting. Like the extra-morainic drift already

[1] Report of the State Geologist of New Jersey for 1893.


GEOLOGICAL SURVEY OF NEW JERSEY.
A MAP OF
NEW JERSEY
Showing
approximately the area
which would be submerged were the
land to sink 100 feet.
1902.
Scale of Miles.
Port Jervis
Milford
Pine Island
Stony Point
Tuxedo Park
Deckertown
Branchville
Franklin
Ringwood
New City
Suffern
Nyack
Piermont
Edison
Newton
Water Gap
Blairstown
Hibernia
Boonton
Paterson
Englewood
Stanhope
Dover
Hackettstown
Caldwell
Montclair
Passaic
Belvidere
Washington
Chester
Morristown
Orange
ESSEX
NEWARK
NEW YORK
EASTON
Phillipsburgh
Peapack
Summit
JERSEY CITY
BROOKLYN
Elizabeth
High Bridge
Clinton
Plainfield
Rahway
HUNTERDON
Somerville
STATEN I.
Frenchtown
Flemington
Perth Amboy
RARITAN BAY
Millstone
New Brunswick
South Amboy
Sandy Hook
Keyport
Atlantic Highlands
Matawan
Rocky Hill
Lambertville
Princeton
Jamesburg
Red Bank
Seabright
Pennington
MERCER
Hightstown
MONMOUTH
Long Branch
Freehold
TRENTON
Asbury Park
Allentown
Belmar
Bordentown
Spring Lake
Manasquan
Lakewood
Point Pleasant
Burlington
Beverly
New Egypt
Mount Holly
Manchester
PHILADELPHIA
Pemberton
Toms River
Moorestown
Whitings
CAMDEN
Vincentown
Seaside Park
Haddonfield
Medford
CHESTER
Woodbury
Bridgeport
Shamong
WILMINGTON
Swedesboro
Mullica Hill
Atco
Pennsgrove
Glassboro
Atsion
Barnegat
Barnegat City
Williamstown
Winslow
Hammonton
Woodstown
Batsto
Harrisia
Tuckerton
Elmer
Malaga
Beach Haven
Salem
Alloway
Egg Harbor City
Vineland
Mays Landing
Bridgeton
Greenwich
Millville
Brigantine
Atlantic City
Somers Point
Longport
Tuckahoe
Ocean City
Port Norris
Sea Isle City
Cape May C. H.
Avalon
Holly Beach
Cape May City
DELAWARE BAY
PENNSYLVANIA
DEL.
NEW YORK
ATLANTIC OCEAN
SUSSEX
PASSAIC
BERGEN
WARREN
MORRIS
HUDSON
UNION
SOMERSET
MIDDLESEX
BURLINGTON
OCEAN
CAMDEN
GLOUCESTER
SALEM
ATLANTIC
CUMBERLAND
CAPE MAY
DELAWARE RIVER
HUDSON RIVER

referred to, its constituents are thoroughly decomposed, where they are of decomposable material, and like the extra-morainic drift, it has suffered extensive erosion since it was deposited. As in the case of the extra-morainic drift, these things argue for its great antiquity. It was indeed the correspondence between the condition and constitution of the Pensauken and extra-morainic drift formations which first suggested their contemporaneity.

To the southward, the drift-like characteristics of the Pensauken disappear. The Newark shale and sandstone fragments, and the stones from the crystalline schist formations diminish in quantity, and sand and gravel derived from the Cretaceous, Miocene, and other formations of the Coastal plain older than the Pensauken, assume a relatively greater importance.

The post-Pensauken rise of the land has been probably somewhat unequal, so that the original upper limit of the marine part of the Pensauken formation is not marked at all points by the 120-130 level. On the other hand, the fluvial part of the Pensauken was not limited to the area submerged, but ran up the valleys to higher levels. Bearing these exceptions in mind, and locally they are of importance, the Pensauken was originally distributed over an area not very different from that represented as submerged on Plate XLIII.

There is a still older formation (the Bridgeton) in the southern part of the State, which contains materials of such a kind, and of such size, as to indicate that floating ice assisted in their transportation. The relation of this formation to glacial formations in the north has not been established.

THE CAUSE OF THE GLACIAL CLIMATE.

The cause of the glacial period is not here discussed, but it may be pointed out that all the older hypotheses to account for the cold climate seem to have failed. The astronomical hypothesis of Croll,[1] depending on variations in the ellipticity of the earth's orbit, and the precession of the equinoxes, ingenious as it was,

[1] Croll. Climate and Time. For briefer exposition of this hypothesis see Geikie's The Great Ice Age, or Ball's The Cause of the Ice Age.

and re-enforced as it has been by the later arguments of Ball,[1] seems not to explain the facts; for, not to speak of its adequacy, it does not put the several epochs of glaciation into the proper time relations. Wallace's proposed modification of Croll's hypothesis in the way of geographic changes in the distribution of land and water, seems not to stand the test of scrutiny, for there is little evidence of the changes suggested at the time the glacial epochs occurred, and were the suggested changes a fact, it is by no means certain that they would have brought about the specified result. The favorite (perhaps because easily understood) hypothesis, that the glacial condition resulted directly from great elevation[2] of the northern lands, likewise seems to fail to explain many of the things which the true theory must explain, besides lacking a convincing measure of independent evidence of its inherent truth.

At the present time, the most plausible hypothesis seems to be one which has for its essential feature a change in the constitution of the atmosphere.[3] The suggested change concerns but a minor constituent of the atmosphere, namely the carbonic acid gas. Small as the amount of this gas in the atmosphere is, its influence on temperature is great. It is believed that doubling its amount would bring on a tropical, or subtropical, climate in our latitude, while halving it would involve a return to glacial conditions. The influence of this gas on temperature has long been known, but it is only recently that an adequate cause of considerable change in its volume has been pointed out, and an attempt made to fit the hypothesis to the complex facts and relations of the glacial period.

Carbonic acid gas is consumed in considerable quantities, in the decay of rocks, especially of igneous rocks. At times when the decay of such rocks is rapid, the supply of carbonic acid in the atmosphere is reduced, and as the impoverishment goes on, the temperature is reduced. Should the process be carried far enough, a frigid climate would result. When the land is relatively high, erosion and the decay of rocks is rapid. High land

[1] Ball. The Cause of the Ice Age.
[2] Upham. Appendix to Wright's Great Ice Age.
[3] Chamberlin. Journal of Geology, Vol. VII, 1899.

therefore, by promoting rock decay, would cause the withdrawal of carbonic acid gas from the atmosphere, and tend to bring about frigid conditions. On this hypothesis, periods of cold climate should follow periods where the land was high, though the maximum of frigidity might be attained after the land was largely reduced to lower levels by erosion.

In addition to the unequal consumption of carbonic acid gas, the supply furnished to the atmosphere is subject to various fluctuations. A single illustration, and it is but one of many, will be mentioned. One source of atmospheric carbonic acid, is in volcanoes. Volcanoes have been notably more numerous and active at certain times in the earth's history than at others.

Considering all the possibilities in the way of unequal supply and unequal consumption of the carbonic acid gas of the atmosphere, and considering the relation of the cold and warm periods of the past to the conditions which might have enriched and impoverished the atmosphere, so far as this most important element is concerned, it is not too much to say that the new hypothesis is full of promise. It is to be remembered, however, that it is still new, and that when it has been tried, as all such hypotheses must be tried, in the light of facts not yet discovered or not yet applied to it, it may be found wanting. In this case, it will be laid aside with the others which have already been abandoned.

It is now well known that there was a period of widespread glaciation about the close of the Paleozoic era, and that it affected not high latitudes, but low, the ice even invading the tropics. The solution of problems of glacial climate must take account of all glacial epochs, whenever and wherever they occurred. While it is not necessarily true that all had a common cause, the presumption is in favor of this assumption. The earlier hypotheses seem to have no application whatever to this early glaciation, and even the later one, while not so hopeless, seems to fail of adequacy.

THE DATE AND DURATION OF THE GLACIAL PERIOD.

The date and duration of the glacial period are matters of the greatest interest, but neither has been determined with numerical exactness. Many lines of calculation, all of them confessedly more or less uncertain, point to the retreat of the last ice sheet from the northern part of the United States, 6,000 years to 10,000 years ago. While these figures are to be looked upon as estimates only, there are so many lines of evidence pointing in the same direction that the recency (geologically speaking) of the last glaciation must be looked on as established. The best data for the calculations which have led to the above results are furnished by Niagara Falls[1] and the Falls of St. Anthony,[2] at Minneapolis. In each case, the distance the falls has receded since the ice disappeared, and the present rate of recession are known with some degree of approximation to the truth. Assuming the rate of recession to have been uniform, the above results as to duration of postglacial time for these localities are obtained.

A strong argument for the recency of the last glaciation is the slight modification which the surface of the drift has undergone. This sort of an argument does not easily lend itself to numerical results.[3]

The time since the first glacial epoch, and, therefore, the duration of the glacial period, is still more uncertain. Various estimates have been made, but all of them on data which are not easily reduced to numbers. A conservative estimate is that the time since the epoch of maximum glaciation (Kansan epoch) is fifteen times as long as the time since the last (Wisconsin epoch). Many geologists would increase this ratio.

---

[1] Gilbert. Science. Vol. VIII, 1886, p. 205.

[2] Winchell. Geology of Minnesota. Vol. II, p. 313.

[3] A summary of the various estimates of the duration of post-glacial time is given by Wright in his Great Ice Age.

CHAPTER VII.

CLOSING STAGES OF THE LAST GLACIAL EPOCH.

CONTENTS.

AQUEOUS FORMATIONS OF LATE GLACIAL AND EARLY POST-GLACIAL AGE.

As the ice-edge in the interior of the continent drew back into the basins of the great lakes, water accumulated abundantly between it and the divides to the south, and sought favorable points of discharge into the Mississippi basin. These fringing lakes made deposits of greater or less amount according to the extent and the duration of the ponded waters. With the progress of events, a very complicated series of such lakes were formed, changing their outlines and outlets with the changing positions of the ice. The shifting series may be regarded as continuing until the drainage assumed its present course.

The deposits made at this time consist of stratified gravels, sands and clays, bordered in some places by beach-lines; but in other places, because the lakes were too small, or their shores too inconstant, or other conditions unfavorable, well defined shore lines were not developed. Among the stratified deposits of this time are clays, more or less abundantly charged with glaciated stones, which have sometimes been interpreted as glacio-lacustrine deposits, and sometimes as the products of a re-advance of the ice-sheet. The latter interpretation may be the true one in individual cases, but the former appears to have wide application. All the existing great lakes between the United States and Canada, and probably the great lakes of northwestern Canada, are bordered by these deposits, which bear witness to the former great expansion of the bodies of standing water.

The Champlain clays and their equivalents.—After the retreat of the ice from the St. Lawrence valley, the sea extended up its lower portion an undetermined distance. The salt water stood 560 feet above the present sea-level[1] in the vicinity of Montreal, and occupied the basin of Lake Champlain. Standing at this height, the sea cannot have failed to connect with Lake Ontario, and perhaps with the lakes farther west. The proof that the sea covered the site of Lake Champlain is found in the marine fossils in the clays overlying the glacial drift at various points about the lake. To explain the presence of the sea over the area of Lake Champlain and its surroundings, it is necessary to suppose that the land about the St. Lawrence bay stood some hundreds of feet lower than now, relative to sea level, at the time the ice melted from the region.

The clays deposited in the Champlain valley during this submergence are known as the Champlain clays, and the epoch of their deposition has sometimes been called the Champlain epoch. The Champlain clays seem to be laterally continuous, with the clays of the Hudson River valley, extending as far south as Haverstraw. The height of the clays in the Hudson valley diminishes to the southward, and at the place last named they are but little above the river.

Similar clays occur at various points in Bergen county, where they are just above sea level, and about Hackensack, where they are mostly below sea level. They are regarded as the equivalent of the Champlain and Hudson River clays. South of Hackensack the bottom of this clay is, in some places at least, more than 100 feet below sea level, and in the Newark meadows farther south its bottom is locally at least 100 feet lower; that is, fully 200 feet below sea level.

---

[1] Sir William Dawson. The Canadian Ice Age, p. 201.

The clays were deposited in standing water, after the withdrawal of the ice. The static condition of the water is shown by the structure of the clay, and the time of deposition by its superposition on till. Either the sea, or standing water at sea level, extended up the west side of the Palisade ridge as the ice withdrew, converting the Newark and Hackensack meadows and some of the adjacent lowland into a bay; or the outlets to the south, the Narrows, Arthur kill and East river were closed, converting the region into a great lake, fed by the waters from the melting ice to the north.

If the sea water, or standing water at the level of the sea covered this area, it was probably because the land was depressed, the amount of depression increasing northward. If the southern outlets were closed, making the area of the meadows and their surroundings a lake, instead of a bay, there are three ways in which, theoretically, this might have been done. These are 1) by elevation of the land in the latitude of Staten and Long islands; 2) by the blocking of the outlets by morainal deposits; or finally 3) by a combination of 1) and 2). If the first were true, the land has since sunk; if the second were true, the Arthur kill, the Narrows and East river are of post-glacial excavation; if the third alternative be true, there has been something of erosion along the outlets, and something of elevation in the region of the clays since they were deposited.

Were fossils present in the clays of the Hackensack region they might decide, or help to decide, the question of its marine or lascustrine origin; but south of Lake Champlain no fossils significant of the origin of the clay have been found in it.[1] If the clay were deposited in an arm of the sea, marine fossils would have been expected, even though the water was cold. Waters in the bays about Greenland are by no means without life, and the clay is admirably adapted to preserving traces of life, if animals or their shells were once buried. If the clay was deposited in a lake fed by ice water, life would have been meager at the best. The absence of fossils, therefore, seems to be against the hypothesis of a bay of salt water.

[1] A skeleton of a carnivorous mammal, perhaps a fox, has been found in the clay near Hackensack.

On the other hand, there is no independent evidence that the land in the latitude of Long and Staten islands stood higher than now when the ice retreated, so that the outlet can hardly be supposed to have been blocked in this way. There is no proof either that the moraine did, or that it did not, constitute a dam between Perth Amboy and Long Island, just after the ice retreated. If it did, its height was probably not more than twenty-five feet above sea level. If it existed, and if there was a corresponding dam across the site of the Narrows and the present East river, a lake might have been formed over the site of the area where the clays are.

There is some independent evidence that the water stood over the area in question much above the level of the clays, and much above the height of any moraine dam which can have existed.

Reference has been made in the preceding paragraphs to a body of water over the area in question, at sea level. If the lowland of northeastern New Jersey were depressed below sea level, it may be doubted whether the water of the bay would have been salt, even if there were no moraine dam between it and the sea. The connection with the ocean would have been relatively slight, and for a long time after the ice had left the State, the discharge of fresh water into the bay must have been great. The presence of occasional bowlders in the clay shows that ice floated out on the standing water, indicating that this was the avenue through which the ice waters were discharged. Such connections as the bay had with the ocean were perhaps outlets, rather than inlets. Under these circumstances, the waters of the bay may not have been salt, or at least not normally salt, and sea life may, on that account, have been absent. This conception, that of a great bay at sea level, the waters of which were fresh or nearly so, seems on the whole the one to which there is least objection. This condition of the bay could not have endured after the ice had retreated so far to the north as to let the sea into Lake Champlain via the St. Lawrence valley; but there is no evidence that the clays of New Jersey were deposited after this time.

If there was a bay, fresh or salt, west of the Palisade ridge after the ice melted, the height of the water relative to the present land was dependent on the amount of depression which affected the area at the time.

The surface of the clay is generally covered by sand, or sometimes gravel, much of which appears to have been deposited either as the body of standing water became shallow, or by streams after the standing water had disappeared. Some of it may have been deposited during a later submergence, for in two or three places an old soil has been found on the surface of the clay, below the sand (see Chapter XII). The sand and gravel over the clay are sometimes unconformable on the clay, indicating that the latter was in some places eroded before the deposition of the former. So far as New Jersey is concerned, the erosion is not known to be of such a character as to demand the emergence of the clay before the deposition of the sand.

Similar clay extends up the valley of the Connecticut, and probably originated at the same time and in the same way. Like the clays of the Hudson valley, those of the Connecticut are at lower altitudes at the south, and at higher and higher levels to the north. Like the clays farther west, the Connecticut valley clays might be explained by submergence beneath the ocean, by the existence of a bay at sea level, the water being essentially fresh, or by the existence of a lake in the valley. The first two hypotheses call for a depression of the land to the north, the last for a blocking at the lower end of the Connecticut valley.

The rise to the northward of the clays in all these valleys, the continuity of the clays of the Hudson valley with those of the Champlain valley, and the presence of marine shells in the clay about Lake Champlain, all point to a northward rise of the land since the late stages of glaciation, and, therefore, to a depressed condition of the northern lands at the time the ice retreated. The coarse, stratified drift which overlies the clay in all the valleys mentioned was probably deposited, in part at least, while this northward rise was in progress, and after the standing water had become shallow, or by rivers after the standing water had ceased to exist. The northward rise of the land would have facilitated the cutting of the outlets to the south, if barriers existed.

The evidence of northward rise of the land since the last glacial epoch is not limited to the Hudson, Champlain and the Connecticut valleys.

In the Great Lake region few marine fossils have yet been detected, and the interpretation of some of these is open to question, but it seems highly probable that brackish, if not saline, waters extended into these lakes, for the marine crustacean *Mysis* has been found living in Lake Michigan, and it is most reasonable to suppose that it underwent adaptation by gradual transition from saline to brackish, and from brackish to fresh waters.

"Around the coast of the southeastern Provinces, and on the south coast of Maine, there are marine deposits that have usually been referred to the Champlain epoch. While this is the more probable interpretation, it is not beyond question, since there are evidences that the marine deposits of the coast of Maine were contemporaneous with the ice of that region,[1] while the marine deposits of the St. Lawrence basin were formed after the ice evacuated it, and unless the view of those who maintain the local character of the glaciation of eastern New England be correct in the fullest sense, the two events of the marine deposits in the two localities were not strictly contemporaneous, though they may have been closely successive."[2]

The conclusion that the northern lands were lower than now when the ice melted carries with it the farther conclusion that the land has since risen, relative to the sea level. Much other evidence, gathered from a wide range of territory, points to the same conclusion. Not only this, but the post-glacial rise of the land seems to have been greater, as the center of the ice field is approached, and amounts to as much as 1,000 feet or more near the center of the field.

ISOSTASY.

These relations between the amount of post-glacial elevation and the center of the ice field have led to the hypothesis (1) that

[1] George H. Stone, Journal of Geology, Vol. I, No. 3, 1893, pp. 246-254.
[2] Chamberlin, in Geikie's The Great Ice Age, p. 769-770.

the low altitude of the land at the close of the last glacial epoch was the result of sinking caused by the great load of ice, and that the sinking was greatest where the ice was thickest; and (2) that the rise of the land since the glacial period is the result of the removal of the load of ice, and that the resilience was greatest where the depression was greatest, namely, where the ice was thickest. This hypothesis, which makes the crust of the earth responsive to load, is the doctrine of *isostasy*.

Attempts have been made to test this hypothesis in various ways. The result of all investigations thus far carried out seems to point to the conclusion that it contains a truth, and that load,

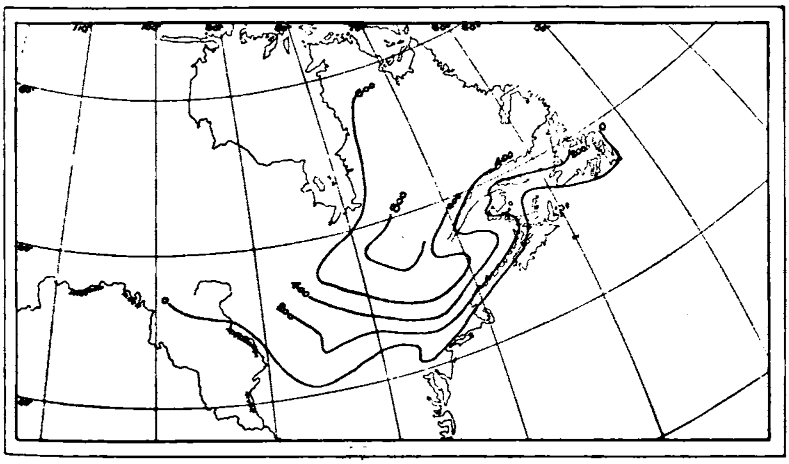


Fig. 51.

DeGeer's ice Isobasic chart. The lines with numbers connect places supposed to have risen the same amount since the melting of the ice, the amount of rise being indicated by the figures.

or the removal of load, affecting a great area, is a real cause of crustal movement. It is not to be inferred, however, that this is the only cause of such movement, or that the crust necessarily responds promptly or uniformly to it. It is probable that other forces originate crustal oscillation, or may limit, delay, or defeat the movement which load, or its removal, would tend to produce.

Post-glacial changes of level in the glaciated area.—Some years since De Geer[1] attempted to determine the amount of post-glacial elevation which the southeastern part of the area covered by the

[1] De Geer, Proc. Bos. Soc. Nat. Hist., Vol. XXV, 1892.

ice had undergone. His conclusions are expressed by the chart, Fig. 51. According to this chart, New Jersey, or at least that part of the State which lies in the latitude of New York, has not suffered elevation since the ice departed.

On *a priori* grounds, De Geer's conclusion would be rational enough, but it does not follow that another would be irrational.

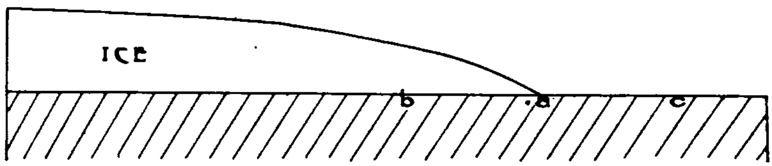


Fig. 52.

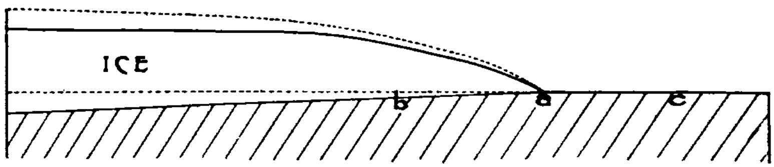


Fig. 53.

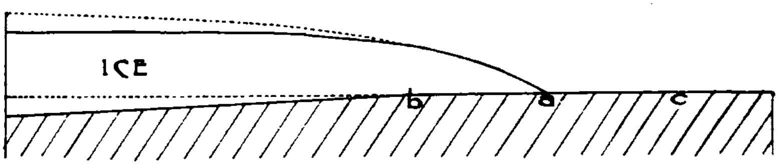


Fig. 54.

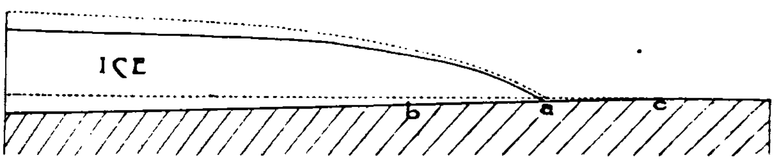


Fig. 55.

Diagrams illustrating the possible effects of ice load, on sinking, as explained in text.

Whatever the constitution of the earth, the crust is so rigid that, assuming the truth of the doctrine of isostasy, it cannot be affirmed that the area of sinking, under load, would correspond exactly with the area of load. The limit of sinking might extend somewhat beyond the load, or might fall somewhat short of it. Fig. 52 represents the edge of an ice sheet, the bed on which it rests not having sunk. Fig. 53 represents the same after depression has taken place, the depressed area corresponding with the area of the ice, and the depression being greatest where the ice is thickest. The positions which ice and land would have had, without the sinking, are indicated by the dotted lines. Fig. 54 represents another conception, namely, that the depressed area may fall somewhat short of the loaded area, while Fig. 55 represents the depressed area as exceeding the area loaded by ice. Granting that the ice cap depressed its bed, Figs. 54 and 55 are perhaps as likely to represent the truth as Fig. 53.

Turning now to the question as to whether any part of New Jersey beside the area of the clays beneath and about the Hackensack meadows was submerged during the last glacial period, at its close, or later, the evidence is not found to be so unequivocal as could be desired. At a few points well above the altitude of sixty feet, there are deltas, or deltoid bodies of stratified drift, which are most significant. These will be described in Chapter XII. On the whole, the evidence seems to favor the conclusion that the northeastern part of the state was covered by standing water to the depth of 100 feet or more after the ice retreated, though this conclusion cannot be regarded as beyond question. If it be correct, the area has risen a corresponding amount since the ice melted.

South of the glaciated area, the evidence is reasonably conclusive that the land of the State stood at least forty to fifty feet lower than now, during at least the closing stage of the last glacial epoch. Evidence of still greater depression since the ice disappeared, perhaps to the extent of 200 feet or more, is not altogether wanting, but it is less convincing. It is not to be assumed, however, that the depression of forty to fifty feet, or that of 200 feet, if such there was, was necessarily the result of the weight of the ice. This may or may not have been the case. Whatever the amount of depression of the extra-glacial area during the last glacial epoch or at its close, it has been elevated at least an equal amount since. Cook pointed out long ago that the coastal region is now sinking. If so, and the conclusion seems well supported, the amount of post-glacial elevation has been somewhat greater than stated above.

COASTAL TERRACES.

The Cape May formation.—Evidence of late glacial or post-glacial submergence south of the moraine in New Jersey is found along the coast and in the lower courses of the valleys of the southern part of the State. Around much of the coast there is an ill-defined terrace 30 to 50 feet A. T., which has every appearance of youth. In some places this terrace appears to have been cut by waves in older formations, and in some places it appears to have been built by waves out of debris which they gathered where their action was destructive. The constructional terraces are, as a rule, composed of material similar to that of the older terraces on which, or against which, they lie. From the coastal terraces, corresponding terraces extend up the valleys, rising up stream. Except near the sea, these valley terraces are thought to be the work of the streams.

This general condition of things holds, with varying distinctness, from Raritan bay to Delaware bay, by way of the coast. Throughout this stretch of coast there is little to fix the age of the terraces beyond the fact that they represent the latest phase of constructional water work in that part of the State, and that their appearance is everywhere that of youth; but following up the Delaware bay and river some light is thrown on the question. Though often ill-defined, terraces corresponding with those of the coast persist along the bay and the lower course of the river, and the valleys tributary to the Delaware have terraces harmonious in level with those of the main stream, and corresponding in all essential respects with those of the valleys which lead to the Atlantic coast. Above Camden, the constitution of the terrace along the Delaware changes, one of the constituents being gravel of fluvio-glacial origin. Passing from south to north this new constituent first appears sparingly, and low in the terrace. Farther north it becomes more abundant, constituting a larger and larger proportion of the terrace material, until, when Trenton is reached, it is the principal constituent. To this point the terrace has risen but little. Traced still farther north, the surface of the terrace rises notably, and though present in places only, may be traced up to the moraine at Belvidere. In this part of the valley the terrace is clearly the remnant of the valley train (Chapter XIII) which the waters from the melting ice developed in the Delaware valley, while the edge of the ice was at the position of the moraine just below Belvidere.

While the glacial terrace at Trenton and above can hardly be said to be continuous with the terrace down to Cape May and up to Raritan bay along its east coast, their continuity is so little interrupted, and they are so harmonious in level, and in the general youthfulness of their features, that there seems to be little reason to doubt their essential contemporaneity. To the material of these terraces south of the region where it is glacial, the name *Cape May formation*[1] has been given. Cape May peninsula is wholly composed of it. It is to be remarked that distinct and unequivocal shore lines at the upper limit of the Cape May formation are wanting, even where conditions for their development seem propitious.

The Cape May formation may be equivalent or partially equivalent in age to the Champlain clays farther north, but their contemporaneity was probably not perfect, and their composition and mode of origin are so different, that the name "Champlain clays" is not applicable to the more southern formation.

The Cape May formation, according to the preceding sketch, is partly fluviatile. There is no good reason why the gravels at Trenton should be excluded from the formation, except that they are more naturally connected with the Delaware valley train, and it seems desirable to distinguish between the formations of the glacial and glacio-fluvial origin, and those which originated in other ways. The failure of the gravels of the Delaware below Trenton to behave as river terraces should, is evidence that the Delaware river was not the only agent concerned in their deposition. They may have been partly and even largely deposited by the stream at the outset, but are believed to have been submerged at a later time.

These terraces along the lower course of the Delaware are often covered with clay-loam, which increases in thickness to the

[1] Report of the State Geologist of New Jersey for 1897, p. 19.

south. The loam occasionally, as at Trenton, contains stones and even bowlders, suggesting that floating ice still came down the valley when it was deposited, but most of it was deposited after glacial drainage had ceased to be vigorous at Trenton or below. At several points between Trenton and Camden, this surface loam is sufficiently clayey to be used for brick, and at Philadelphia its use for this purpose is extensive. That the clay-loam at low levels about Philadelphia is of marine origin, is indicated by the marine diatoms and sponge spicules, which, along with fresh water species, are found in it, up to elevations of at least forty feet. Though the shells of both fresh and salt water diatoms occur, it is easier to account for fresh water species in marine deposits, than for marine species in river deposits. If the land were forty feet lower than now, the salt water might have furnished the marine diatoms, while the streams coming into the bay brought in the fresh water forms. The marine species are perhaps not demonstrative evidence of marine submergence, for diatom shells and sponge spicules might be carried about by the wind.

Such in brief is the evidence drawn from the southern part of New Jersey, pointing to the conclusion that this part of the State was forty to fifty feet lower than now at the close of the last glacial epoch. The relations of land and water which a sinking of fifty feet would entail, are shown on the map, Plate XLIV.

There is good evidence in the distribution of the extra-morainic glacial gravels along the Raritan (see map, Plate XXVIII) that this stream was not flowing east of some such point as the junction of the North and South Branches when the drainage from the ice was coming down Green Brook, for the gravels were carried *not only several miles up the valley of the Raritan, but also quite across the valley and some distance up the valley of the Millstone on the other side.* The distribution of these gravels points to the cessation of the current of the stream at some such level as fifty or sixty feet.[1]

If the Raritan at this time flowed up the present course of the Millstone, as has been conjectured, it would account for the

[1] This point can only be adequately presented when the details of the ~~distribution of this gravel~~ have been given. See ~~Part II of~~ the report, Chapter XIII.

failure of glacial gravel down the Raritan below Fieldville, but if the stream flowed up the present course of the Millstone, it should have carried into that valley a larger amount of gravel than it did, if it had much of a current.

Within the area of the glacial drift there is also a little indecisive evidence pointing to the same conclusion. There is an indistinct terrace of material of glacial origin about Perth Amboy, which seems to be in keeping with the terraces farther south. Furthermore, the surface of the glacial drift about Elizabeth and Rahway is often covered with red clay similar to the fine part of the till beneath, but which has not the appearance of normal till. If water stood over this region temporarily after the deposition of the till, this peculiar surface development of the till might be explained. This clay has no well-defined upper limit, but it is most conspicuous at elevations corresponding with those of the terrace already described. It should be understood, however, that this clay is not everywhere present, even below forty feet, and that the surface of the till below its level never shows decisive evidence of wave-wear, and often shows a topography which seems inconsistent with such wear.

In spite of the general failure of such unequivocal marks of submergence as shore lines, deltas, etc., it is confidently believed that New Jersey, south of the moraine, and perhaps north of it, stood forty to sixty feet lower than now during and since the last glacial period.

HIGH LEVEL LOAMS.

Evidence of submergence and later re-emergence of the southern part of the State to the extent of more than sixty feet, is for the most part less tangible and less susceptible of convincing statement; yet such evidence is not altogether wanting, either south of the moraine or north of it.

At various points there are high-level loams, the origin and explanation of which have occasioned much speculation, but for which no satisfactory explanation has been found. This loam is most widespread in the Coastal plain region, though it is not confined to that province. It occurs at various elevations up to 200 feet and more, and from this altitude ranges down to the low-lying Cape May formation. Within the areas where it occurs, it is by no means continuous, and its character is often so poorly defined that it cannot be distinguished from the weathered products of the formations on which it lies. But occasionally it occurs in such positions and relations, and has such a distinctive composition, that it cannot be regarded as the weathered product of the terrane below, or as local wash derived from any adjacent formation, or as a deposit made by the wind. These decisive occurrences of the loam tend to carry conviction concerning that which is in itself indecisive. This high level loam is what was designated "High-level Jamesburg" in some of the earliest reports.[1] In thickness the loam ranges from zero up to twenty feet or more, though it rarely exceeds six or eight feet, and is still oftener less than five.

In Philadelphia this loam is represented by the Philadelphia brick clay. It overlies the Cape May terrace and the Pensauken gravel, and runs up to the levels of 150 feet or more. The loam at high levels seems to be continuous with that on the Cape May formation along the Delaware. The high level loam has, however, not been traced into actual continuity with that of the low levels in an exposed section, for no such section exists; but what appears to be the same body of loam has been seen in sections at many points and at most levels between its highest position and the Cape May terrace. In the last position it is post-glacial, and probably marine. If the loam above is continuous with that below, as it seems to be, it also must be post-glacial.

North of the Coastal plain, this high level loam lies on the Newark series at various points south of the glacial drift, and farther north on the drift itself. In its more clayey phases, it is used for brick clay. The brick clay south of Pennington up to elevations of about 200 feet, represents it. In the vicinity of Trenton and Trenton Junction, where it lies now on the Pensauken and now on the Newark formation, the clay-loam is

[1] Report of the State Geologist for 1894.

extensively used for brick. In its basal part, there are often pebbles and large stones, and sometimes it is distinctly pebbly throughout. The loam is best developed on surfaces of slight relief, but it occasionally caps isolated hills.

At Morrisville, opposite Trenton, a loam overlies a) remnants of the Pensauken formation, and b) the crystalline rock of the locality. The loam was well exposed by numerous cuts in the spring of 1902, at altitudes ranging from sixty feet to 120 feet. The Trenton gravel proper is here limited to sixty feet. The aggregate length of the exposures seen must have been as much as a mile. The character of the loam was essentially constant throughout the section. Its distinctness from the Pensauken was not more marked than its distinctness from the decayed products of the crystalline rock. Its youthful appearance was in striking contrast with both. In its base, there were pebbles and bits of rock from the underlying beds, and while there was no absolute plane of separation, the division was as sharp as it usually is between superposed formations. This loam has a depth of as much as eight feet in some places, and is locally stratified. The composition of the loam is so like that of the fine material of the Trenton gravels, and so unlike that of the base on which it rests, that it cannot be doubted that its connection is with the former. The only question which exists is as to its eolian origin. If it were blown up from the Trenton terrace below, it would have no significance in this connection; but it contains, though rarely, rounded stones several inches in diameter well up above its base, and in some places masses of rock several feet in diameter from near-by ledges. These occur in such positions that they cannot be supposed to have worked down slope. Many of them are too deep below the surface to have been buried by human agency. Shore ice seems to be the only explanation of their presence in the loam. Here then we seem to have loam, as young as the Trenton gravel formation (last glacial), rising up to 120 feet at least, and not of eolian origin.

Clays which may be contemporaneous with the loams and clays just mentioned, and which may have had a similar origin, overlie the last glacial gravels and sands at the Plainfield brick yards.

In that vicinity they reach an altitude of fully 200 feet.

Farther northwest, near Pluckamin, there is at a few points, a little surface clay which is highly calcareous. It has been identified up to altitudes of 170 feet. It is a deposit formed by standing water, and seems to have been connected with the glacial waters of the last ice epoch. It has no resemblance, physically, to the loams farther south, but may have the same genetic significance.

Over wide areas of the Brunswick shale, in the vicinity of Millstone, Somerville, White House, etc., there is a little clay,

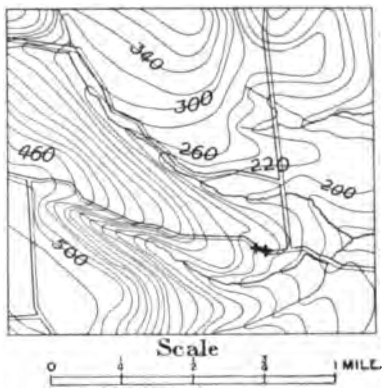


Fig. 56.

Sketch showing the position in which the laminated clay near Flemington occurs. The exact locality is marked by the crosses.

one to five feet thick, which does not appear to be strictly residuary, though its material was derived from the local shale. It has the look of clay deposited beneath standing water, and resembles the clayey parts of the till over which the waters of Lake Passaic stood. These clays are physically unlike the loams referred to above, but they may be its equivalent and have the same significance.

Again, two miles north of Flemington, in a road cut, there is a little laminated clay, which was deposited in standing water. It occurs at an elevation of about 240 feet. Fig. 56 represents the relations in which the clay occurs. Between this point and the ocean it is not easy to see how any basin would have existed.

In the Coastal plain, the base of the loam often contains numerous pebbles, or in some cases the pebbles and stones are aggregated at its base. Among the stones in this position are often wind-worn stones, and sometimes great numbers of them, which have not been found in the underlying beds. Frequently, too, the stones at the base contain worn bits of ferruginous sandstone derived from the cemented parts of the underlying gravel. The pebbles and stones at the base of this loam are as a rule hard, and pebbles of thoroughly decayed rock, such as are common in the underlying gravels, are absent. These phenomena indicate the exposure of the surface beneath the loam before the latter was deposited, and therefore that the loam is not a phase of the underlying formation, but something distinct from it.

It is not possible to assert that all these loams and clays have a common origin, or that they constitute a *formation* in any proper sense of the term. The doubt on this point led to the abandonment of the name (Jamesburg) earlier applied to the loam. It is recognized that there are many ways in which surface loams may originate, and yet have much resemblance to one another. They may be the result of biotic agencies, such as earthworms and insects, which bring up fine earthy matter to the surface; they may represent wind-blown dust; they may represent the weathered product of the underlying formation; they may be local accumulations of surface wash; or they might in some cases represent merely the last stage of deposition of the underlying formations. But none nor all these suggestions will explain some of the loams or clays referred to above.

A comparable loam is found at numerous points in the northeastern part of the State, over the red drift composed chiefly of Triassic sandstone and shale debris. In many places, but not everywhere, it is sharply separated from the underlying drift. In color, it is generally yellowish or yellowish brown. In texture, it varies from sand to clay. It sometimes contains pebbles, and even bowlders, though neither are common. Frequently there are bowlders at its very base, partially in it, and partially in the till which lies beneath. In its typical development, the loam is never distinctly stratified. Nowhere does this loam have its typical development at an elevation of more than 240 feet, and below this level it is distinct over a relatively small part of the surface within the area where it exists; and even where it is present, it does not always possess very sharply defined characteristics. It is absent from steep slopes, but may be present on gentle ones, and on flat surfaces, and is particularly prone to occupy depressions in the surface of the underlying drift. Good illustrations of this loam may be seen at the stone quarries at Avondale, though the base of the loam here is not sharply differentiated from its till. The following Figure (Fig. 57) represents the relations seen in an excavation for a building just west of the railway station in Passaic in 1902.

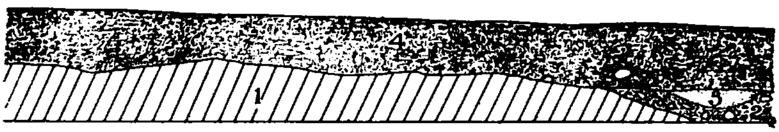


Fig. 57.

Diagram illustrating the position and relations of the yellow loam just west of the depot at Passaic. 1 is the Newark formation; 2 is till; 3 is stratified drift; and 4 is the yellow loam. A single stone occurred in the face of the section as seen. Depth of section, ten feet.

It is not possible to affirm that this loam on the glacial drift is a formation distinct from the drift in origin, or that all of it was contemporaneous, or had the same origin. It was formerly thought[1] that it represented dust accumulated on the ice by the wind, and let down on the drift beneath when the ice melted; but the similarity of the loam to that over the surface farther south raises the question of their community of origin, and the hypothesis previously advanced in explanation of the loam over the glacial drift, is not applicable to that elsewhere. Any of the processes by which loam may originate, may have been operative here. Furthermore, it is not possible to assert that the loams of the glaciated area are the equivalent, either in time or in mode of origin of those farther south.

[1] Report of State Geologist for 1893, pp. 217-224.

It would be easy to dismiss the loams with the suggestion that they may have originated at different times and in different ways, not always determinable; but a dismissal of the question is not equivalent to its solution. The facts which have been mentioned and many others of the same sort which will not be here detailed have raised the question whether there was not a deep, but very temporary submergence of the State to a much more considerable extent than has been commonly recognized, at, or soon after, the close of the last glacial epoch.

It may here be added that a surface loam over glacial drift, and over non-glaciated surfaces as well, is widespread. In some parts of the Mississippi basin the loess corresponds to it in position, though loess rarely covers the drift of the Wisconsin epoch.[1] It is to be noted further that the loess (and its equivalents) is a very variable formation. Various hypotheses of its origin have been entertained, but there is no evidence that it is marine.

Aside from the loess, and from loam and clay which has been correlated with it, there is in many places loam or clay over the drift of the Wisconsin formation, and over surfaces where there is no drift. These clays and loams reach up to great altitudes. They have as yet not attracted the attention they deserve.

[1] Journal of Geology, Vol. IV, p. 929.

CHAPTER VIII.

POST-GLACIAL CHANGES.

CONTENTS:

IN THE DRIFT ITSELF.

So soon as the ice melted and left the drift exposed to the elements, they began their work upon it. At the outset, the drift was not covered by vegetation, and its absence allowed the wind and the water to work freely on the fresh material. The drifting of dust and sand by the wind, and the erosion of the surface by the rain, and by the rills to which the rain gave rise, were probably active at the beginning; but so soon as vegetation got a foothold on the new formation, it tended to retard the work of both wind and water.

The changes in the drift which have taken place since the deposition of the drift may be grouped in three classes: (1) those accomplished by the wind; (2) those accomplished by running water, and (3) those accomplished by weathering.

Wind work.—The wind has not worked great changes on the surface of the drift. Locally, as on the east side of Newark bay, about Hackensack, and at some points along the Passaic below Paterson, sand has been heaped up into dunes; but the dunes of the drift-covered area are few and small. Wind-drifted sand, too small in amount to constitute dunes, is more widespread. It occurs at various points, and to the depth of a few feet on the east sides of some of the valleys (Delaware, Black, Passaic, Hackensack, etc.), which contain sand. Locally it has been blown up on the trap ridges (notably Long Hill) from the shores of Lake Passaic. Traces of it are found in many other situations.

The amount of dust which has been blown about since the ice departed is past calculation, for in its lodgment it is not concentrated as the sand is. This lack of concentration results from the fact that it is carried higher in the air than the sand, and surface obstacles interfere less with its progress. While its amount cannot be calculated, it probably far exceeds the amount of wind-blown sand.

Stream erosion.—The amount of post-glacial stream erosion which has been accomplished in northern New Jersey is, on the whole, exceedingly small. In many places the streams have not lowered their channels at all, while in other places they have effected more considerable results. The irregular disposition of the drift, nearly filling the valleys at certain points, and leaving them nearly free from drift at others, gave occasion for these variations in the subsequent work of the streams. In many places where the drainage of a valley was ponded by drift, the water has cut through the barrier, deepening the channel greatly at that point, while above and below the dam there has been little or no erosion, In general, however, the surface of northern New Jersey remains very much as it was at the time of the retreat of the ice.

Post-glacial erosion in the valley of the Delaware has been more considerable than in any other valley of northern New Jersey. The river has cut its channel from the level of the highest gravel terraces to its present bed. In the narrow parts of the valley, as at the Water gap, post-glacial erosion has been sufficient to remove all the gravel originally deposited there. Locally the river has lowered its channel as much as 120 feet, and in several places as much as 100 feet, and flood plains of some width, frequently a half mile or more, have been developed at the new level (Fig. 58).

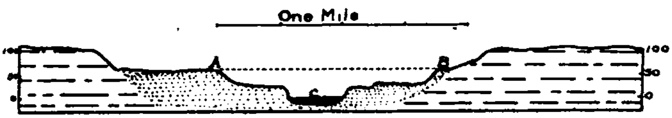


Fig. 58.

Cross-section illustrating post-glacial erosion in the Delaware valley at Trenton. The filling below A B has been removed in post-glacial time.

The tributaries of the Delaware have done less. Flatbrook has deepened its valley sixty feet in some places, and none at all in others; Paulinskill has cut down forty-five feet in some places (Fig. 59), none at all in some others, and in still others it has even

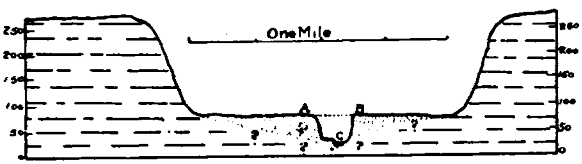


Fig. 59.

Section illustrating the post-glacial erosion in the valley of Paulinskill, two miles nort h east of Hainesburgh. T he filling below A B has been removed.

silted up its valley (Fig. 60); the Vernon, Papakating and Wall-

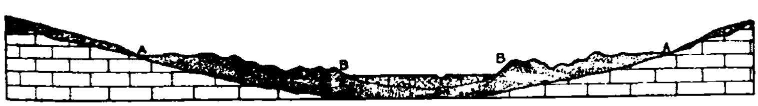


Fig. 60.

Section illustrating valley aggradation in post-glacial time. 1 represents the filling.

kill valleys have been but slightly changed, except the latter at Ogdensburg, where the cutting may have been considerable. The Pequest has cut a gorge forty to forty-five feet deep across the moraine between Danville and Townsbury.

Along the Rockaway valley there has been fully 100 feet of erosion at some points, as in the vicinity of Powerville and Boonton, where the drift filling of the valley was thick. The Pequannock, Wanaque, Ramapo and Pompton have rarely lowered their valleys more than fifteen to forty feet, and in some places none at all. The same may be said of the Passaic, which, except at Stanley, has lowered its bed above Little Falls hardly at all. At Totowa it has probably lowered its channel fifty to ninety feet. Below Paterson it has deepened its channel thirty to forty feet in many places, though this is above the average. The Saddle, Hackensack, Pascack and Tienekill have rarely deepened their valleys so much as forty feet since the drift was deposited, and the average deepening has probably been less than half that amount. These figures give some idea of the small amount of erosion which has taken place in post-glacial time even along the larger streams. The erosion along the smaller ones is still less. This slight amount of erosion would not in itself necessarily mean shortness of time; but the alternative explanation, lowness of grade, is not applicable to some of the streams, though it is to others.

The amount of post-glacial erosion is not to be measured simply by the depths to which the streams have sunk their channels in the valleys which existed after the ice was gone. The extent to which new ravines and tributary valleys have been developed in the drift is also to be taken into account. Judged by this standard, we must conclude that the duration of post-glacial time is not long, for valleys of post-glacial origin are few. In many regions the details of drift topography, even where such as to be readily modified, remain much as they were when the ice disappeared.

In general it may be said that most valleys have been deepened a little, and some of them, locally, a good deal; many ravines and small valleys have been developed in the drift; and a few lakes and ponds have been drained by having their outlets lowered to the levels of their bottoms.

Could the number of tons of debris which have been eroded from the surface of the drift and carried down the streams, much of it to the sea, be stated, the figure would doubtless be impressive, but the effect on the drift topography has been slight. In addition to the erosion accomplished by the streams, there has also been a small amount of erosion about the shores of the lakes and ponds, but its aggregate amount is small.

Weathering.—The changes that belong under this heading have made little alteration in the geography of the drift, but they have, in their proper measure, changed the character of the drift itself. The principal agents of weathering are heat and cold (especially freezing and thawing), plants and animals, the air, and the water which sinks into the soil. Frost penetrates two to four feet; burrowing animals stir up the surface to some similar depth; the roots of herbaceous plants extend down a few inches to a few feet, and those of trees much farther; water sinks beneath the surface, and goes down to depths far beyond the base of the drift.

Some of these agencies loosen the surface material, rendering it more easily eroded by wind and water. The water, aided by the carbonic acid it dissolves from the air in its descent, and by the various other acids it takes up as it sinks through the soil, dissolves out from the drift such mineral constituents as are soluble. Various other chemical changes take place, among them oxidation, hydration and carbonation, involving the action of atmospheric elements, in connection with water. Chemical changes of one sort and another have doubtless affected the drift from top to bottom, but they are rarely of such a nature as to be readily detected, except at and near the surface. Their most obvious result is change of color. The deeper parts of the till have, in general, the color of the comminuted products of the rock entering into its composition. Outside the Triassic area, the prevailing color is some shade of grey, but with the color of the body of the drift, the color of its surface portion is often in contrast. The latter is generally brown, or brownish, a color which results primarily from the peroxidation and hydration of the iron. In the drift of moraine age, the alteration of color is moderately complete down to a depth of two feet, and often down to three, but is rarely noticeable at a depth of more than five feet. The lime carbonate has usually been completely abstracted to the depth of two or three feet, and occasionally to depths of five or six feet. The greater the amount of lime carbonate present, the less the depth to which it has been leached out. Where the till is composed mainly of Triassic material and is therefore red, its surface has often been bleached to some extent, and has a lighter color than the parts beneath. Weathering, partly physical and partly chemical, has also affected the surfaces of bowlders. These changes in the drift indicate that the duration of post-glacial time has been sufficient to allow of somewhat complete leaching and oxidation of the drift down to a depth of rather more than two feet, and of partial alterations to a depth of three or four feet more. How long this would be in years cannot be stated, but it would seem that no estimate of post-glacial time has been made which is too short for the result which has been accomplished.

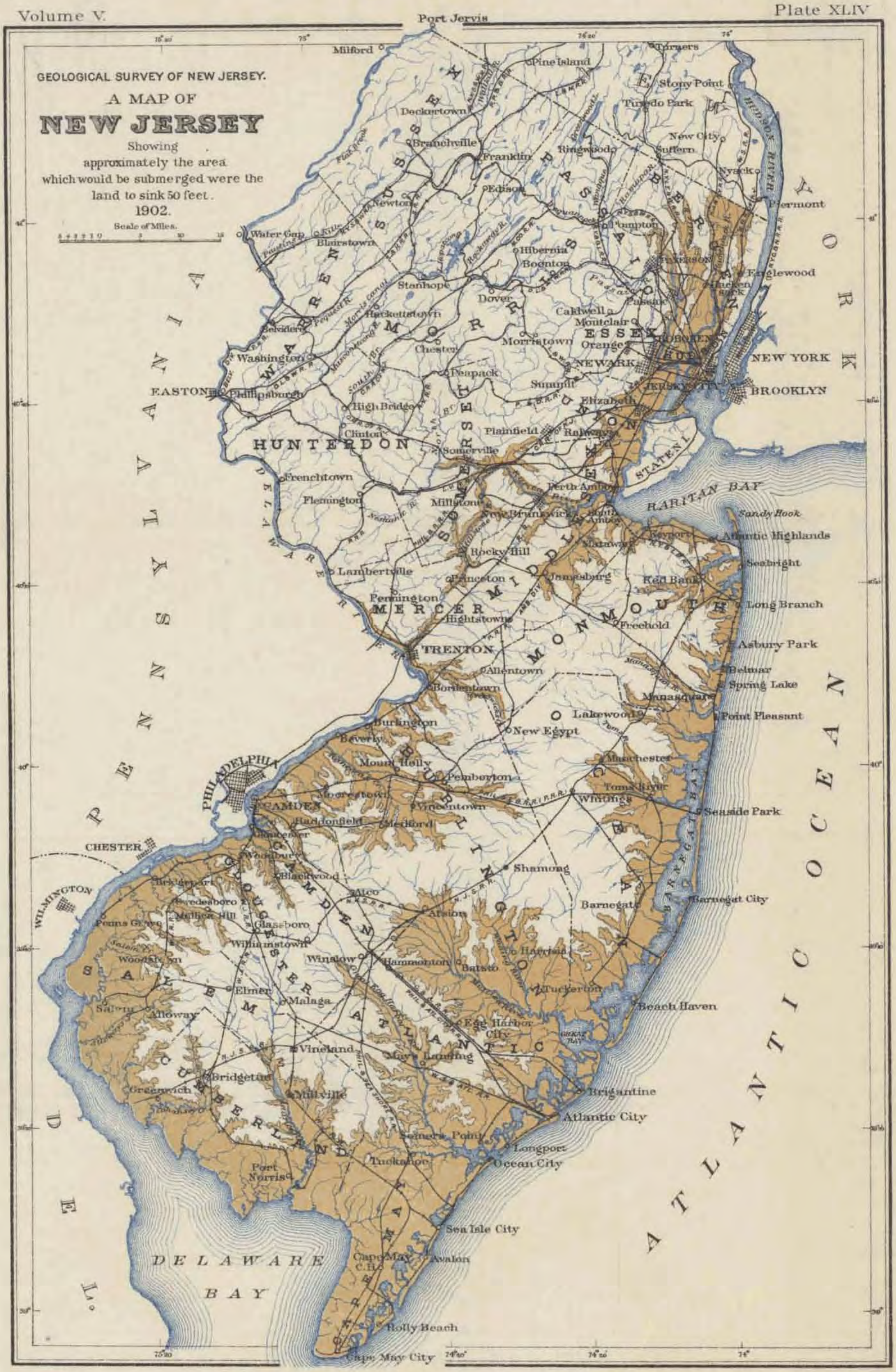
POST-GLACIAL DEPOSITS ON THE DRIFT.

The post-glacial changes enumerated above are mostly of a destructive character, but certain constructive changes have also taken place. Three or four classes of deposits have been made at one place and another on the surface of the drift.

Dunes.—The work of the wind has already been referred to. One phase of this work has resulted in the deposition of eolian sand and dust, locally in recognizable quantities.

Alluvial deposits.—Along some of the streams there have been deposits of alluvium. This is often true of the same streams which have done a considerable amount of post-glacial erosion. After lowering their channels in the drift, they have frequently developed flood plains at the new and lower levels. Where circumstances favored, they have aggraded their valley bottoms without first eroding them, so that through parts of their courses some of the streams flow at levels slightly above those at which they flowed when the ice first withdrew (see Fig. 60). The alluvial deposits will be referred to further in Chapters X, XI and XII.

Lacustrine deposits.—In the lakes there has also been some small measure of sedimentation, the material being furnished by the inflowing waters or acquired by the waves from the shores. The effect of this deposition has been to diminish the capacity


GEOLOGICAL SURVEY OF NEW JERSEY.
A MAP OF
NEW JERSEY
Showing
approximately the area
which would be submerged were the
land to sink 50 feet.
1902.
Scale of Miles.

of the lake basins. Since the outflowing water tends to cut down the outlets of the lakes, both inflowing and outflowing waters conspire to destroy the lake basins.

Peat.—In marshy places, such as the Great swamp, the Great Piece, the Pequest and the Hackensack meadows, deposits of another sort take place. In addition to the earthy matter which drainage brings to them, there is an accumulation of vegetable matter. In such situations the growth of vegetation is rank. On dying, it falls, is largely covered by water, and so preserved from complete decay. When the vegetable matter is reasonably free from inorganic matter it constitutes peat; otherwise, it is black earth, which grades into alluvium. Organic matter to the depth of several feet is found in many places, and the greatest known depth within the State is twenty-seven feet. Minor accumulations of peat occur in numerous places where ponds and lakelets formerly existed, and there is some organic matter, together with much inorganic in most places where the surface is continually moist.

Shell marls.—In the northwestern part of the State in Sussex and in the northern part of Warren counties, there are, at many points, beds of shell marl, composed of the shells, or of the material of shells, of myriads of freshwater molluscs. Among the shells, those of gastropods (snails, periwinkles) are by far the most common. In many places, the descendants of the animals whose shells made the marl beds are still living, and their shells will in turn be added to the accumulation. Locally, the marl has accumulated to the depth of at least fourteen feet.

The marl is found only in relatively low, undrained, or poorly drained, places. It is often found under the humus or peat of the marshy borders of lakes, and not infrequently extends out considerable distances under the water, sometimes making the bottom distinctly white. Some of the numerous "White" ponds of this part of the State owe their names to the marl about their borders. The marl also occurs in many marshes or meadows not associated with lakes, and in such situations is covered by a layer of vegetable matter a few inches to a few feet in thickness. The marl in the marshes is identical in kind and in origin with that of the ponds. The marl marsh often represents the last stage of the marl pond.

The shell marl beds nowhere occur south of the moraine, and for their occurrence the ice was indirectly responsible by giving origin to the basins without which the marshes, ponds and lakes could not have existed.

A somewhat exhaustive account of the shell marls was given in the report of the State Geologist for 1877, and little additional data has been gathered since that time.

Infusorial earth.—In addition to the shell marl and the humus, there is another class of deposits due to organisms. This is the infusorial earths. Like the marls just mentioned, the infusorial earths are made of shells, but they are primarily the shells of plants instead of animals, and are of silica instead of carbonate of lime. The plants secreting the shells were diatoms, microscopic forms which abound in certain waters.

The only considerable bed of infusorial or diatomaceous earth known occurs just east of Drakesville in Morris county. The "earth" underlies a swampy tract, just as much of the marl does, and the shells were accumulated in a shallow pond or swamp, which furnished the conditions necessary for the life of the diatoms, and for the exclusion of other forms of sediments. This earth has been utilized to some extent in the manufacture of giant powder. Diatom shells occur often in great numbers in many of the sediments of post-glacial age; but in general they are so subordinate to the material with which they are associated as not to be detected, except by microscopic examination.

CHANGES IN THE SURFACE OF THE ROCK.

The surface of the rock, like the upper part of the drift, has undergone some change since the glacial period. In the Highlands, striæ upon exposed rock surfaces, in so far as they once existed, have almost uniformly been obliterated, though the *roche moutonnée* outlines of the ledges are generally preserved, and the surface is usually firm and fresh. Where the constitution of the rock is particularly favorable, disintegration has affected its surface layer sensibly for a short distance, though rarely more than an inch, and generally much less. Bowlders of gneiss are to a comparatively large extent firm and fresh. Other varieties of rock show little sign of change. Post-glacial talus has accumulated but sparingly at the foot of ledges.

The exposed limestone ledges north of the moraine have almost uniformly lost all trace, not only of striæ, but of glacial outline (see Chapter X). Not infrequently they are as angular, rough and honeycombed as ledges outside the moraine. Wherever there is even a thin (three or four foot) coating of till, the glacial outlines, and often the striated surfaces, are perfectly preserved. Limestone bowlders on the surface are almost uniformly roughened, angular, and in some cases honeycombed, while those a few feet below the surface are as uniformly fresh and striated.

The exposed Hudson river rocks are variously affected. The exposed surface of shale and slate is uniformly much broken by the frost, but not notably altered chemically. In some cases the rending and splitting action has progressed to a depth of two or three feet. It is not certain however that all of this is post-glacial. Disintegration, which is demonstrably post-glacial, has rarely gone more than a few inches. The thicker-bedded, coarser-grained sandstones have been but little changed. Bowlders of shale have been somewhat cracked and fissured by the frost, and slightly discolored.

The Oneida and Medina ledges show but little traces of post-glacial wear. Their exposed surfaces have usually been roughened sufficiently to obliterate striæ, but that is all. The bowlders are slightly etched, but otherwise show no signs of decay. Much of the talus along the foot of Oneida escarpment is of post-glacial origin.

The elæolite syenite northwest of Beemerville affords the most marked example of post-glacial disintegration of rock. Its surface is completely disintegrated to a depth of at least three or four feet. The rapid disintegration of this rock is due chiefly to its mineralogical composition.

On the trap ridges, the weathering has been less than in the Highlands. From surfaces which have been continually exposed since the glacial epoch, the striæ have generally disappeared, though glacial grooves, even shallow ones, are sometimes still distinct. Where smooth, broad surfaces of trap were left exposed, a fraction of an inch would probably represent the average amount of disintegration effected in post-glacial time. The freshness of the surface of the trap outcrops on Palisade ridge is in marked contrast with the surfaces of the outcrops of limestone, shale and gneiss.

In the region of the Triassic shale, the post-glacial weathering on the exposed rock has been comparable to that in the Kittatinny valley.

CHANGES OF LEVEL.

Since the ice departed the northern part of the State as well as the southern has undergone more or less deformation and change of level. This has already been implied in the statements made concerning the history of the closing stages of the glacial period. In that connection it was implied that the rise of surface since the ice melted has been as much as forty to sixty feet, and may have been much more.

There is abundant evidence that in this general rise the elevation was not equal at all points, and, therefore, that the surface was warped or deformed in the process. Explicit evidence of the deformation is found in connection with the old shore lines of Lake Passaic. These shore lines must have been essentially horizontal when formed, but at present they depart sensibly from horizontality. The highest point of the shore line of the maximum stage of the lake is near the northeast end of the basin, while the lowest is at the southwestern extremity, the respective figure being 412 feet and 345 feet.

While the ice lay north of the lake, its mass would have exerted an attractive influence on the water of the lake, tending to raise its level at the north end. This would have been on the same principle that controls the level of standing water at the present time. This principle is illustrated by the fact that the water of the ocean near the Himalaya mountains is 300 feet higher than that at Ceylon, the difference being due to the attractive influence of the mountains. The ice sheet would, of course, have been much less efficient than the mountains, because much less massive at any one locality.

The departure of the shore lines of lake Passaic from horizontality is more than can be attributed to the attractive influence of the ice. Furthermore, the shore line does not rise steadily to the north, as would have been the case had the attractive effect of the ice been the cause of the departure of the shore line from horizontality. There is, therefore, no doubt that the basin of the lake has suffered deformation, the northern end rising, relative to the southern.

It should be noted that the northward rise is relative only so far as the direct evidence derived from the shore line is concerned. This evidence gives no criteria for deciding between the following propositions: 1), The whole basin of the lake has risen, but the northern end more than the southern; 2), the northern end has risen, while the southern has remained in the position it occupied during the life of the lake; 3), the northern end has risen, while the southern has been depressed; 4), the northern end has remained as it was while the lake existed, while the southern end has sunk; 5), the whole basin has been depressed, the northern end less than the southern. Between these several alternatives the general testimony of known facts concerning post-glacial changes of level points to the first.

HUMAN MODIFICATIONS.

If nature has proceeded slowly with her changes in the drift, as is her wont, man has been less considerate. It is true that there are many parts of the drift which man has not seriously interfered with, but it is also true he has tampered with it extensively at other points. It is not too much to say that in all that part of the State which is directly tributary to New York City, the details of the surface of the drift have been greatly changed. There has been extensive grading for roads, railroads, cities, villages and individual buildings; there have been extensive excavations for clay (Woodbridge, Hackensack), gravel and sand; new channels have been made for the minor streams, or they have been confined within unnatural limits by walls which interfere with their normal activity. Even the rock beneath the drift has been attacked, and the beauty of the Palisades, which the great continental ice sheet spared, has been threatened. Dams have been built and reservoirs established, seriously interfering with the course and the work of the water; marshes and ponds have been drained; and, more important than all, broad areas have been deforested and brought under cultivation.

Many of these changes were necessary, and some others are needed; but, beneficial or not, they have changed the face of the land, and some of the least obtrusive changes are among the most important. Especially is this true of the changes which follow deforesting and cultivation. The effects of forests on water have been discussed by Mr. Vermeule[1] in an earlier report. It need only be mentioned in this place that the removal of the forests facilitates the flow of the rainfall into the streams, and thereby promotes floods at the time of heavy rains, and droughts afterwards, and by interfering with the steadiness of flow of streams, interferes with their utilization for waterpower.

The effect of cultivation, which often follows deforesting, is to loosen the surface, and to keep it bare (free from vegetation) during at least some part of the year, thereby facilitating the blowing of dust and sand when it is dry, and the removal of soil and surface earths by water when it is wet. The stimulation of erosion by the removal of vegetation is greater than any except those who deal directly with the soil, realize. It is, perhaps, not an overstatement to say that in a region of moderate relief the rate of erosion is increased a hundred fold, as the result of the cultivation of the soil. The removal of this excess of earthy matter affects not only the surface of the land, but also the streams, the lakes and the sea, with all their myriads of life. It affects the purity of the water of the streams, and so its availability for water supply.

[1] Water Supply, Vol. III of the Final Report of the Geological Survey of New Jersey.

PART II.

LOCAL DETAILS.

OUTLINE.

In the preceding part of this volume a general outline of the glacial period has been given, in order that the relations of the drift of New Jersey to that of the rest of our country, and of our continent, may be understood. In this general discussion, constant reference has been made to the phenomena of the State, for illustration of the general principles enunciated. For those who are interested in the details of the glacial geology of New Jersey, fuller data are presented in this part of the volume, which takes account of the results of glaciation in the various parts of the area affected by the ice. In the presentation of these data, many details concerning the methods by which ice works, and many details concerning the history of the ice sheet which made the drift of New Jersey, will appear. These data are presented under the following chapter headings:

(1) The terminal moraine of the last glacial epoch;

(2) The drift of the Appalachian province, including the Kittatinny valley and mountain;

(3) The drift of the Highlands;

(4) The drift of the Piedmont (or Triassic) plain;

(5) The stratified drift of the morainic age, south of the moraine;

(6) The extra-moraine glacial drift of greater age than the moraine.

CHAPTER IX.

THE TERMINAL MORAINE.[1]

CONTENTS:

ITS COURSE.

The general characteristics of terminal moraines, together with their mode of formation, have been discussed in Chapter III. The course of the terminal moraine across New Jersey is indicated on the map accompanying this report, plate XXVIII. Coming over from Brooklyn, it crosses Staten Island, and enters the State at Perth Amboy; thence it follows a general northwesterly course to Denville, about thirty miles distant. At Denville its course becomes westerly. After a course of rather less than twenty miles in this direction, it turns

[1] Many of the details here given were worked out in the field by Messrs. Kümmel and Peet. The work of Dr. Kümmel was chiefly west of the Highlands.

gradually to the southward, and thence to the Delaware it follows a west-southwest course. At the Delaware it makes another turn, and has a general northwesterly course to Pocono, Pa. Between Jamaica and Pocono, therefore, the moraine is disposed in the form of two great loops or lobes, the one between Jamaica and Denville, the other, much less pronounced, between Saxton Falls and Pocono. The first loop has a width of about forty miles, and a length equal to about half its width. The second loop has nearly the same width, but a length of but ten miles. the lower end of the former loop is at Perth Amboy; that of the latter at Belvidere. One side of each of these two great loops lies in New Jersey. Between the loops is a great re-entrant, the head of which is between Denville and Saxton Falls.

In addition to the great lobations referred to above, there are minor ones. Thus, on the west side of the eastern loop, between Perth Amboy and Denville, there are two minor loops, or crenations, the re-entrant between them being in the vicinity of Summit, where the moraine crosses the Watchung mountains. Other minor lobations appear farther west, as in the Musconetcong and Pequest valleys.

THE OUTER BORDER OF THE MORAINE IN DETAIL.

Its nature and relations.—The outer border of the moraine is generally, though not always, well defined. In some places,

Fig. 61.
Diagram illustrating an outwash or moraine plain where it is distinct from the moraine.

especially in valleys and on low lands, it is bordered on the south by stratified drift washed out beyond the edge of the ice by the waters arising from its melting. In such situations the line of junction between the moraine and the stratified drift is sometimes distinct, and sometimes indistinct. In the former case, the definition is partly topographic and partly constitutional. Here the plain of stratified material abuts against the moraine of irregular topography and unassorted material (Fig. 61). Where the definition between moraine and bordering stratified drift is indistinct, it is often because the edge of the ice was inconstant in position, while the moraine was making.

In other places, the moraine is bordered by till deposited by the ice when it advanced temporarily beyond the position of the moraine, and in this case the border of the moraine is often some-

Fig. 62.
Sketch of terminal moraine near Hackettstown.

Fig. 63.
Sketch of the topography just outside the moraine near Hackettstown.

what indefinite. In still other places, the moraine is bordered by drift deposited by an earlier ice sheet. In such cases the contrast between the younger morainic drift and the older non-morainic is usually sharp. Where the moraine is not bordered by drift, its edge is generally clearly defined both by the topography, (Figs. 62 and 63) and by the material, though locally the drift is so thin that its margin is not topographically distinct.

Its position.—From a point two miles or so west of Perth Amboy (see Plate XXVIII) the outer border of the moraine has a northwest course to a point southwest of Fords Corners. Thence it lies just north of the road between Fords Corners and Metuchen, until the latter village is approached. The outer edge of the moraine then becomes slightly irregular. It crosses the railroad just above Robinvale station, then turns westward, and includes the hills in the north edge of Metuchen. Thence it is continued northwestward to a point a half mile west of Oak Tree. From this point to Netherwood the border is again slightly irregular, but, in a general way, it is the line of junction between the high, rough land on the east, and the low, level land on the west (see Plate IX). From the Netherwood station the outer border runs east of north, passing east of Scotch Plains and just west of the Springfield triangulation station on First mountain. Thence its course is nearly due north to Summit, and a little beyond. Here it curves southward, across the railway track just west of the station, and bends south so as to include most of the village, then turns northwest to a point about three-quarters of a mile south of Stanley. Here the moraine is interrupted by the Passaic.

Beyond the Passaic, the outer border of the moraine is about three-quarters of a mile southwest of the D., L. & W. railway as far as Madison. Its course is then a little more westerly, approaching and crossing the railway just east of Convent. From this point it has an irregular course in a northwesterly direction to a point a quarter of a mile from the Whippany river, beyond which it is but a few rods east of the railway, nearly to Tabor. Here it swings around the hill on which Tabor is built, the hill determining a small re-entrant at this point. Thence it has an irregular northwest course to Denville. West of Denville the outer edge is irregular for a few miles, and the exact position assigned it is somewhat arbitrary, on account of the large amount of irregularly disposed stratified drift lying along it.

For two miles west of Denville it lies north of the Rockaway, but crosses that stream a mile south of the village of Rockaway. Thence it recedes to the north around the high hill west of the village (Fig. 64), and south again on the west side of the same hill, to the northwestern part of Dover.

At Dover the outer border is interrupted by the Rockaway. West of the river it lies between Sterling mine on the north, and Spring mine on the south. The outer border bears west-northwest until it approaches Duck pond, near Rustic, where it swings to the south of the pond. At Rustic, it bends sharply to the

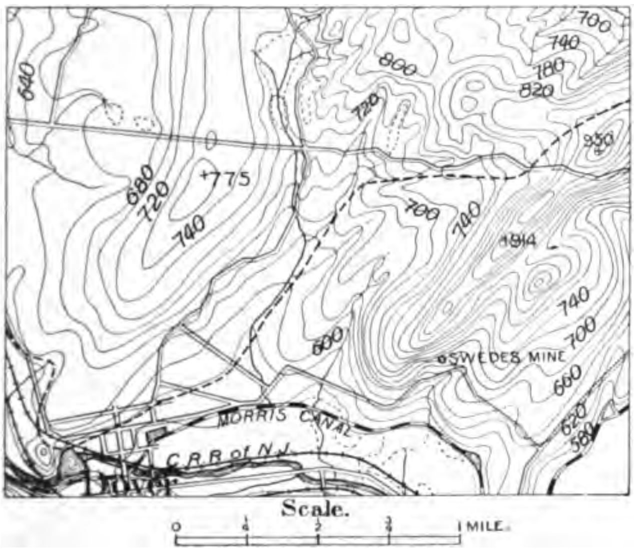


Fig. 64.

Illustrates the bend in the outer margin of the moraine occasioned by a high hill at Dover. The broken line represents the outer or southern edge of the moraine.

north in the lee of some high hills to the northeast, making a re-entrant (Fig. 65) nearly a mile in north-south extent. Mount Arlington station lies on the east side of the re-entrant, and Mountain pond on the west. From Mountain pond, the line extends three-quarters of a mile farther south, from which point its course is west, and then southwest, to a point just north of Wolf mine. Beyond this point it skirts the marshes between Wolf mine and Budds lake, lying a half mile or so north of the latter, whence it has a westerly course to a point half a mile south of Saxton Falls. Here it turns abruptly to the south, in the valley of the Musconetcong (Fig. 66).

From a point on the Musconetcong creek, about a mile north of Hackettstown, the line crosses the valley first in a west then a northwest direction to a point on the Hackettstown-Allamuchy road, just south of the canal. From this point, under the influence of the high land to the northeast, over which the ice came, the moraine swings to the north for half a mile. Thence it

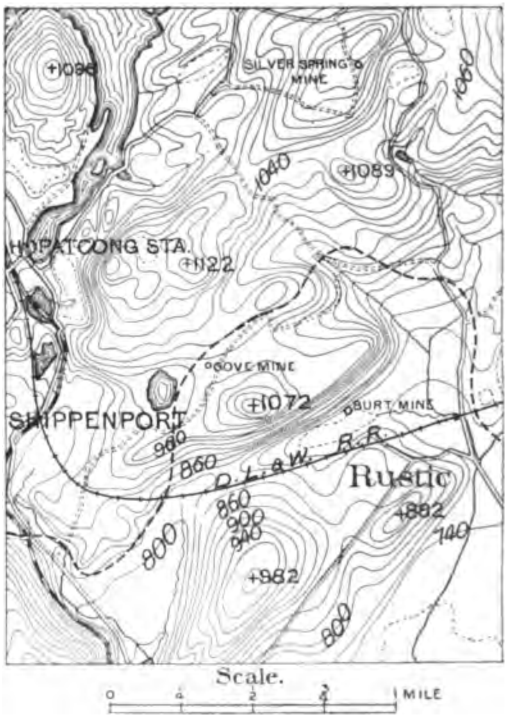


Fig. 65.

Bend in the outer margin of the terminal moraine at Rustic, occasioned by high elevations a little to the north. The ice passed over these elevations, but its forward motion was retarded. The broken line represents the outer edge of the moraine.

curves first west, and then southwest, looping around the north and west sides of the 980-foot hill, but ascending to the 910± col on its west side, whence it descends and crosses the Hackettstown-Petersburg road near the residence of the late A. R. Day. Thence for nearly a mile it lies just north of the east-west road which connects the Petersburg road to Hackettstown, with the Petersburg road to Townsbury. Farther west the line crosses this road, turning south on the west side of the 1,066-foot hill, and descends to the Hackettstown-Vienna road. This it crosses and then turns west, or a little south of west, lying along the north side of the 1,146-foot hill at that point, rising on its slope to an elevation of about 920 feet. It crosses the Danville-Beattystown road one and a half miles southeast of the Pequest

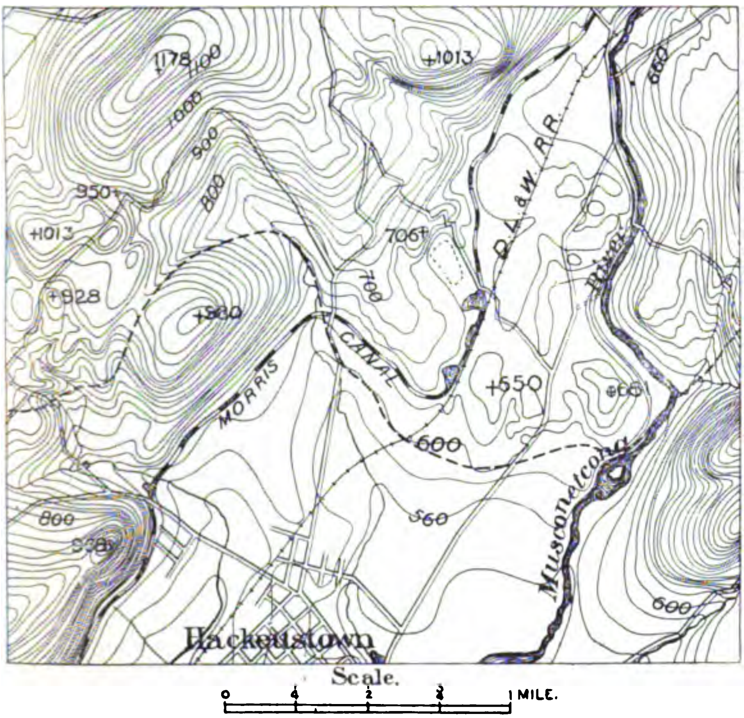


Fig. 66.

The bends in the moraine near Hackettstown occasioned by topography. The broken line represents the outer margin of the moraine.

river. From this point the line is deflected a little to the northwest, and passes just north of the crest of the 936-foot hill. Although the moraine phase of the drift is here limited to the north side of the hill, it is evident from the drift on the south slope that the hill was at some stage overridden by the ice, which extended half a mile down its southern side.

Descending from the high land at this point, the moraine turns promptly to the south and lies in the Pequest valley, its outer margin lying against the steep slope of the gneiss highland to the southeast. The moraine here does not rise above the foot of the steep slope, but drift bowlders on the slope above the moraine show that the ice once crowded up some distance on the slope.

Three-fourths of a mile south of Townsbury the moraine boundary turns west, and, crossing the valley, reaches the river a mile southwest of the village. The outer margin of the moraine is not distinctly marked here, and on account of the massive bodies of stratified drift associated, its exact location is somewhat arbitrary. By Professor Cook[1] it was placed half a mile farther north, where the strongly marked morainic topography begins, but faint indications of morainic topography extend to the line above located. A minor lobe of ice extended down the valley as far as Pequest Furnace, and possibly as far as Oxford Furnace, but did not develop a marginal moraine at its limit.

From the point where the outer edge of the moraine reaches the river, it turns abruptly northeast along the right bank of the stream, a little above the road. Just before Townsbury is reached it turns north, then west for three-quarters of a mile, and then south, crossing the Townsbury-Buttzville road about forty rods east of the corner where the road to Hope turns northward.

On the road leading west from Townsbury no drift is seen on the steep eastern face of the mountain more than about 140 feet above the Pequest, nor along the road across its top, until a point near the junction of the Hope road is reached. The only exceptions to this statement are a few quartzite bowlders which are believed to belong to an older sheet drift. Here, within the space of a few feet, the transition is complete from the reddish-brown gneiss-residuary soil, to the lighter color of the till. From the road the line can be distinctly seen crossing the plowed fields and entering the woods to the southwest. Nowhere else is a more marked and sudden transition from the residuary soil to the till observable (Compare Figs. 62 and 63).

---

[1] Annual Report for 1880, page 31.

From a point a mile west of Townsbury the moraine turns sharply to the southwest along the base of Mt. Mohepinoke. For two miles its outer border is nearly parallel to the Townsbury-Buttzville road, and to the base of the mountain, and no more than an eighth of a mile to the southeast. This notable deflec-

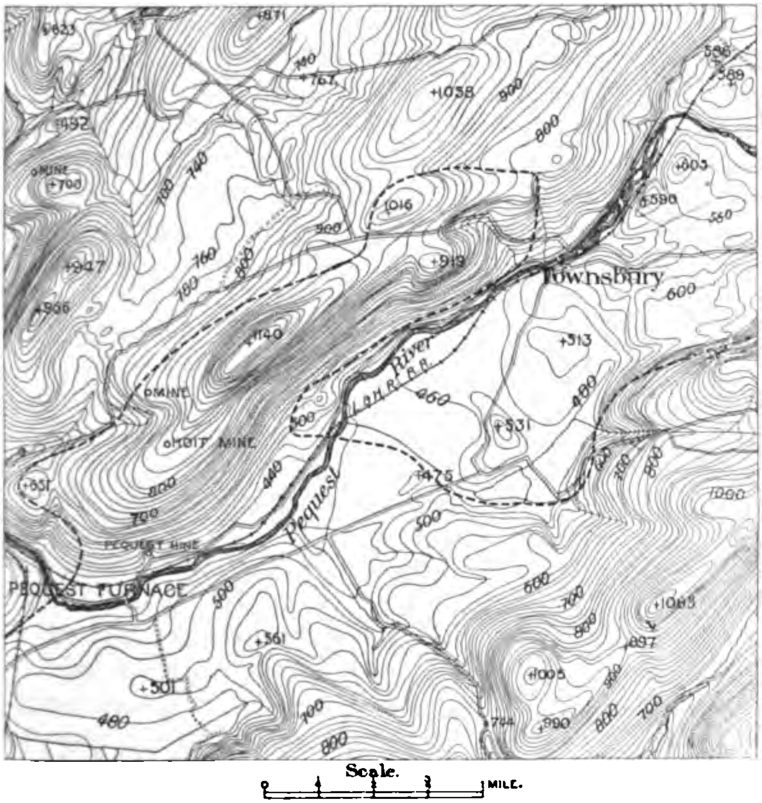


Fig. 67.

Bend in the outer margin of the moraine at Mt. Mohepinoke. The mountain is the 1140-foot hill, and the position of the outer edge of the moraine is indicated by the broken line.

tion of the moraine about Mt. Mohepinoke (Fig. 67), reflects the direct influence of the mountain, which rises about 700 feet above the valley, on the motion of the ice. The reëntrant amounts to more than a mile. A quarter of a mile north of the Pequest, and near the southwestern end of Mt. Mohepinoke, the boundary turns southeast for half a mile, and passes just east of Pequest Furnace, where it turns southwest, passing just north of the summit of the 726-foot hill between Oxford and Buttzville. Thence it continues westward for two miles, nearly parallel to the L. & H. R. railway, and half a mile south of it, passing north of two gneiss hills 723 feet and 725 feet in altitude, a mile south by southeast from Bridgeville. Escaping these hills, it turns southwest and then south into the valley of Pophandusing brook, about half a mile east of Oxford Church.

West from Oxford Church to Belvidere there is no trace of the moraine. It is probable that much of the ice work in this region was subsequently obliterated or obscured by the copious drainage which the melting ice discharged through the valley. Two and a half miles southwest of Oxford Church, and two miles south of Belvidere, is an area about a mile long and half a mile wide where morainic topography is well developed. The area is surrounded by stratified drift, but seems to represent the southernmost extension of the ice which made the moraine. Its altitude is less, and its position farther south, than that of any part of the moraine west of Denville.

THE INNER MARGIN IN DETAIL.

Its nature and relations.—While the outer margin of the moraine is, with relatively few exceptions, readily located, the same cannot be said of the inner margin. The rough topography which characterizes the terminal moraine often grades into the more gently undulatory topography of the ground moraine in such a way that any line which may be drawn between them will not everywhere separate phases of drift which are markedly unlike. The inner border of the moraine is therefore often confessedly arbitrary.

Its position.—Starting at Perth Amboy, the inner border of the moraine is approximately parallel with the outer border, and a mile to a mile and a half from it. It curves northwestward and crosses the Pennsylvania railway just northeast of Menlo Park. A little farther northwest, a morainic spur projects itself into the ground moraine northwest of New Dover. From the L. V. railway northward to Westfield, the inner border is a mile to a mile and a quarter from the outer. Just north of Westfield there is another eastward projecting spur of the moraine, running out from Locust Grove a mile and a half, nearly to the Rahway river. Just north of Locust Grove, the inner border of the moraine is a half to three-quarters of a mile from the outer. Thence it runs in a northeasterly direction to a point a half mile west of Springfield. Here it turns to the northwest, following a northwesterly course to a point half a mile south of Short Hills; thence it curves to the east to a point two miles beyond Short Hills. From this point it curves southwest to a point a mile or less east of Stanley.

Beyond the Passaic valley, the inner border of the moraine is difficult of exact location nearly to Boonton. The inner face of the moraine was here modified by the waters of Lake Passaic, below the level of which some of the characteristic morainic features were destroyed. North of the Whippany river, the inner border is on the east face of the 495-foot hill, one and a half miles northeast of the center of Morristown. Thence it passes northward through Littleton, and northeastward to the road from Denville to Parsippany, midway between these villages. Here a spur of drift, which has been mapped as terminal moraine, runs off a mile or so towards Boonton. Beyond this spur, the line runs northward to the Rockaway river, and then turns westward by a zigzag course to a point a mile north of Rockaway. From this village to Mount Hope, a crooked east-west line marks the inner border. From a point just south of Mount Hope two and a half miles north of Dover, it crosses the southern point of Green Pond mountain, and has a nearly due west course from near Silver Spring mine, to Lake Hopatcong. West of the lake, the inner border of the moraine lies just north of Brooklyn, whence it bends southward to Port Morris. Thence it extends south of west, passing south of Stanhope, but including the Stanhope station of the D., L. & W. railway. From Stanhope station, the line runs south of west for one and a half miles, and then by a slightly undulatory course, west to Saxton Falls.

Where the moraine crosses the Musconetcong valley, its inner margin is one and a quarter miles north of the outer; thence it turns northwestward, crossing the Hackettstown-Allamuchy road about two miles south of Allamuchy pond. From this point it runs nearly west, passing just north of Petersburg, and following closely the road from this village to Vienna. Between Vienna and Danville, and for one and a half miles northwest of Danville, the inner limit is marked by the south end of the Pequest meadows. It then extends southwest past the southern end of Green's pond and around the southern point of Jenny Jump mountain, reaching Beaver brook half a mile below Sarepta. From this point southwest to its junction with the Pequest, Beaver brook marks its limit. Between the junction of the Beaver with the Pequest and the Delaware, a small area of drift of morainic topography is included in the moraine.

WIDTH.

From the foregoing, it appears that the width of the moraine varies from half a mile to something more than two miles, its average being about one mile.

TOPOGRAPHIC POSITION AND RELATIONS.

Relation to topography.—The lobate form of the moraine has been referred to. The axis of the eastern lobe, as shown both by the position of the moraine loop itself, and by the striæ on the bed rock, is in the great valley between the Palisade ridge on the east, and First mountain on the west. The axis of the second is less well defined, just as the lobe itself is, but, for present purposes, may be said to be in the Kittatinny valley. The great re-entrant between the lobes lies on the Highlands. It thus appears that the moraine has its most southerly position on the low area of Newark or Triassic rock in the eastern part of the State (latitude 40° 30′), and its most northerly position on the

Highlands (40° 54′). West of the Highlands its latitude is intermediate between these extremes.

This relationship between the position of the moraine and the topography, is not accidental. Taken in connection with related phenomena elsewhere over the whole of the glaciated area, it clearly means that high and rough lands hindered the movement of the ice, while low and less irregular surfaces, by contrast, facilitated it. That this generalization is correct is shown by the position of the moraine with reference to individual hills and valleys, for at the crossing of every considerable valley, the moraine loops somewhat to the south, and at the crossing of every considerable ridge, somewhat to the north. It follows that the larger lobes, like that between Jamaica and Denville, correspond with the great depressions, while the minor lobes on the borders of the larger, such as that at Hackettstown (Pl. XXVIII and Fig. 66) correspond to the lesser depressions. Conversely, the great re-entrants between the great lobes, such as that which has its head at Dover, correspond in position with mountain or highland areas, and the minor re-entrants between the minor lobes, with individual hills, ridges or mountains. The minor lobes and re-entrants are numerous and considerable where the relief is great, as between Denville and the Delaware, but few and insignificant where the relief is slight, as between Perth Amboy and Denville. The one marked irregularly in this part of the moraine is the re-entrant at Summit (Pl. XXVIII), where the one strong relief feature (the Watchung mountains) is crossed. It follows from the foregoing, that the altitude of the moraine in the re-entrants is greater than that in the lobes.

The explanation of the relationship existing between the position of the moraine and surface configuration, is not far to seek. Whatever the real nature of ice movement, it behaved, so far as the position of its edge was concerned, much as if it were a stiff viscous fluid. Its thickness in the depressions was greater than that over elevations in the same latitude. The greater its thickness, the more rapid its motion, and the farther it moved before being melted. The ice moved farther in a wide valley than in a narrow one of the same depth, because of the less friction in proportion to the volume of the ice, in the former case. Furthermore, a rough surface impedes ice motion, while a smooth one, by contrast, facilitates it, and the highlands of New Jersey are notably rougher than the lowlands. These general principles find abundant illustration in the disposition of the terminal moraine of New Jersey.

The vertical range of the moraine between Perth Amboy and the Delaware is about 1,200 feet, and the range in latitude between twenty-five and thirty miles. The highest point (1,208 feet) is about a mile east of the south end of Lake Hopatcong; the lowest is near sea level, at Perth Amboy. From Perth Amboy to Fanwood, the crest of the moraine rises to a height of about 200 feet, but with this increase in height, it recedes nine miles to the north. In the next six miles it rises to an altitude of more than 500 feet, and recedes five miles farther to the north, to the northern end of Union county. From Chatham to Littleton its crest rarely reaches much above 400 feet. That its course should still be north of west across the relatively low land of eastern Morris county seems, at first thought, opposed to the generalization that the moraine lies farther south on lowlands. But the relief map, showing the direction of ice movement, shows that the ice which made that part of the moraine between Summit and Littleton had been passing very considerable elevations to the north, and these elevations interfered with its progress as much as if they had lain at the border of the ice. East of Tabor the moraine rises to an altitude of nearly 600 feet, and north of Dover it reaches an altitude of nearly 1,000 feet, and at the same time its most northerly position. Between Perth Amboy and Dover, therefore, along the west side of the Jamaica-Denville lobe, the moraine has a vertical range of 1,000 feet, and recedes more than twenty-five miles to the north.

From Dover to Saxton Falls the moraine descends into valleys and rises up to the summits of the gneiss hills with apparent indifference. Between these points it has a maximum range of nearly 600 feet in altitude, and yet its position varies no more than two miles in latitude. This apparent independence of topography is apparent only. Were the valleys which the moraine crosses capacious, and did they extend considerable distances northward in the direction whence the ice came, the moraine would have lain much farther south in them. But even here local topographic features were not without their influence, as shown by Figs. 64–67. Thus a little southwest of the apex of the reëntrant of the moraine, just west of the Mount Arlington station, and a quarter of a mile north of the D., L. and W. railway, there is a hill rising to a height of 1,072 feet, about which the edge of the ice wrapped, and, in accordance with the laws of glacier motion, moved forward down the valley toward Drakesville some distance farther than on the highlands to the northeast. The maximum difference in height of the inner and outer borders of the moraine on any one meridian is about 400 feet. This is at Rustic, where the outer border of the moraine has an elevation of about 800 feet and the inner about 1,200 feet.

In the Musconetcong valley, which is more capacious than the valley to the east, the crest of the moraine has an altitude of 600 to 681 feet, and lies several miles farther south than at Shippenport and Stanhope. In crossing the mountain separating the Musconetcong from the Pequest, the moraine crest reaches a maximum height of more than 1,100 feet, and recedes about a mile to the north. In the valley of the Pequest its altitude ranges from 580 to 600 feet, and its position is again farther south. From this comparatively low elevation it rises rapidly on Mount Mohepinoke to a height of 1,131 feet, receding at the same time more than a mile to the northward. From this altitude it descends into the valley of the Pequest at Buttzville, advancing at the same time several miles to the south. Here its altitude ranges from 621 feet half a mile west of Pequest Furnace, to 520 and 530 feet near Buttzville. In the vicinity of Oxford Church it lies upon a side hill, and its height varies from 660 to 360 feet within less than a mile. At its westward extension, near the Delaware, its crest is 387 feet, and here, where it reaches its lowest altitude, it also reaches its lowest latitude west of Denville. Within the stretch from Hackettstown to the Delaware its summit, therefore, has a range of about 800 feet in altitude, and its position a range of about seven miles in latitude.

Between Perth Amboy and the vicinity of Dover the range of the moraine in altitude is about 1,000 feet, while its position in latitude changes about twenty-eight miles; between Dover and the beginning of the Delaware lobe, say at the crossing of the Musconetcong valley, the range in altitude is nearly half as much, while the variation in latitude is no more than two miles; between Saxton Falls and the Delaware the range in altitude is about 800 feet, and the variation in latitude but six or seven miles. From these facts it is seen that while the greater ranges in latitude accompany the greater ranges in altitude, the variations in the two senses are not proportionate. Between Perth Amboy and Dover, less than thirty-five feet of elevation, on the average, go with one mile of variation in latitude. If this ratio were applicable to the next stretch along the head of the reëntrant (Denville to Saxton Falls), where the range in altitude is about 450 feet, the variation in latitude would be about thirteen miles, while it is scarcely two. Again, the ratio of the first stretch applied to the east side of the Delaware lobe, would give a range of more than twenty-five miles in latitude, while the actual range is only one-fourth of this.

These apparent inconsistencies, like all apparent inconsistencies in nature, are not real. The preceding figures take account of the variation in altitude of the moraine (representing the edge of the ice) only, while the topography of the surface farther back, in the direction whence the ice came, was almost equally effective in determining the position of the edge of the ice. Thus the recession of the moraine (edge of ice) between Perth Amboy and Denville seems out of proportion to the variation in altitude. Taken by themselves, the figures for this stretch would seem to mean that the slope of the upper surface of the ice, for the twenty-eight miles nearest its edge, was but little more than thirty feet per mile. The actual slope for the marginal part of the ice was surely several times as much.

The real explanation of the great recession of the moraine here is found in the high and rough land over which the ice which reached points north of Summit had come. If this high land had ended just north of the edge of the ice, and if the ice, after passing it, had reached a surface near sea-level between Chatham and Dover, it would still have advanced but little south of the position of the moraine. Again, the surface of the moraine at Summit is more than 100 feet higher than that at Belvidere, yet in the former position the moraine is six or eight miles farther south than in the latter. The reason is, that the ice which reached Belvidere had been impeded much more by rough and high land than that which reached Summit.

The moraine rests on surfaces of various attitudes, as well as altitudes. Here it lies on a surface which is comparatively smooth, or which was comparatively smooth before the moraine was made, as between Metuchen and Scotch Plains, and between Chatham and Morris Plains; and there on a surface which was already rough when the ice covered it, as between Denville and the Delaware. Where the surface on which it rests had notable relief, the moraine sometimes lies on a southward slope, showing that the ice which made it halted on a down grade; while in other situations it lies on a northward slope, showing that the ice was stopped in its attempt to override the opposing elevation. The moraine, therefore, sustains various relations to the details of topography, as well as to the great topographic features.

As a result of the lobation of the moraine, it is much longer than a direct line between its extremities. The extent of the crenulation is roughly indicated by the fact that the distance from Perth Amboy to Belvidere by direct course is about 50 miles, while the length of the moraine between these points is about 80 miles.

THE MORAINE AS A TOPOGRAPHIC FEATURE.

In general.—Taken as a whole, the terminal moraine can hardly be said to be a prominent topographic feature, even though it is sometimes 100 feet or more in height. True as this statement is, a false impression is likely to be conveyed by it, unless it is given a moment's reflection. A ridge 100 feet high might seem sufficiently large to be obtrusive. But if the ridge be a mile wide, with symmetrical slopes, a height of 100 feet would mean a slope of 100 feet from the center to either margin, that is a slope of 100 feet in a half mile. This would be a rise of less than one foot in twenty-five. This is by no means a steep slope, and a ridge of such proportions would not be a particularly conspicuous topographic feature, except where it crossed a flat country. If a moraine have half the height and twice the width indicated above, and these are not uncommon dimensions, the slope would be greatly reduced. A rise of fifty feet per mile would mean less than one foot in one hundred, a rise which would be hardly noticeable, except in a region where the surface was otherwise flat. The height of the moraine above its surroundings is not infrequently much less than fifty feet, and it often crosses areas whose relief is much greater than its own height. It is, therefore, not always, perhaps not commonly, a conspicuous topographic feature. It is more commonly conspicuous from its outer face than from its inner.

In detail.—Commencing at the southeast, the moraine, seen from the outside, is a conspicuous topographic feature, from Fords Corners to Metuchen. Near the former place (Plate IX) the highest point of the moraine rises something like 140 feet above the plain southwest of it within the space of a quarter of a mile. The outer face of the moraine is again abrupt, and the moraine conspicuous east of South Plainfield, Avon Park and Plainfield (see Plates IX and XXVII). It is here the more conspicuous because it is adjacent to the nearly level plain about Plainfield. East of South Plainfield the moraine rises ninety feet within the space of little more than a quarter of a mile. Due east of Grant Avenue station it rises about 100 feet within a like distance. The same general relations hold to a point a mile northeast of Scotch Plains.

From this point to the Passaic the moraine is not conspicuous. From Stanley to Morristown (Plate X) it is commonly thought to present an abrupt western face; but the abrupt western face which fronts the Great swamp is not the face of the moraine, but the face of a long subaqueous overwash plain[1] or of a series of delta plains, lying just outside of the moraine, and owing their existence to the extinct Lake Passaic. The delta plain is built against the moraine, and conceals its outer face. Above the plain, the moraine is nowhere conspicuous between the Passaic river and Convent. For two miles or so north of Convent it is again more prominent.

[1] Annual Report of the State Geologist of New Jersey, 1892, page 99.

Between Madison and Morristown the moraine is quite as conspicuous from the inner side as from the outer. West of Black meadows the inner slope rises as promptly as the delta front does above the Great swamp on the outer face.

From Morristown to Dover the moraine is nowhere conspicuous. Approached from the south, at Dover, it rises up promptly from the gravel plain which borders the Rockaway, and constitutes a prominent landscape feature. One block north of the Central Railroad station at Dover, the ascent from the gravel plain to the top of the moraine is made within a distance of 300 yards, within which space the rise is about sixty feet. Where the moraine crosses the higher land south and southwest of Port Oram it is again inconspicuous. In the valley farther west, south of Hopatcong Junction, it rises abruptly twenty to thirty feet. It also has an abrupt outer face south of Mount Arlington station; south of Shippenport, east of the canal; south of Stanhope and west nearly to Budds lake; and north of Budds lake. At the last point it rises up promptly forty to sixty feet. Between Budds lake and Saxton Falls it is not strongly marked.

North from Hackettstown, the moraine appears as a series of low, irregular swells, presenting an abrupt outer face, and constituting a low wall across the valley. In contrast with the high hills of gneiss and other crystalline rock which hem in the valley on either side, it is insignificant topographically; in contrast with the low plain of the Musconetcong to the south, it is conspicuous. On Pohatcong mountain the moraine is insignificant as a topographic feature, for although the morainic topography is well developed, the constituent hills and ridges sink into relative insignificance amid the greater hills and valleys of the underlying rock. In the valley of the Pequest the moraine again becomes a more notable topographic feature, crossing the valley as a great irregular wall, cut through only by the narrow gorge of the river. On Mount Mohepinoke and westward through Buttzville and Bridgeville to the Delaware, the moraine nowhere constitutes a prominent ridge.

THE TOPOGRAPHY OF THE MORAINE.

In general.—The real conception of the nature of a terminal moraine will never be gained until the distinction between the moraine as a topographic feature, and the topography of the moraine is fully appreciated. Considered as a topographic feature, the moraine should be studied especially with reference to the abruptness of its slopes, its height and its relations, *as a whole,* to its surroundings. If it stands up notably above its surroundings, and with steep slopes, it is a conspicuous topographic feature, without reference to the details of its own topography. As already pointed out, the moraine is likely to be a more conspicuous topographic feature in a region which is otherwise flat, such as that between Fords Corners and Scotch Plains, than in one which has a strong relief, such as that between Denville and Saxton Falls. On the other hand, the details of the topography of the moraine may be striking, where the moraine itself, as a whole, does not form much of a ridge, and so is not a conspicuous topographic feature. This is often the case in regions of pronounced relief.

The topographic phases of the moraine are various. In places it is very rough, hillocks and hollows, or interrupted ridges and troughs, following each other in rapid succession and tumultuous arrangement (Fig. 62 and Pl. XXVII). Its relief is sometimes scores of feet within narrow geographic limits (Plates IX and X). The depressions enclosed by the elevation are frequently marked by marshes, ponds, and lakelets, wherever the material constituting their bottoms is sufficiently impervious to retain the water falling and draining into them. These rough moraine features are well developed east of Plainfield, especially from Oak Tree to Locust Grove (Plate XXVII). Here its billowy surface, with its rapidly-shifting curves, its numerous hillocks and kettle-like hollows, is so well developed as to make the surface fairly typical of strongly-developed terminal moraine topography. In other places the characteristic morainic features are more subdued, the billowy relief being far from bold.

As may be inferred from what has already been said concerning the distinctness of the outer and inner margins of the moraine, the characteristic morainic topography made by the close association of hummocks, kettles, ridges, and troughs, is, in general, better marked in the outer half of the moraine belt than in the inner. It is far from being developed with equal strength at all points, either in the outer half or in the inner.

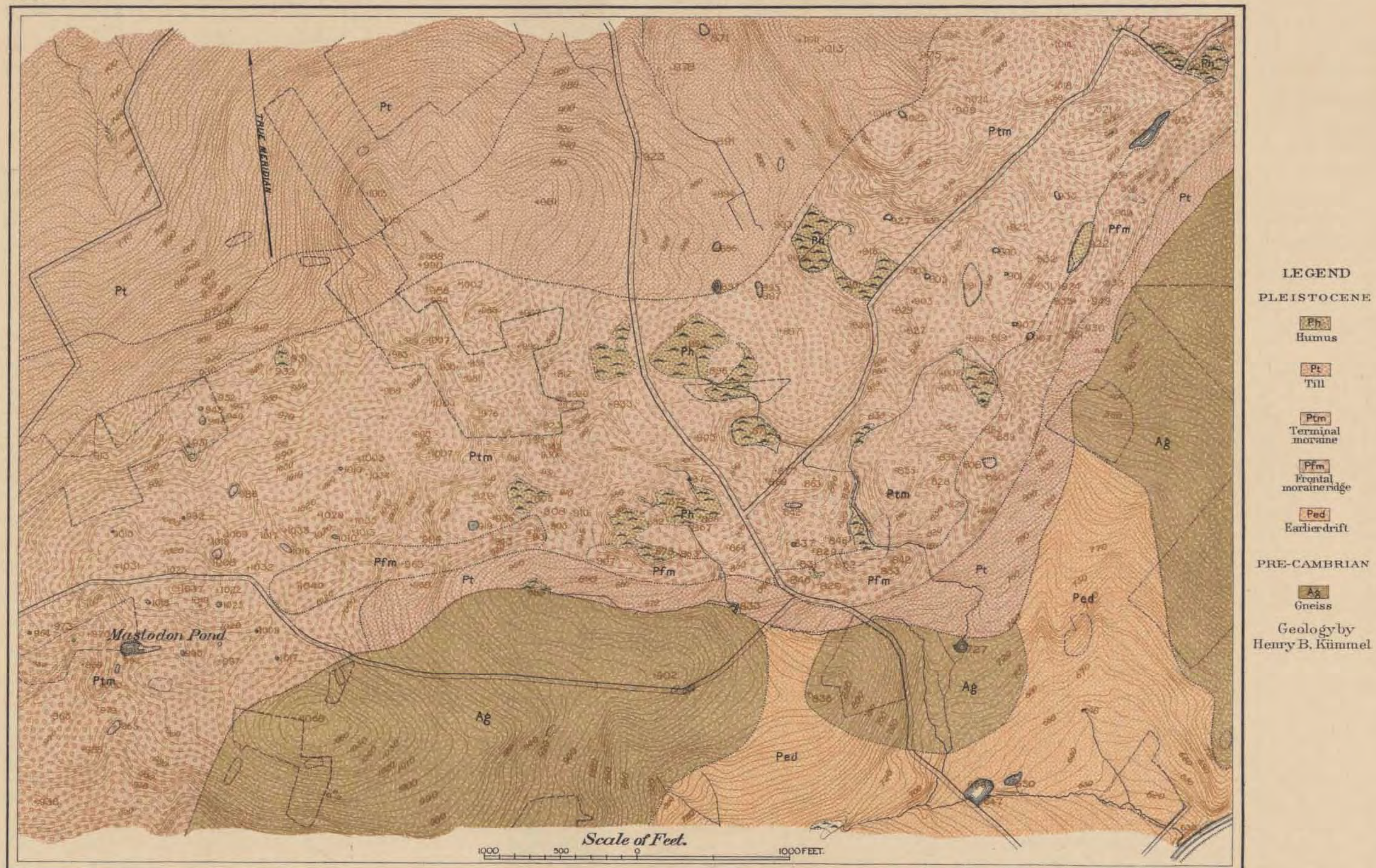
In detail.—Commencing with the southeast, the morainic topography is not notably rough at Perth Amboy. The adjacent undulations of surface are not commonly more than ten or fifteen feet, though now and then the surface becomes rough enough to attract attention. Northwest of Fords Corners there are considerable undulations, giving a strikingly rough surface, locally so rough that the land has not been cleared. Characteristic morainic topography, though not of an especially strong type, is shown a half mile north-northeast of the railway station at Metuchen, and an equal distance northwest of Robinvale station. It is also well marked about Oak Tree, and north of the L. V. railway between Oak Tree and Netherwood, near the outer face of the moraine. Here the topography is frequently very rough. Hillocks ten, twenty, thirty, and even forty feet high, are associated with abrupt depressions of circular or elongated form, some of which are twenty or thirty feet below their surroundings, though more of them are but five to fifteen feet deep. Numerous little ponds and marshes appear at the surface. This type of topography is shown on the accompanying map (Plate XXVII).

From Netherwood to Locust Grove the roughness of the topography is not striking, though usually not indistinct. From Netherwood to Short Hills and beyond, the surface is much forested, so that the topography is not well seen. From the Passaic river to Convent, the surface is nowhere very rough, but north of Convent the moraine topography is well developed at several points. It may be well seen a mile and more east of the Morristown station, on the road to Afton, where advantage has been taken of its unique topography for the location of summer residences. The rolling topography at this point, while much less declared than at some other points, illustrates the surface features which characterize the moraine throughout most of its course. From Morristown to Denville the moraine is nowhere very rough, except in the forest region east of Tabor, and here there is little opportunity to see it to good advantage. It has a relief much greater than might be inferred from the topographic map, which at this point, has contour lines at intervals of twenty feet, and so fails to bring out the peculiar knobbiness of the surface.

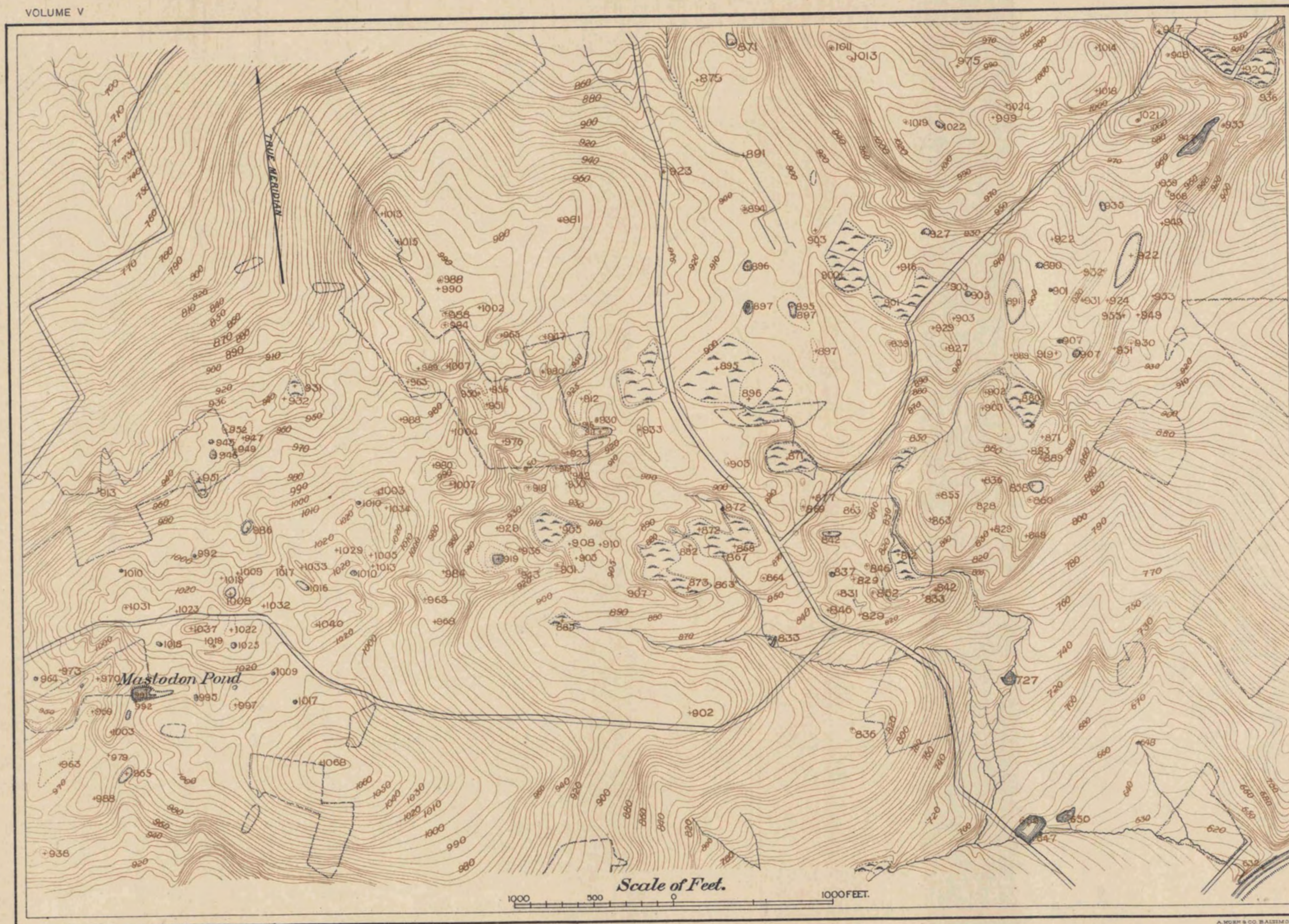
At a few points in the moraine there are striking depressions. The most notable of these occurs just north of Convent, south of the east-west road which crosses the moraine at this point. According to the topographic map, this depression is something more than sixty feet deep. It probably represents the position of an ice-block, about and over which drift was deposited. On melting it gave rise to the "kettle." There is another conspicuous sink, fifty feet deep, just outside the moraine, a few rods southwest of the railway, half a mile northwest of Convent.

On the north side of the canal at Dover the moraine has its normal development, with a mildly-accentuated topography, sinks and hummocks of ten feet relief being more frequent than greater ones. The most strongly-marked topography in this immediate locality is found on the inner border at the Teabo mines, something more than two miles north of Dover. At this place the relief between the tops of the hummocks and the bottoms of the sinks is fully thirty-five feet. South of Port Oram the topography of the inner border of the moraine is strong, with a relief of twenty-five feet, but as the moraine rises from an elevation of 700 feet to one of 931 feet, the topography becomes weak. The surface of the moraine again becomes rough as it descends to the west about Hopatcong Junction. Southwest of the station. the relief is about thirty-five feet.

North of the gravel plain of the Rockaway river, which divides the moraine into a north and south division at Port Oram, the moraine has a strongly-accentuated topography, with a relief of fifteen to thirty feet. The inner edge of the moraine here assumes the kame phase. Typical morainic topography is well shown along the Hopatcong branch of the Central railway, a short distance north of the point where the road crosses the D., L. & W. railway.



THE MORAINE NORTHWEST OF HACKETTSTOWN



THE MORAINE TOPOGRAPHY NORTHWEST OF HACKETTSTOWN.

The outer portion of the moraine at Mount Arlington station ıd south of it, has a rough topography, with rapidly rising and llling swells and sinks. Between the tops of the knolls and the ɔttoms of the adjacent hollows, there is a maximum relief of ɔrty feet. The topography of the inner border of the moraine, hich is about 400 feet higher, is much less strongly marked! At hippenport the relief of the moraine is about thirty-five feet. Vest of Shippenport, the topography is rough, with a relief of venty-five to forty feet. Great kettles are occupied by marshes nd some of them by ponds.

South of Stanhope, the topography of the moraine is more aried, the knolls of which it is made being sometimes broad and entle, and at other times abrupt and closely set, so as to give he surface a choppy appearance. Between Stanhope and Budds ake the topography is characteristic, but not markedly rough. It becomes rough again a mile southeast of Saxton Falls, where it has a relief of forty feet.

A mile northeast of Hackettstown the contrast between the flat, level suıface of the Musconetcong valley and the hummocky, tumultuous character of the moraine to the north is striking. The roads from Hackettstown to Waterloo and Allamuchy cross it where characteristic morainic topography is well shown. Just east of the Allamuchy road, there is a large conspicuous kettle, forty to fifty feet deep. Since this is in plain view from the road, it is particularly obtrusive; but other depressions, fully as large, are found in the woods and fields to the northwest. One and one-half miles northwest of Hackettstown the moraine topography is also strongly developed, north of the east-west road which connects the Petersburg road to Hackettstown, with the Peterbsurg road to Townsbury. Looking north from this road across a slight depression, the moraine is seen in fine development on the opposite slope (Fig. 62). Looking south, the smooth, regular slope of the drift-free gneiss ridge (Fig. 63) is in striking contrast with the moraine. The general relations of the moraine near Hackettstown are shown on Plate XLV.

In the vicinity of Townsbury the topography is often markedly hummocky. Sinks of various shapes are associated with hummocks, giving rise to the characteristic roughness of the surface.

OnMount Mohepinoke, west of Danville, the moraine is strongly developed, especially on the undulating top of the mountain. Good views of the characteristic topography can be obtained at a number of places along the road on the mountain west from Danville. Kettles twenty to thirty feet deep are not uncommon. The gently sloping area about a mile to a mile and a half east of Green's pond is strongly morainic, and affords a good illustration of the characteristic topography. At other points, as on the steep western and northwestern face of the 947-966 hill southeast of Green's pond, morainic topography is barely discernible, but here, as in almost all similar cases, the very weakly-marked topography is local only. Green's pond is a good example of a lakelet formed in a southward-draining valley, across which a dam of glacial drift was deposited.

CONSTITUTION OF THE MORAINE.

The constitution of the moraine is very variable. In some parts it is mostly of till; in others, it is mainly of sand and gravel; while in still others, the two sorts of drift are intimately associated. More commonly than otherwise, gravel lies at the surface of the moraine, even when its deeper parts are chiefly of till, but this is by no means the uniform rule. In general the topography is roughest where gravel is abundant, the sharpest hillocks having the character of kames.

In addition to the variations just mentioned, the lithologic composition of the till and of the stratified drift varies from point to point, according to the nature of the formations over which the ice had passed. The proportions of bowlders, gravel, sand and clay are likewise subject to wide variation. From Perth Amboy to Summit, the moraine is composed very largely of material derived from the Newark (Triàssic) series. It is predominately red, and more commonly clayey than gravelly. The red till of the moraine is well shown in the deep railway cut at Fanwood, and less well along the railway between Metuchen and Menlo Park. It is also shown in the cuts along the railway just north of Metuchen, though the till is here associated with much stratified sand and gravel. Green Pond mountain bowlders occur throughout this stretch of the moraine with increasing numbers to the northwest. Granitic or gneissic material, though it is nowhere predominant south of the Passaic river, is also found in subordinate quantity in the moraine between the points mentioned. Where the moraine crosses the Watchung mountains between Locust Grove and Summit, and from Summit northeastward through Short Hills, the trap of the Watchung mountains furnished much of its material.

From the Passaic to Tabor, gravelly material predominates over till. This is essentially true of that part of the moraine between the Passaic and Convent. From Madison to Littleton and beyond, the inner face of the moraine below an altitude of 360 feet has a good deal of gravel, for which Lake Passaic seems to have been partly responsible. In the vicinity of Morristown, Green Pond mountain conglomerate bowlders are abundant.

About Morristown, and especially north of this point, gneiss becomes the predominant element of the drift, though material derived from the red shale and sandstone is common, and locally abundant as far north as Tabor. From Denville to Dover (the eastern border of the Highlands), all other constituents are very subordinate to the material derived from the schists and gneisses of the Highlands. At many points all other stony ingredients constitute less than ten per cent. of the total amount of stony material of the drift. In this region the proportion of stony to earthy constituents is often large, bowlders sometimes making fifty per cent. of the whole. The stony material is often in the form of large bowlders, four to six feet in diameter, many of which are abundantly striated and conspicuously worn.

Of the minor constituents between Dover and Hackettstown, those derived from the Green Pond mountain belt are the most important. The sandstone, slate and limestone occur in smaller pieces than the gneiss, Green Mountain conglomerate and quartzite, and, being softer, are much more commonly striated.

The till of the moraine on the Highlands has been observed to be calcareous at a few points only, and that usually where limestone is one of the obvious constituents. The exposures in the moraine, chiefly along the railway, show wide variations in constitution. Here coarse material predominates, and there fine; here stratified drift, and there unstratified; here the material is compact, and there it is loose. Occasionally the drift of the moraine is so compact that bowlders in a clayey matrix are broken in being taken out.

As the moraine descends from the Highlands to the Musconetcong valley at Saxton Falls, its constitution changes promptly. Here sixty to seventy per cent. of the stony materials are of fresh, bluish limestone, in most cases distinctly striated. This change in constitution goes with a change in the nature of the underlying formation, which is here limestone. The gneiss bowlders have fresh, polished surfaces, and show very little sign of weathering subsequent to the deposition of the till. The color of the till is buff to grey, with a bluish tinge due to the great abundance of material derived from the blue limestone. The till here is highly calcareous, sometimes even at the surface.

West of the Musconetcong, the constitution of the moraine again changes, in keeping with the change in the character of the underlying rock, and gneiss and other crystalline bowlders again become dominant, but the limestone continues in abundance for several miles.

An excellent opportunity for contrasting both the morainic and the extra-morainic topography, and the morainic and extra-morainic material of gneissic origin, is afforded by the area along the road running east and west a mile and a quarter south of Petersburg (see Figs. 62 and 63). At the residence of the late A. R. Day, the road touches the moraine, and then runs to the westward just south of it for two-thirds of a mile, gradually approaching, and finally entering it. Along this road, where it runs over residuary soil outside the moraine, the surface masses of local gneiss are usually angular, and show no sign of wear. They are never smooth or polished. Some of them are more or less rounded, the result of concentric weathering, but their surfaces are never such as to simulate those of glacial bowlders. The gneiss is here coarse grained and quartz-bearing, and the residuary soil contains a large amount of quartz, giving the soil a loose, coarse, sandy appearance.

Leaving the residuary material to the south, the character of the surface material changes completely at the moraine. The change may be most readily seen in the character of the stones along the fences. Quartzite, sandstone, limestone, and various gneiss bowlders abound, so soon as the moraine is reached. Most of the bowlders show distinct evidence of wear, in that they possess rounded or beveled angles, and smoothed sides.

The contrast in color is not so marked, but there is yet a difference. A little below the surface, the till is buff to bluish-grey, whereas the gneiss residuary has always the higher color, indicating greater oxidation. In the color of the residuary earths, however, much depends on the constitution of the rock from which they are derived.

Where the material of the moraine is calcareous, this element is slight or absent immediately beneath the sod, but appears at greater depths. Not infrequently, the stratified drift is highly calcareous, even very near the surface. This is somewhat remarkable, as the loose drift is easily penetrated by water, which tends to leach out the lime carbonate. On the other hand more ground water evaporates from such a surface, and whatever it contained in solution, is left where the water evaporated. The amount of calcareous matter in the moraine varies considerably, but it is everywhere present between Hackettstown and Townsbury.

On Pohatcong mountain, the moraine is composed largely of till, but as it descends into the Pequest valley, the amount of stratified material increases notably. In the vicinity of Townsbury, the material is neither typical till nor well-stratified drift. Enough fine material was carried away by the water issuing from the ice along the natural drainage line afforded by the low limestone valley, to make the deposit which remains much less compact than typical till. The materials are, however, but little water-worn, and striated stones are not uncommon.

In the vicinity of Danville, the association of stratified drift and till, so common in the moraine, is well shown in a number of cuts, though the great mass of the moraine belt is composed of loose, stratified sand and gravel, containing bowlders one to three feet in diameter. It is always highly calcareous, the pebbles frequently being coated with lime carbonate and sometimes even cemented together by it. Oxidation has notably affected no more than the uppermost two or three feet of the drift. Along the road from the school-house to the depot, the moraine is largely of till, but the till is only superficial, stratified drift being found beneath. At the first exposure along the railroad south of the depot, gravelly till is shown overlying and more or less completely surrounding the gravel, which appears in pockets in the till. On the side of the cut towards the higher part of the hill, a much larger part of the material is stratified, showing that the till is more abundant on the lower slopes. The same relation is shown at a gravel pit just south, where till is found to make up the body of the hill.

The moraine within the Pequest valley, from Danville to Townsbury and beyond, was formed by the combined influence of water and ice, whereas in the formation of the moraine lying on Pohatcong mountain, water had little share. So soon as the moraine ascends from the Pequest valley to the west, its material is largely till, sometimes very compact, and sometimes loose and gravelly. Its surface is generally strewn with bowlders.

About Buttzville the moraine contains pieces of gneiss, schist, Potsdam, Oneida and Medina sandstones, quartzites and conglomerates, Hudson River sandstone and shale, limestone, black flint, and a few pieces of igneous rock. The relative abundance of these constituents is indicated roughly by the above order. Limestone is much less abundant than in the vicinity of Townsbury, but this diminution is what should be expected when it is remembered that the general course of ice movement was southwest by south. The long stretch of gneiss in the Jenny Jump mountain lies to the northeast of this locality, and there is no immediate source whence limestone could be derived, save the rock immediately underlying the moraine. A deep railroad cut half a mile north of the Buttzville depot, and another shallower cut the same distance northwest of the Bridgeville depot, give good exposures, and show the relationship of the till to the gravel and to the underlying rock.

North of Oxford Church, and, indeed, most of the way from Buttzville to the Delaware, the moraine is predominantly of stratified drift, containing some large bowlders and cobbles. This part of the moraine shows the tendency, already mentioned in connection with the moraine near Townsbury, to change to stratified drift in the valleys along which there was strong glacial drainage. In the Delaware valley, the moraine topography gives place to the gently undulating surface of the overwash plain, which is continued south as a valley train, to Trenton and beyond. The small isolated moraine area two miles south of Belvidere, rising above the general level of the valley train, is the only example of true moraine material in the Delaware valley south of Belvidere.

Surface bowlders.—The surface of the moraine is often thickly strewn with bowlders. This is true where it is composed of gravel as well as where it is of till. The bowlders are sometimes well worn and sometimes angular. They are of all the various types of rock which enter into the composition of the moraine, but gneissic bowlders predominate, and have the largest average size.

Great numbers of bowlders are found on the surface 1) north of Dover, east and south of the Baker mine; 2) west of Port Oram, on the north and east side of the Rockaway river where it cuts across the moraine in coming down from Berkshire valley, where the bowlders are notable for their large size, many being five and six feet in diameter; 3) at the south margin of the moraine south of Mount Arlington station and west of Duck pond; 4) south of Stanhope, towards Budds lake. Here a few limestone bowlders were found in addition to those of gneiss and Hudson River sandstone. Bowlder-strewn surfaces are the rule rather than the exception throughout the highland region of the State. They are less abundant east of the Highlands and in the Pequest valley. Bowlders are not now abundant at many points where their numbers were once large. Their removal is one of the incidents of settlement.

DEPTH OF DRIFT IN THE MORAINE.

The greatest known depth of drift in the moraine which has come to knowledge is reported from Mount Arlington station, where a well has been driven 260 feet without striking rock. The drift of the moraine is also very deep between Morristown to Madison, where few excavations have reached its base, although depths of about 200 feet have been reported at several points. Such figures are far above the average depth, which probably falls short of seventy-five feet.

CHAPTER X.

THE DRIFT OF THE APPALACHIAN PROVINCE.[1]

BY ROLLIN D. SALISBURY AND HENRY B. KÜMMEL.

CONTENTS.

[1]The detailed work on the drift of the Appalachian province of the State was done by Dr. Henry B. Kümmel. This chapter is based on his report.

GENERAL SUMMARY.

GEOGRAPHY.

The Appalachian province of the State (see Plate XLVI) includes the area west of the Highlands, and north of the Newark series. This report has to do chiefly with that part of the province which lies north of the moraine. The area is divisible into a western, a middle and an eastern part, the area west of the Kittatinny mountain, the Kittatinny mountain and the Kittatinny valley, respectively. The topographic relations of these several areas are illustrated by Figures 1, 2 and 3 of Plate XLVII.

Area west of Kittatinny mountain.—The area west of the Kittatinny mountain is of slight extent. From the Delaware Water gap to Flatbrookville, the river flows against the base of the mountain, except as it is separated by terrace deposits. But north of the Wallpack bend the river lies well to the west of the mountain base. Here the Flatbrook and Clove brook valleys separate the Kittatinny range on the east, from lesser ridges (Wallpack and Hogback) on the west, and these ridges, in turn, separate the Clove and Flatbrook valleys from the Delaware. The backbone of this ridge is, for the most part, the resistant Esopus (Caudi Galli) formation, while the valley to the east is underlain by limestone, the least obdurate formation in the northwestern part of the State. The relatively low belt west of the Wallpack and Hogback ridges is likewise underlain by limestone. The Flatbrook-Clove brook valley is largely occupied by stratified drift, and the till is chiefly confined to the ridge west of it.

The Kittatinny mountain.—The Kittatinny mountain, which forms the eastern border of the region described in the last paragraph, is also the western or northwestern boundary of the valley of the same name. It is the most striking topographic feature of northwestern New Jersey. Within the State it extends from the Delaware Water gap on the southwest, to the State line on the northeast, a distance of about thirty-six miles; but it is continued in both directions beyond the limits of the State. The general direction of the range in New Jersey is about northeast and southwest, but near the New York line its course changes to N. 15° E. In width, the range varies from two miles or less near the Water gap, to four or five miles near the State line. Throughout a part of its course the range is double-crested, and the eastern crest, where two exist, is usually somewhat higher than the western.

The two slopes of the mountain are notably unequal. The east slope is steep, in places almost precipitous. The west slope is less abrupt, though even here the angle is often high. The inequality of slope finds its explanation in the dip of the rock, which is to the northwest.

The Kittatinny mountain has several notable features. Among these are (1) its relatively even crest; (2) its steep eastern slope, and (3) its continuity. In reality the crest is less nearly level than it seems. It declines to the southwest, but the decline is so gradual that, seen from a distance, it looks nearly level. It is the bold front which the range presents to the valley on the southeast, which occasions the sharp definition of the boundary of the latter. There are several gaps in the range, yet they are so narrow or so shallow, that they do not occasion notable interruption in the crest of the range, as seen from most points. To this general statement the Delaware Water gap is an exception.

The mountain is composed of the tilted beds of the Oneida quartzite and conglomerate, and of the Medina sandstone and shale. The Oneida conglomerate forms both the eastern escarpment and the crest of the mountain throughout its course. For most of the distance from the Water gap to Beemerville, the eastern slope of the mountain has a precipitous ledge above, and a slope of talus, derived from the ledge, below. The ledge escarpment is usually 100 to 200 feet high, and the talus 200 to 300 feet. Much of the talus is due to the disrupting work of changes of temperature in post-glacial times.

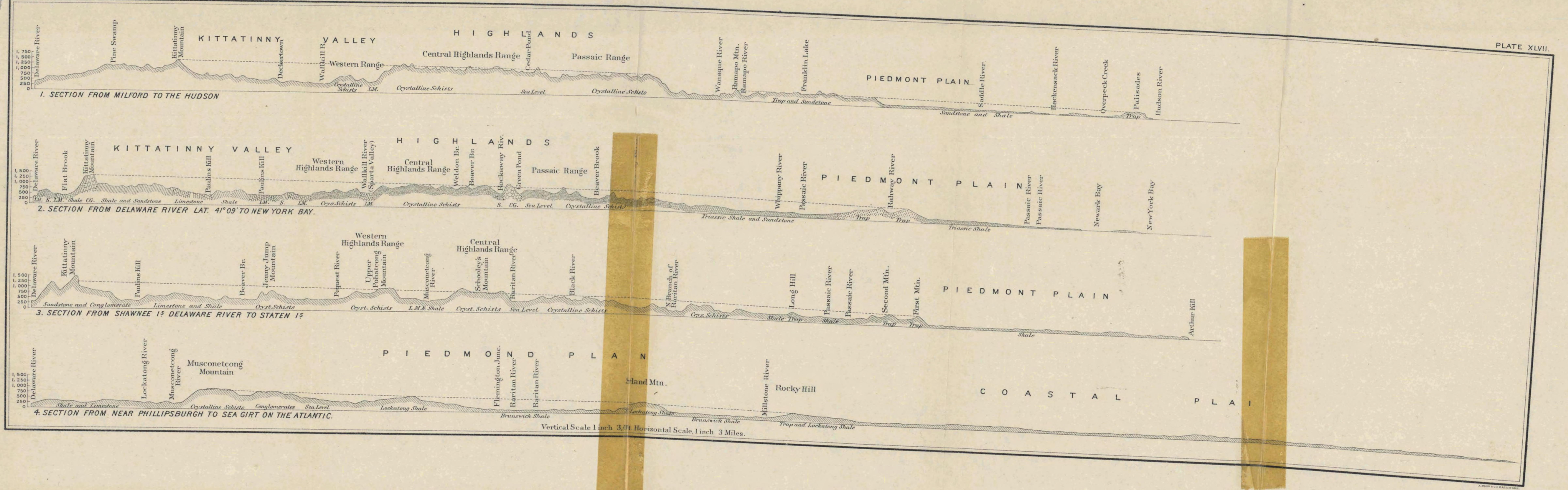
The Kittatinny valley.—The Kittatinny valley is a broad northeast-southwest depression, ten to thirteen miles wide, lying between the Highlands on the east (Plates XLVIII and XLIX) and the Kittatinny mountain on the west (Plate L). Its southeastern margin is less clearly marked than the northwestern, both because the Highlands on this side rise less abruptly than the Kittatinny mountain on the other, and because the front of the former is less continuous than the latter. The altitude of the western margin of the valley, where it abuts against the base of the Kittatinny mountain, is from 900 to 1,000 feet, and about 600 feet below the crest of the range. The altitude of the eastern margin of the valley is 400 to 600 feet, and likewise about 600 feet below the crest of the bordering uplands.

Within the Kittatinny valley, there are two notable elevations. These are the Pochuck mountain, 1,100 to 1,200 feet high, in its northern portion; and the Jenny Jump and Mohepinoke mountains, more than 1,100 feet high, in the southern part. The Kittatinny valley, therefore, is a broad depression, about 600 feet


GEOLOGICAL SURVEY OF NEW JERSEY.
A MAP OF
NEW JERSEY
Showing the
FOUR PRINCIPAL TOPOGRAPHIC DIVISIONS
OF THE STATE.
1902.
Scale of Miles.
PENNSYLVANIA
NEW YORK
ATLANTIC OCEAN
DELAWARE BAY
RARITAN BAY
Appalachian Zone
Highlands
Piedmont Plain
Coastal Plain

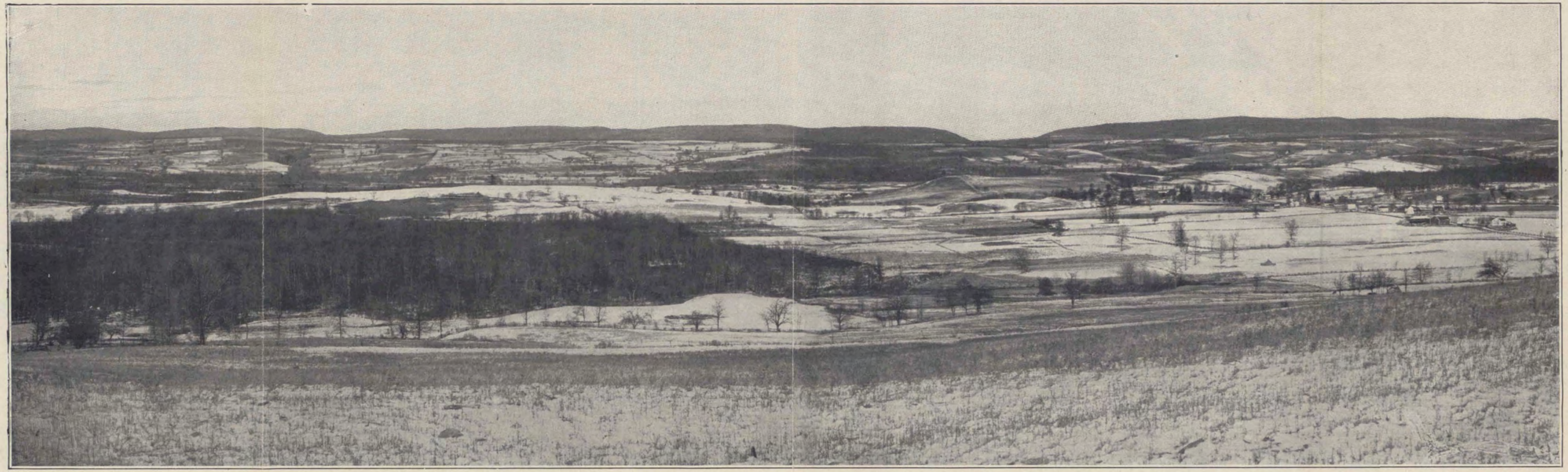
GEOLOGICAL SURVEY OF NEW JERSEY, VOLUME V.

PLATE XLVII.



View across Kittatinny valley from Sand pond, on Kittatinny mountain. The Highlands are seen in the background.

View from the Yellow Frame Church, on county line, near Johnsonburg, looking east across the Kittatinny valley to the Highlands.



View of Kittatinny valley and Kittatinny mountain from Smith's hill, near Newton.

below its lateral boundaries, with a notable massive elevation in either end.

Even apart from the Pochuck, Jenny Jump, and Mohepinoke mountains, the bottom of the valley is by no means flat. It does not correspond to the conventional idea of a river valley, and, indeed, is not a river valley in the simple sense of the term. Through it flow numerous streams, separated by divides, which, though they seem low in this mountainous region, are yet much higher than many of the stream divides in the Piedmont and Coastal plains.

Within the main valley there are two principal sub-valleys, parallel with each other, and with the main depression. The sub-valleys are 200 to 300 feet below the divides which separate them, and the divides have an altitude ranging from 700 to 900 feet A. T. Tributaries to the main sub-valleys have been developed to such an extent that the floor of the great trough is thoroughly dissected into a series of hills and valleys, and has a notably undulatory topography.[1]

The larger topographic features of the valleys are due to stream erosion and weathering, operating on rocks of different degree of resistance; but the details of topography are, to a considerable degree, the result of glaciation. The effects of preglacial erosion, of glaciation, and of subsequent weathering have all been somewhat different on the shale and on the limestone, and as a result, the belts where the two sorts of rock come to the surface present very different topographical appearances. The drift over the two sets of areas is unlike, both in kind and amount. As a result of these differences, the belts where the two sets of formations come to the surface are of different importance agriculturally.

DIRECTION OF ICE MOVEMENT.

The direction of ice movement in this part of the State is shown on Plate VIII (in pocket). From this Plate, and from

[1] **The topography of the valley is shown in detail on the topographic maps of the Survey, and has been described and explained in Vols. I and IV of the Final Report.**

Plate VII (p. 6), showing the character of the formations over which the ice passed, general inferences may be drawn concerning the composition of the drift from point to point. These maps will be referred to repeatedly in the pages which follow.

On the Kittatinny mountain and west of it.—West of the mountain, the trend of striæ and the topographic features are in general harmony. On the southern and narrower part of the Kittatinny range, the direction of movement, S. 10° W. to S. 25° W., was less westerly than the trend of the mountain, and the ice tended to pass over the crest of the latter into the Kittatinny valley. One effect of this tendency is seen in the distribution of drift from the southern end of the Kittatinny range over the southern part of the valley to the southeast.

On the northern and broader part of the mountain a somewhat different direction of motion prevailed. At the eastern base of the mountain, the striæ are essentially parallel to its abrupt front (S. 40° W.); but with increasing altitude the westing slowly increases until the summit is reached, when it increases at a bound, and the striæ point nearly west, and in some cases even north of west. These striæ make it clear, 1) that the ice here *tended* to diverge to the westward from the valley; 2) that along its lower slope, the abrupt eastern face of the mountain held the ice in approximate parallelism with itself; and 3) that with increasing altitude the westerly tendency became more and more pronounced until, when the summit was reached, the ice escaped the influence of the mountain escarpment, and turned promptly to the west. Under these circumstances, drift was not here carried from the valley up over the mountain, though drift from the mountain crests, and to some extent from the upper part of the eastern slope, was carried to the west slope. The relations of ice movement to topography at the north and south parts of the mountain, are suggested by Plate VIII.

In the valley.—In the Kittatinny valley, the movement of the ice corresponded in a general way with the trend of the valley, though the correspondence was not perfect. In the first place, the movement of the ice throughout most of the valley had a westing slightly less than that of the trend of the valley; and in the second, the ice tended to diverge on either hand from the main direction of movement in the axis of the valley, advancing more to the east (or less to the west) in the eastern part, and more to the west in the western, the divergence to the west being generally trivial and that to the east more pronounced.

Along the northwest side of the valley, the movement was nearly in harmony with the trend of the valley, being about S. 36° to 40° W., with no notable *general* variation between the northern and southern parts. There were local departures from the general direction at certain points, as noted in connection with the statements concerning the striæ of Kittatinny mountain. On the eastern or southeastern side of the valley the ice tended to crowd up on to the Highlands. The tendency to easterly divergence was rather greater at the south than at the north. The trend of the valley is about S. 45°–50° W. The general direction of the striæ along the north half of its eastern (southeastern) side is about S. 28° W. and along the south half S. 20° W. It follows that the tendency was to carry drift from the valley to the Highlands, but not from the Highlands to the valley.

With the foregoing facts concerning the general geography and geology of the valley, and the direction of ice movement, in mind, the details of its drift will be stated more in detail.

THE TILL.

Distribution and thickness.—Till, or ground moraine, occupies the larger part of the surface in the Appalachian province, the stratified drift being confined chiefly to the valleys. Over much of the area the till is extremely thin, sometimes being present in patches only, and again represented only by scattered bowlders. In general it attains its best development on broad summits, inter-stream surfaces and in cols, and is thinnest or wanting on steep slopes, narrow ridges and in narrow valleys. It is thicker on the gentler western slope of Kittatinny mountain than along the narrow crest and steep eastern escarpment, a distribution which is manifestly due to the topography. It is, in general, thicker on the western side of Kittatinny valley than on the eastern, partly, at least, as the result of the broader summits and inter-stream surfaces in this part of the valley. Its maximum thickness in the Kittatinny valley exceeds its maximum thickness on Kittatinny mountain. The greatest known thickness of till in the valley, more than 100 feet, is just at the edge of the valley southeast of Ogdensburg.

The first general impression obtained from traversing this part of the State is that the body of till is slight. This impression is, perhaps, not altogether trustworthy, since the minimum thickness on the nearly bare rock ledges and bowlder-strewn knolls is readily seen, while the greater thicknesses are discovered less readily. If the till is thick enough to conceal the rock, it is often difficult from surface indications to form any conception of its depth. The general differences between a thinly veneered rock topography and a till topography may give some clue, but does not permit accurate determination. Well-borings, cuts, etc., supply some data, but for this region they are few and far between. The constant tendency, therefore, is to underestimate the amount of till. With this condition of things in mind, the following estimates of the average thickness of the till in the various parts of the region are made. For the area west of Kittatinny mountain, probably not more than eight or ten feet: the west slope of Kittatinny mountain, six to eight feet; along the crest of the mountain, not more than two or three feet; on the limestone belts of the Kittatinny valley, from five to ten feet; on the shale belts, from eight to twelve feet; in the Vernon valley, more than five and certainly less than twenty feet. For the whole area the average thickness is probably between eight and twelve feet, the terminal moraine not being included. The greatest depth of drift recorded in this province is at Hamburg where a well penetrated 135 feet[1] of drift before reaching rock. The average depth of drift shown by the records of twenty wells, mostly in the sub-valleys of the Kittatinny valley, is about forty feet;[2] but it is to be noted that the wells are chiefly in the positions where the drift is thickest.

[1]Report of the State Geologist for 1896, p. 187.
[2]Published in the annual reports of the Survey.

Constitution.—The till is largely of local origin, and so reflects the character of the underlying rock. In general, it may be said that the till is more local in origin than the stratified drift, and, in general, it is more local where it is thin than where it is thick. Where its thickness does not exceed a few feet, a notable change in its constitution, in passing from one formation to another, is evident, usually within a few hundred yards or even feet. Where the drift is thick the change, so far as the surface of the till is concerned, is less prompt. The till is generally compact, as the result of the clayey matrix furnished by the shale, but it also abounds in bowlders, of which those from the Kittatinny mountain are most conspicuous.

Glaciated materials.—The percentage of glaciated bowlders and pebbles in the till varies according to the lithological constitution of the drift. East of the mountain, bowlders derived from the Oneida formation are most conspicuous, and, in general. about forty per cent. of those a foot or more in diameter show signs of glaciation, though distinctly striated bowlders are much less abundant. Perhaps a third of the surface bowlders in the region show some evidence of ice wear. The percentage may rise as high as seventy-five, and fall as low as ten. This unusually high percentage of surface bowlders showing signs of glaciation is the result of the resistant character of the bowlders themselves. Rarely has a surface bowlder of limestone retained the marks of glaciation; but in the till below the zone of weathering probably three-fourths of them are distinctly glaciated, and most of them striated. Probably half of the Hudson River shale and slate bowlders on the surface show marks of glacial wear, and where the till over the shale hills attains any considerable thickness, the glacially worn imbedded pebbles and bowlders form a still larger proportion.

The question of superglacial till.—Of the hundreds of exposures of till examined, only three showed such a difference in the constitution of the upper and lower parts as did not seem explicable on the basis of the greater weathering of the upper part. Two of these were west of the Kittatinny mountain, the first a mile southeast of Flatbrookville; the second southeast of Tri-States; the other in Kittatinny valley, near its eastern border near Ogdensburg. In the railway cut near this place, the upper eight feet of the till contains more gneiss, less limestone, and more unworn pebbles than the lower part. Other deep exposures in the vicinity showed no such differences. At the second locality, the upper two or three feet of the till was derived chiefly from the Oneida formation, whereas the lower part came largely from the underlying Medina. No similar difference was observable in another cut in the same vicinity. These differences are in line with those supposed to exist between superglacial and subglacial till; but it is quite as reasonable to suppose that the upper part, as well as the lower, is subglacial, so far as its deposition is concerned. The upper part of the till as it now lies was, perhaps, carried a little higher in the ice before it was deposited.

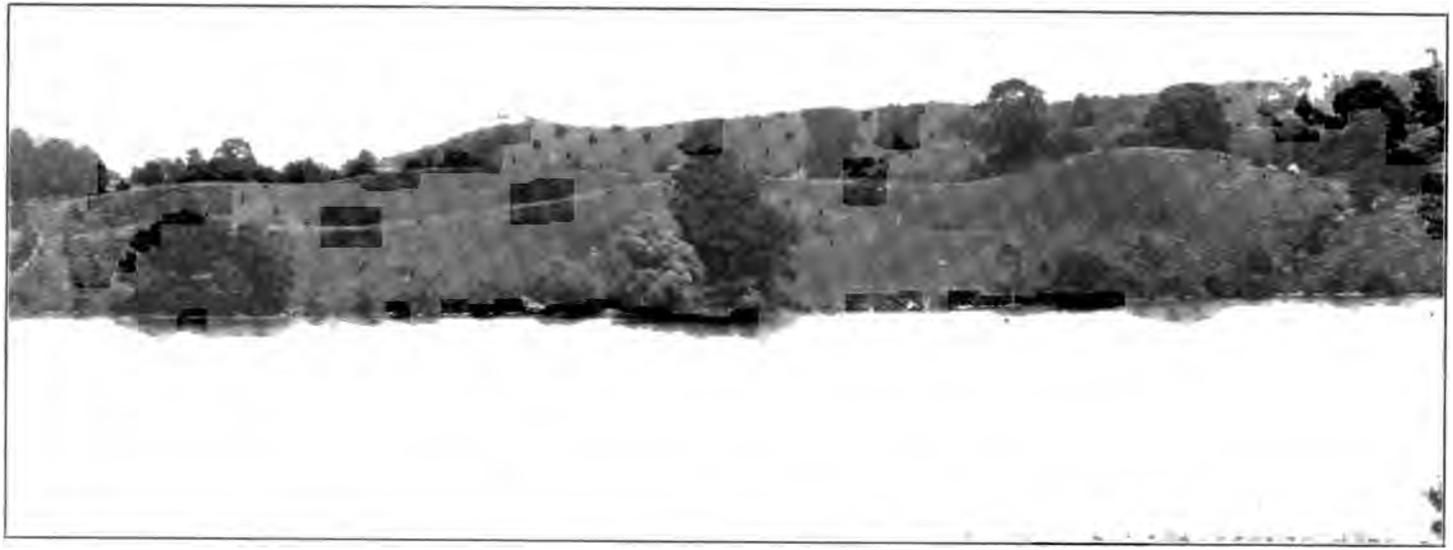
In contrast with these three cuts, there are many which show no difference betewen the upper and lower parts, other than that due to weathering and oxidation. It is to be said, however, that over large areas the exposures are too shallow to reveal any differences which may exist.

When the till of the northern part of the State is compared with that of the moraine, no essential differences as to (1) the original freshness of the material, or as to (2) the amount of oxidation subsequent to deposition, are evident.

Special aggregations of till.—Besides the prevalent ground moraine, a fairly well defined belt of recessional moraine extends from Ogdensburg, *via* Balesville, to Culvers gap. This is probably to be correlated with similar aggregations of drift across the mountain in the Flatbrook and Delaware valleys. The moraine is usually well developed in the valleys, but not on the divides between them. This disposition seems to indicate that it was made during the closing stage of the glacial epoch for this region, when the ice had lost much of its thickness. In this condition it seems to have retained sufficient thickness and vigor of motion in the valleys to heap up considerable accumulations of drift, but was too thin and lifeless over the ridges to accomplish much. In the valleys, the moraine topography is distinctly, although not ordinarily strongly, developed. Exceptionally, it is almost as pronounced as in any part of the terminal moraine (Plate LI).

Although the topography of the moraine is distinct, and not

PLATE LI.



Moraine topography at the north end of Lake Grinnell, looking east across the lake.

infrequently strongly marked, the moraine as a topographic feature is of little importance. The region which it crosses is one of strong relief, and the accumulations of drift, although very considerable in themselves, are so insignificant when compared to these greater elevations, that they do not to any appreciable extent affect the general topography.

There are minor morainic aggregations of drift elsewhere, but not in connected belts.

The special phase of ground moraine known as drumlins has possible representation between Franklin Furnace and Hamburg.

THE STRATIFIED DRIFT.

The stratified drift of the Appalachian province occupies but a fraction of the surface of the glaciated part of the Appalachian province. It is chiefly, but not wholly, in the valleys through which the glacial drainage flowed. These correspond, for the most part, with the valleys of the present streams.

Much of the stratified drift of the valleys has certain peculiarities of disposition, which make this region a rather remarkable one, so far as this phase of drift is concerned. Instead of being disposed wholly as valley trains (see Chapter IV, Part I), much of it takes on the less common phases of kame terraces and kames, indicating its deposition at the margin of the ice, rather than beyond it. At the same time its disposition is such as to show that the ice against which it was deposited was not in motion, or at any rate not in vigorous motion, either when the deposition took place, or later. Its irregularities of form are due in part to the fact that it was deposited against irregular bodies of ice, and in part to the changes which took place in its slopes when the ice against which it was deposited melted.

The origin of kames and kame terraces has been discussed in Chapter IV of Part I. Kames and kame terraces find illustration in nearly all the valleys of this province, but especially in the Flatbrook valley west of Kittatinny mountain, and in the valleys of Paulins kill, Papakating and Little Papakating creeks, Clove and Pequest rivers, and in the Vernon valley. Below these terraces, in or near the bottoms of the valleys, till and rock sometimes appear, even where there has been no post-glacial erosion. The relations of the stratified drift, the till, and the rock clearly show that the bottoms of the valleys were protected by ice while the deposition of gravel and sand was going on above, between the ice and the valley wall (see Fig. 33, p. 121).

Associated with the kame terraces are kame areas, or even isolated kames. These kame areas differ from the kame terraces chiefly in failing to develop the terrace form next the valley wall. They in turn grade into plains of stratified drift, the surfaces of which are characterized by depressions.

In some places these depressions are slight, but in others they are so deep that they have given origin to lakes. The deep depressions in the stratified drift were doubtless occupied by blocks of ice when the surrounding gravel and sand were deposited. A series of lakes originating in this way is found in one of the upper branches of the Pequest river, east of Newton. Another irregular sort of body of stratified drift closely associated with the kame terraces in origin, is illustrated by the embankment of stratified drift in the valley of the Wallkill at Ogdensburg. This body of drift (see Plates XXXIII and LVII) seems to have been deposited in a huge crevasse in the stagnant ice of the valley.

The irregularites of disposition possessed by the kame terraces are shown especially in the cross sections of the valleys (Fig. 34, p. 123). But there are other irregularities in their disposition, and in the disposition of some of the valley trains of the region, as seen in profile. Neither the valley trains nor the kame terraces have, as a rule, continuous down-stream slopes for any considerable distance. They appear to have been developed in sections (see Fig. 38, p. 127). This disposition of the stratified drift gives a clue to the history of the retreat of the ice sheet over the region as already pointed out (p. 127). In this region the disposition of the stratified drift has given a much more adequate idea of the successive stages at which the edge of the ice halted in its retreat than is given by the recessional moraine.

In addition to the drift deposited by streams in valleys which were free of ice or encumbered by it, there is stratified drift which was deposited in temporary lakes. In some cases, the deposits take the form of lacustrine flats, of which the Quaker Settlement plain in the valley of the Pequest is an example; and in some cases the form of deltas, of which the North Church delta, near Hardystonville, is the best example (see Fig. 43).

There are some notable kames in the province, some of which are directly connected with the valley drift, and some of which are not. The most notable group is that near Hamburg, shown on Plates XXX and XXXI.

Eskers have little development in this part of the State. The best examples are in Sussex county, one west of the Kittatinny mountain, and one east of it. The latter, near the State line southwest of Unionville, is the longer, but its length is less than a mile.

The thickness of the drift, where stratified drift instead of till occupies the surface, is not readily estimated, for wells rarely reach its base. It is certainly greater than the thickness of the till, perhaps, on the average, two or three times as great.

LOCAL DETAILS.

TILL WEST OF KITTATINNY MOUNTAIN.

In Wallpack township the ridge which lies between the Delaware and the Kittatinny mountain is steep, narrow, and but thinly mantled with till; what there is occurs chiefly in the lower places. The hill tops and steeper slopes are strewn with debris of the underlying rock, with which there is but little material foreign to the ridge. From Bevans to a point north of Montague, the ridge is wider, and is more uniformly covered with till, like the Kittatinny mountain in the same latitude. In places, indeed, the till is so thick as to make it difficult to trace the limits of the various rock formations. Northeast of Montague, the ridge again narrows, its sides become steeper, and outcrops of rock more common. Over much of this part of the ridge there is hardly more than a trace of till.

The till on the various formations constituting the ridge differs somewhat in constitution, being influenced by the underlying rock. It is somewhat more calcareous on the limestone, than on the grit and shale. In general, it has a compact, clayey matrix, containing many well worn and glaciated bits of rock, chiefly shale, slate and grit. Many of them are from the Esopus grit; others may be from the Hamilton or Hudson River formation, or from both. Oneida, Medina and Hudson River stones and bowlders are common. Limestone bowlders also occur.

Although the till is generally clayey and compact, there are areas where its surface is sandy, and its texture loose. These occur almost exclusively on the Delaware side of the ridge, on the slopes above the stratified drift. Much of this surface sandiness is due to sand blown up from the Delaware terraces. In general, the sand is too thin, and too unequally distributed to be differentiated from the till on the map.

The till has usually been oxidized to depths of three to five feet, but locally where the lime content was exceptionally large, complete leaching has not penetrated to that depth.

There are good exposures of till along the road (1) a quarter to a half mile northeast of Bevans; (2) at the corners three-fourths of a mile north by west of the same place; (3) a few rods west of Layton on the road to Dingmans (very calcareous); (4) at the bend in the road three-fourths of a mile east of the Fisher school-house; (5) a mile north of the Hainesville hotel; (6) a pit near the road, a mile and a quarter west of the Hainesville hotel. At the last exposure the till is very stony, being indeed made up mostly of stones, many of which are not characteristically glaciated. The matrix is sandy rather than clayey, but there is no assortment of the material, nor rounding by water. More than fifty per cent. of the stones and bowlders are limestone. Clayey, stony till is exposed along the roads leading south and southeast from the Montague hotel, and there is an exposure twenty feet deep along the stream bank between the hotel and the river. A well dug a little north of the hotel penetrated twenty feet of compact calcareous clay containing many small stones and large striated bowlders. The till was calcareous within a foot and a half of the surface. Beneath the twenty feet of till, there were found twelve feet of gravel, most of which was cemented by lime carbonate into firm conglomerate. Beneath the conglomerate is loose sand.

Recessional moraines.—In two localities, the till has the topography of a terminal moraine. One of these is a mile north of Layton. Though the morainic topography is best developed in the valley of the Flatbrook, and on the west slope of the Kittatinny mountain above, it may also be seen on the west side of the Flatbrook. It is, however, not traceable across the ridge to the Delaware. It re-appears in the Delaware valley a mile and a quarter north of Dingman's ferry. Above the Delaware terrace it extends northeast, diagonally up the slope of the ridge, having an average width of from one-quarter to one-third of a mile. The topography is sharply marked in the vicinity of the Fisher school-house, and from the hill just back of the school, a fine view can be had of the moraine as it descends the hill from the northeast. The moraine ends in the woods a little over a mile to the northeast. Small bowlders and cobbles are abundant on the knolls, much more so than on the surrounding areas of till. That part of the moraine belt west of the school-house, at about the same level as the gravel terrace, is composed largely of stratified drift, but at the higher levels till constitutes the greater part of the moraine.

A little southeast of the northern end of this moraine belt, is a small area of like topography. This and other isolated patches connect the Delaware valley moraine with the one in the Flatbrook valley. There can be little doubt that they were contemporaneous in origin.

The Montague moraine.—On the hills southeast of Montague, there is a morainic area, of characteristic though not strongly marked topography. The undulations rarely have a relief of more than fifteen feet. Both till and stratified drift enter into its composition. The surface is thickly strewn with bowlders and cobbles, the greater number of which are from the Oneida, Medina, Esopus and Hudson River formations. Good views of the morainic topography are to be had along the Sussex (Deckertown) turnpike, and along the Hainesville turnpike half a mile southeast of the Montague hotel.

This moraine area stretches eastward nearly to the crest of the ridge separating the Delaware from the Flatbrook-Clove brook valleys. On the top of the ridge the moraine is not developed, but re-appears to the east, and is continued across the Flatbrook-Clove brook valley.

The belt is here more than a mile wide, and so completely fills the valley as to act as a watershed between the Flatbrook, and the tributaries of a stream which, heading on the back of the mountain, crosses the valley, cuts through the Hogback ridge, and finds its way to the Delaware a little above Montague. The Sussex turnpike crosses the moraine area, and from it good views of the moraine topography can be obtained. Much of the material is gravel and sand, so much, in fact, that this part deserves to be called a kame moraine. Some of the knolls are of loose sand, with their surfaces free from cobbles. Over most of the area, however, the cobbles and bowlders are extremely abundant, much more so than on the adjoining till areas. Sharply marked knolls and kettles of twenty to thirty feet relief are common, and some of the hillocks are massive. The moraine topography does not extend east of the road along the foot of the western slope of the mountain.

With the exception of a few small clearings, the back and top of the mountain are thickly wooded east and west of Mashipacong pond, and on a line between the moraine just described and that north of Libertyville. Under these conditions a faintly marked morainic belt, or even one distinctly developed, might readily escape observation. Slight suggestions of morainic topography were noted north of the road about a mile east by south of Mashipacong pond. But with the exception of this slight suggestion, no trace of a moraine was observed on this part of the mountain.

Three and a half miles due north of Blairstown there is a small tract, in which the topography is slightly morainic, but the area cannot be correlated with any definite morainic belt.

TILL ON THE KITTATINNY MOUNTAIN.

Along the crest of Kittatinny mountain till is present in patches only. Bare *roche moutonnées*, generally weathered enough to obliterate the striæ, occur every few rods or even yards along the crest. There is a little till in the depressions between the successive swells, but the aggregate amount of till on the top of the mountain is trifling. On the western slope the till is somewhat thicker.

From the escarpment on the east face of Kittatinny mountain till is, of course, essentially absent. Below the escarpment the movement of the ice was such as to clear away the pre-glacial talus in some places (to the north), and such as to allow of a material increase in the aggregation of blocks of the Oneida rock at its eastern base, in others. As the ice passed obliquely over the southern part of the ridge into the Kittatinny valley, it tended to "pluck" (p. 70) masses of rock from the top of the escarpment, and to leave them below. This is the region where the till is thick at the base of the mountain. Farther north, where the ice moved from the valley obliquely up over the mountain to the west, the drift at the eastern base of the mountain is scanty. Where the mountain crest is cut by ravines and gaps, its eastern face is not a cliff, and is thinly mantled with drift.

Pahaquarry and Wallpack townships.—The till in these townships west of the crest is generally thick enough to conceal the rock, although outcrops can hardly be said to be rare. For example, outcrops of rock are very common along the top of the subordinate ridge west of the village of Millbrook, where the till is thinner than on the slope of the main ridge to the east. There are also high ledges of the Medina formation along the Flatbrook from one and a half to two miles south of Wallpack post-office. Outcrops are common also along the old road which crosses the mountain from near Shoemaker ferry south of Catfish pond, and along the road leading east from Flatbrookville across the mountain. Occasionally, as shown by well borings, the till attains considerable thickness, even where outcrops of rock are common. Thus the till is twenty-two feet thick a mile southeast of Flatbrookville, though outcrops are numerous in the vicinity. Since by far the greater part of the area is uncultivated, excavations are few and generally shallow, and thicknesses of drift are not readily determined.

In constitution, the till is, on the whole, rather local. On the Medina sandstone area it is generally red, and has a clayey, or more rarely a gravelly, matrix. Much of its stony material, derived from the underlying rock, is angular and unworn. In addition to the stony matter from the underlying Medina formation, Oneida bowlders are more or less common, though the striæ in these townships point a little less to the west than the trend of the mountain. Masses from the Oneida ledges above doubtless descended the slope to some extent before the advent of the ice, and furnished some of the bowlders of the drift, while others came from farther north, where the movement of the ice was more westerly, or the trend of the ridge less so.

There are some slate and sandstone cobbles in the till which probably came from the Hamilton formation west of the Delaware.

On the Oneida formation, the till commonly has a yellow or yellow-brown color. It is less clayey than that on the Medina, and in general much more stony. The rock fragments are often angular, showing little wear. In addition to the local bowlders there are Medinas, and pieces of slate (Hamilton or Hudson River).

The material from a well, dug in 1895, a little east of the four corners a mile southeast of Flatbrookville, gave an insight into the constitution of the till at some distance beneath the surface. The till in the bottom of the well was so compact that blasting was resorted to in order to loosen it. Bluish-black limestone, most of it beautifully striated, was by far the most abundant stony constituent of the till. This probably came from the limestone beds west of the mountain, for the striæ (S. 17° and more W.) show that the ice moved from these beds obliquely up the mountain slope. Esopus (Caudi-Galli) grits and sandstones are very abundant, and their presence on the mountain is to be explained in the same way. These materials illustrate the lifting power of the ice, for the beds from which they came are several hundred feet lower than the well. Oneida and Medina fragments also occur, the latter being the more abundant. The clayey matrix is highly calcareous, showing that much limestone had been ground up in its making. The till from the well is different, lithologically, from that seen in the shallow exposures along the road. In them the Oneida and Medina bowlders predominate, and although Esopus grit is present, no limestone pebbles were found. While data are meager, the difference observed suggests that the upper and lower parts of the till are somewhat unlike in constitution.

On some of the outcrops striæ are common. This is especially true on the road east from Flatbrookville, where the rock surface has been uncovered recently. Striæ varying from S. 17° to S. 56° W. were noted here. Along no other road on the southern part of the mountain are there so many striated surfaces exposed.

Sandyston and Montague townships.—In these townships the mountain widens and becomes more plateau-like. Here the till attains such thickness as to generally conceal the rock, except on the steep slopes of ravines, and the crests of the Oneida hills along the eastern margin of the mountain.

Cuts of till, or exposures of any sort are rare, and in a region so generally uncleared as this, few data concerning the till can be obtained. Such exposures of rock as occur are generally on the steeper slopes, where the road-beds have been worn two to five feet below the general level. From such exposures, it would seem that the till is somewhat evenly distributed, but that it is not thick. So far as is shown by the shallow exposures along the roads, it is often sandy or gravelly, and without the compactness which characterizes till with a clayey matrix; but since the exposures rarely reach below the zone of weathering, this superficial looseness may be the result of surface changes.

The best exposures seen on this part of the mountain are near the State line on the Port Jervis-Coleville turnpike; a little northeast of the toll-gate the till is exposed to a depth of ten feet. In the bottom of the cut, the matrix is clayey and compact, somewhat foliated, and thickly set with stones. Its color is that of the Medina sandstone, of which it is chiefly composed. A few rods farther east is another exposure fifteen feet in depth. In this cut, the upper part (two or three feet) is composed chiefly of debris from the Oneida formation, whereas the lower part is largely from the Medina. The matrix is compact, reddish clay. There is here a lithological difference in the upper and lower parts which cannot be accounted for by the superior oxidation of the surface portion. The lower part is more local in constitution, while the upper is made up of material which was probably carried by the ice above its base. The ice here moved westward (see map, Plate VIII) and carried debris from the Oneida over to the Medina. Passing the crest of the range, Oneida debris may have been lodged in the ice so as to be above the base on the lower lands farther west (pp. 77-8). This Oneida material may in time have become superglacial by the melting of the surface, or subglacial by the melting of the bottom. In either case it would have been deposited on material which had been pushed along in the base of the ice, and which was, therefore, more largely local. The amount of possible superglacial till here is not more than three feet. At the cut nearer the toll-gate, a corresponding subdivision of the till does not exist, all at that point corresponding to the lower part of the other cut. This is one of the few places in the State where the upper part of the till seems to be distinct from the lower in constitution, though the weathered upper part is often different from the lower, unweathered or little weathered part.

In addition to the bowlders of local rock (Medina and Oneida) there are some of Esopus grit, some of sandstone (Hamilton or Hudson River), occasional pieces of limestone, and rarely a piece of gneiss. There are bowlders brought up on the mountain from both sides. The gneiss must have come from the northeast, and this is in harmony with the direction of the striæ, which, east of the mountains, are more to the west than the trend of the mountain itself. Hudson River fragments might have come from the same direction, but the pieces of Esopus grit came from the west. The evidence afforded by the material is confirmed by the striæ west of the mountain, which show that the ice moved from the Wallpack ridge south by west up the west slope of the Kittatinny mountain.

In general the till is very stony, and large bowlders are so numerous, even where the bed rock is completely buried, that most of the area has been regarded as worthless for agricultural purposes.

STRIÆ[1] WEST OF THE KITTATINNY VALLEY.

Pahaquarry township.—Striæ have been recorded in nine localities in this township, as follows: 1) Along the wood road up Dunnfield creek, S. 32°–33° W.; rock, sandstone. 2) Along the road up the mountain east of Labar's island, on the steep west slope, S. 15° to 18° W.; rock, sandstone. These are parallel to the strike of the mountain side at this point. 3) *Striæ are common in the vicinity of the Far View House on the steep westward and northwestward slopes of the mountain; direction S. 43° to 53° W.; rock, sandstone. 4) One-fourth of a mile northeast of the last, along the road, S. 60° W. and S. 70° W. 5) One-fourth mile northeast of the last, S. 65° W. 6) On the northeast slope of the mountain, three-fourths of a mile west of Sunfish pond, S. 61° W. and S. 48° W., the former at an elevation of about 700 feet, and the latter at about 1,100. The side of the mountain strikes about S. 60° W., so that the ice in the lower part of the valley moved parallel to the valley. Higher up on the sides the motion was more to the southward. 7) Along the wood road on top of the mountain, about one and a half miles southwest of Catfish pond, and two-thirds the way up the slope, S. 16° W. 8) A quarter of a mile north of Millbrook, on southeast slope, S. 5°–7° W. 9) On the road, a mile north of the above, top of a steep bluff facing west, S. 16° W.

Wallpack township.—Striæ are very numerous along the road crossing the mountain east of Flatbrookville. They are mostly on Medina sandstone. The following have been recorded: 1) Half a mile southeast of the village of Wallpack, elevation 630 feet, directions S. 35° W. and S. 43° W.; grooves, parallel to side of the mountain. 2) One-fourth of a mile south of the above, elevation 700 feet, direction S. 18° W.; parallel to the local slope. 3) Half a mile east of 1), elevation about 900 feet, direction S. 11° W. Striæ here point up the local slope. 4) One and one-eighth miles east by south of Flatbrookville, elevation 1,080 feet, direction S. 7° to 17° W.; grooves and

[1]Corrected for magnetic variation.

*Striæ marked thus * are good illustrations of glacial markings.

striæ. 5) One-fourth mile east of the last, elevation 1,106 feet, direction S. 31° W. and S. 56° W., both distinct. 6) One-fourth mile east of 5), at same elevation, direction S. 20° W. Within a few rods are many exposures on which striæ vary from S. 10° W. to S. 23° W., the commonest direction being S. 20° W. There is no apparent reason for these wide variations within narrow limits. 7) Along the road ascending the steep northeast face of the mountain, east of Flatbrookville, S. 48° W., at an elevation of 600 feet, and S. 56° W. at about 800 feet. The influence of the narrow Flatbrook valley and of the Delaware valley, is seen in the greater westing of these striæ as compared with those on the top of the ridge. 8) Near the four corners a mile and a half northeast of Flatbrookville, S. 53° W.; rock, shale. 9) Along the road one-fourth mile northeast of 8), S. 58° W.; rock shale. 10)* Fine striæ are found on shale along the river road a mile above Smith's ferry. One set, S. 70° W. is crossed by a second and later set, S. 53° W. On other outcrops within a few feet, readings S. 56° W., S. 58° W., S. 62° W., were obtained. All these striæ are distinctly marked. They are located very near the bottom of the steep-sided, narrow Delaware valley, and when compared to the more southerly trend of those on the top of the mountain they show the westward divergence of the ice caused by this valley. 11) On the top of Wallpack ridge one and three-eighths miles southwest of Wallpack center, S. 50° W.; rock, Esopus grit. 12) Along the road three-eighths of a mile east of south of Wallpack cemetery, S. 38° W.

Sandyston township.—1) On Kittatinny mountain, two miles south of Bevans, S. 52° to 55° W.; rock, sandstone. 2) On Wallpack ridge a mile west of Layton, on road, S. 28° W.; rock, shale.

Montague township.—1) Three-fourths of a mile south of Montague, on road, S. 34° W.; rock, Esopus grit. 2) On road half a mile east of Montague, S. 68° W.; rock, Esopus grit. 3) A mile northeast of Montague, above Chas. E. North's grist mill, average direction S. 82° W. One reading on north slope of hill, S. 94° W. or W. 4° N.; rock, shale. 4) Half a mile northeast of 3), at about the same elevation, on a horizontal surface, S. 58° W.

Striæ occur along the road which crosses the Hogback ridge south of Mashipacong island, as follows: 5) On the steep northwestern slope of the ridge there is a fine example of a *roche moutonnée* of black shale. On it there is a broad, shallow groove, fifteen feet long; direction S. 71° W. Some striæ in the groove are parallel to it, and some cross it obliquely, having the direction S. 56° W. The S. 56° W. striæ are the deeper, though the others can be traced as individual scratches for longer distances. These striæ are nearly parallel to the side of the valley. 6) One-fourth of a mile east of 5) and 200 feet higher, S. 55° W. 7)* At the foot of the steep slope a mile northeast of 5) is a fine exposure of striæ on a *roche moutonnée* of Esopus grit. Some of the individual striæ are more than six feet long. Their directions are S. 63° W., S. 66° W., and S. 53° W., the first set being most prominent. This exposure is about 300 yards from the road.

Striæ are abundant on the outcrops along the Deckertown-Montague turnpike, where it crosses the Oneida conglomerate towards the eastern side of the mountain. The markings are found exclusively on ledges which have been exposed by excavations along the road, and not on the outcrops of rock which have not been protected by drift. So potent is weathering in destroying striæ on unprotected surfaces, that even the hard siliceous Oneida quartzites have been roughened sufficiently to lose their markings. Numerous striæ also occur on the wood road leading north from the turnpike. 8)* Along the turnpike one and three-fourths miles southeast of Mashipacong pond, at an elevation of about 1,130 feet, S. 83° W. A few rods farther east and a little higher, S. 75° W., with others nearly intermediate in direction between these two. One or two hundred yards to the east along the road, and at an elevation of about 1,280 feet, striæ range from S. 83° W. to S. 87° W. Some of these outcrops show fair examples of glacial grooving and chattermarks. Eastward along the road to the crest of the mountain, outcrops and striæ are common. Their bearings are as follows: S. 93° W. (or W. 3° N.), S. 93° W., S. 86°

W., and S. 96° W. (or W. 6° N.). All those under 8) are on slopes facing north and west.

9) No striæ were recorded on the crest of the ridge in this township, but on the eastern slope, a few rods from the crest and not many feet below it, striæ bear S. 78° W.; forty feet lower down, S. 66° W.; and on the slate at the foot of the steep Oneida escarpment on the east side of the mountain and 340 feet below the crest, S. 38° W. The significance of these variations is referred to elsewhere (p. 266).

10) The wood road leading north from the Deckertown turnpike, near the crest of the Kittatinny mountain, crosses a small valley about 160 feet deep, and ascends to another rock ridge. The valley where crossed by the stream trends about S. 40° W. Striæ half way down the side of this valley trend S. 86° W., agreeing very closely with those found along the turnpike. Ten or fifteen feet above the bottom of the valley the striæ bear S. 36° to 41° W. Ascending the opposite slope the striæ ten to fifteen feet above the valley bottom point S. 28° W.; seventy-five feet above the valley bottom, S. 58° W.; a few feet higher, S. 68° W.; and on a broad, flat surface of rock 120 feet above the bottom, S. 68° W.* This last exposure is one of the best on the mountain. The rock is bare for an area twenty by thirty feet. Its surface has been smoothed, and it is traversed by innumerable parallel striæ. The striæ on the sides and bottom of this small valley show better than those at any other known locality in northern New Jersey, the deflecting power of a narrow valley on the direction of motion of the ice which filled it. Their directions suggest that the ice was thin when the striæ were made.

11) Striæ are very common on the freshly uncovered Oneida outcrops in the vicinity of High Point and the hotel west of Lake Marcia. Many, also, were found along the road south and southwest of the Point. On the Port Jervis turnpike no striæ could be found in the summit of the pass across the mountain, but a few rods to the northwest and about seventy feet below the summit, indistinct striæ were noted bearing S. 112° W. (W. 22° N.). On an Oneida ledge a short distance to the northwest and along the new road to Lake Marcia, striæ also bear S. 112° W. The elevation is here 120 feet below the summit of the pass. A few

rods southwest along the road which turns south from the Port Jervis turnpike, striæ on horizontal surfaces on a hill top, bear S. 95° W. and S. 97° W.; but at the elbow in the road half a mile southwest, they bear S. 27° W. There is no apparent reason for this local return to the normal direction. Probably the striæ having the great differences in direction were made at different times, when the local direction of movement was different. Three-eighths of a mile west of the two localities last mentioned, indistinct markings on a horizontal surface were noted, trending S. 117° W.

Along the road, half a mile south of High Point hotel, striæ on the east slope of a knoll bear S. 82° W. and S. 98° W., and *point up* the slope. About High Point hotel, striæ are abundant. Near the water's edge, their trend varies from S. 82° W. to S. 102° W., *in all cases, pointing up the steep slope.* On the crest of the hill, at an elevation of about 1,640 feet, the readings vary between S. 97° W. and S. 103° W. On High Point, grooves have the directions S. 78° W., and S. 82° W.

Striæ on a horizontal surface along the Port Jervis turnpike at the foot of the steep hill west of the High Point hotel have a direction S. 130° W. This is directly down the slope. The markings are indistinct, and in view of their direction there may be some question as to their glacial origin. A short distance to the southwest, on a surface which inclines steeply to the west, striæ point S. 45° W., or obliquely down the slope. The reason for the wide divergence in these two readings so near together is unknown.

STRATIFIED DRIFT WEST OF KITTATINNY VALLEY.

Summary.

The stratified drift of the Delaware valley north of the moraine, is disposed in the form of terraces. The material is of glacial origin and was deposited by the waters arising from the melting of the ice. The glacial origin is shown by the glacially marked cobbles and bowlders found at a few localities. The constitution of the material is such as to necessitate the conclusion that ice was concerned in its origin, for it contains material which could not have been secured by the river by the ordinary processes of erosion. For example, Oneida and Medina pebbles are found in the gravel above Wallpack bend. The upper course of the Delaware does not cross these formations, and its tributaries could not have supplied them in the existing quantities. The only source of these pebbles, for this part of the valley, is in the debris supplied by the ice. That the gravel was deposited by running water is shown by its disposition, its constitution and its structure.

The surface of the uppermost terrace at most points represents the depositional surface developed while the valley was being aggraded, during the decadence of the ice sheet. Generally speaking, the valley was filled to the height of the highest terrace. Much of the filling has since been removed by the stream, which is still engaged in clearing out the deposits of the closing stages of the glacial period. The highest terraces represent the remnants of the old aggradation plain. The notably discordant levels of the original aggradation surface, and its failure to decline regularly to the southward, show that the gravel and sand were not deposited continuously from the State line to Belvidere. Rather were they deposited in sections. When the ice stood at the position of the moraine below Belvidere, gravel was being deposited below that point. When the ice drew back from its maximum stand below Belvidere, gravel was deposited in the valley between the moraine and the new position of the ice front. But before this part of the valley was aggraded to the level of the part below the moraine, the ice had retreated still farther north, and the scene of active deposition was shifted to its edge. While deposition was active in the section above the moraine, the stream was probably cutting a channel through the moraine and the high gravel plain below it. It is probable, indeed, that when the ice retreated from the moraine, a lake came into existence in the valley between the moraine and the head of the high plain just south of it, and the ice to the north. Such a lake would have been of very short duration, for it would have taken but a short time for its outflow, which must have been voluminous, to cut a channel through the loose material which dammed it in on the south.

Just below points where the edge of the ice remained for a considerable period of time, as at the recessional moraine above Dingman's, the valley was aggraded to a notable degree. At other places the filling was less. This is the explanation of the fact that the original surface of the river-deposited drift was lower at some points than at others farther down stream. Though subsequent erosion has removed much of the fluvio-glacial deposits, the places where the edge of the ice halted can be determined by the disposition and slope of the remnants of their original surface. The more notable halts were a little above Dingman's (Fisher school-house), just below Montague, and perhaps just above the State line. The topography of the deposits at these points, as well as the coarseness of the material and the extent of the filling just below, shows that they were made at the immediate edge of the ice. In some cases, deposition took place about isolated ice masses, the sites of which are now marked by notable sinks, developed as the buried ice melted.

It follows from the foregoing, that the gravels of the Delaware below Belvidere were deposited chiefly at an earlier time than those north of the moraine, though some of the material from the upper reaches of the river has doubtless been carried down to lower latitudes in post-glacial time.

During the post-glacial degradation of the valley, flood plains and terraces have been developed below the plain of glacial aggradation. The present flood plain, which is often a low terrace, and some of the lower terraces above it, belong to this category. Each of these secondary terraces is the remnant of a flood plain. The lowest is, therefore, the youngest.

The material of the terraces varies from fine sand and silt to bowlders several feet in diameter. So far as determined from the comparatively few exposures, the greater part of the valley drift is gravel, though the predominating surface material is sand. The alluvial plain is almost always deeply covered with it. The same is generally true of the secondary terraces, and also for parts of the highest or fluvio-glacial terrace. Cobbles and bowlderets are very common on the surface of the highest terrace, even where the bulk of the surface material is sand.

The greatest depth of stratified drift recorded in the valley of the Delaware above Belvidere, is at the village of Delaware, where the gravel at the site of a well is ninety-three feet deep.[1]

In the Flatbrook-Clove brook valley.—These two valleys are really one, since the divide between them is low, and the ridges which hem them in on either side are common to both. Although this valley is separated from the closely parallel Delaware valley by a narrow ridge, nowhere more than two miles wide, yet very different conditions prevailed in the two valleys when their interesting deposits of stratified drift were made. The stratified drift deposits in the Flatbrook and Clove brook valleys are among the most interesting in the northern part of the State.

The gravel deposits in this valley present all the various phases of topography developed by the presence of stagnant ice when the deposits were being made. In many cases the various phases of topography grade into one another within the space of a few rods. The broad terrace and pitted plain topography is shown over much of the area between Bevans and Layton, and between the large swamps a mile and a half east of Montague; and sharply marked kames, kettles, and winding ridges occur in good development south of Bevans. At several points the deposits form a network of ridges and mounds, or reticulated kame areas, the best example being on the right bank of the Flatbrook, two miles above Flatbrookville.

The following generalized cross section (see Fig. 34, p. 123) is characteristic of this valley and of stagnant ice deposits in general. A broad and somewhat swampy flood plain in the axis of the valley, probably underlain by till, is bordered by a strongly marked kame belt, a few rods in width, on one or both sides. This passes gradually by an irregular kame-faced slope into a flat-topped terrace which extends to the side of the valley. Examples of this combination of forms are found (1) north of Wallpack Center, on the west side of the brook; (2) half a mile south of Layton on the east side; and (3) on the west side

[1]Annual report for 1896, p. 195.

of the brook just below the second moraine, about two miles southeast of Montague. Large flat-topped kames, in some cases probably representing the deposits made in ponds in the ice, occur (1) east of the millpond a mile and a half south of Bevans; (2) between Bevans and Layton; (3) north of the second moraine; and (4) between the head waters of the Flatbrook and the Clove brook.

History of Deposition.—From a study of the elevations of the terraces along this valley, something of the history of the deposition is made clear. At Flatbrookville the terraces are 420 feet A. T.; two miles above, 448 feet (ninety feet above the brook); six miles above, at Wallpack Center, 449 feet; eight miles above, at the millpond, 476 feet; nine miles above, at Bevans, 490; at Layton, eleven miles above, 550 feet (thirty feet above the brook); at the moraine, a mile above Layton, 620 feet; fourteen miles above Flatbrookville, near Hainesville, 640 to 650 feet; at the second moraine, two and a half miles above Hainesville, 740 feet; and the kame terrace north of the moraine, 640 to 670 feet. Between the Delaware and the head of Flatbrook valley, the channel of the brook rises from about 320 feet to 700 feet. (See Fig. 1, Plate LII.)

The elevations of the terraces in the Flatbrook valley show several important facts. (1) The gradient of the terraces, taken as a whole, is less than the gradient of the present stream. This is the reverse of what is found along most valleys filled, or partially filled, with fluvio-glacial deposits. The explanation is to be found in the conditions prevailing when these deposits were formed and since. When the deposits were made, the Delaware was being aggraded, and the height of the terraces at the mouth of the Flatbrook was determined by the height to which the Delaware valley was filled. The cutting in the lower part of the Flatbrook valley has kept pace with the cutting in the Delaware where the tributary joins it, but the lesser stream has not lowered the upper part of its valley at an equal rate.

From a point about two miles above Flatbrookville to Wallpack Center, a distance of four miles, the aggradation level (see Fig. 1, Plate LII) is nearly horizontal. From Wallpack Center the terraces rise northward by a gradient which increases rapidly as the moraine a mile north of Layton is reached, the rise in the mile below the moraine being seventy feet. With the increase of gradient there is a marked increase in the size of the materials composing the terrace.

Independently of the moraine itself, this disposition of the gravels shows that the ice halted in its retreat just north of Layton. While its edge stood here, the gravel deposits, certainly as far south as Wallpack Center, were chiefly formed. The topography of the deposits, and the form and size of the wide, swampy flood-plain, show that during the period of deposition more or less stagnant ice lingered in the axis of the valley below the moraine, and that the deposits were made around and between the ice blocks.

North of the moraine above Layton the terrace is ill-defined for some distance, but the gravel deposits appear to be somewhat lower than those just south of the moraine. A little above, the terrace ascends with increasing gradient to the second moraine, three miles above Hainesville, where the elevation is 740 feet. This moraine marks the position of a second halt in the retreat of the ice, during which the gravels between the second moraine and the first were deposited. Here, again, as below the other moraine, the deposits were made around blocks of ice in the valley south of the front of the great body of ice.

North of the second moraine is a kame terrace and a kame area, having an elevation 100 feet less than the moraine. This rises to the northward. Its position, its elevation and its topography show that it was formed after the ice had retreated north of the second moraine. These stages of deposition correspond with those made out for the Delaware valley.

The deposits along the Clove brook, which extend from this kame area to the State line, are irregular in height, showing no aggradation level, or any distinct stages of deposition.

Since the valley of the Clove brook drains northward, local lakes may have been formed in front of the ice as it retreated down the valley. If this was the case, they were temporary, for there is no decisive record of their existence.

Along the Big Flatbrook above its junction with the Little Flatbrook near Bevans, stratified deposits occur of the same

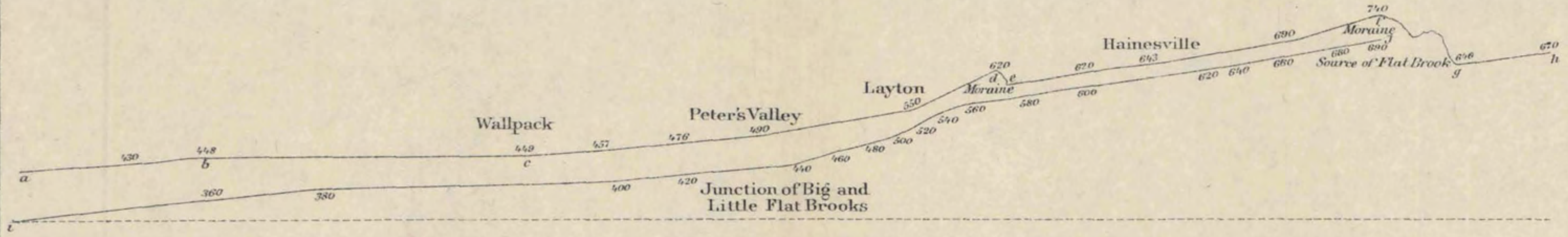


FIG. 1.

Horizontal Scale
½ inch per mile

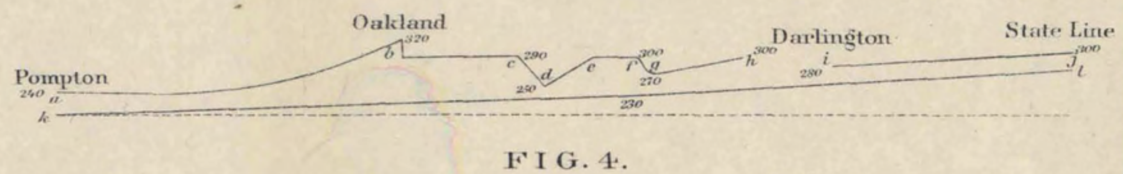


FIG. 4.

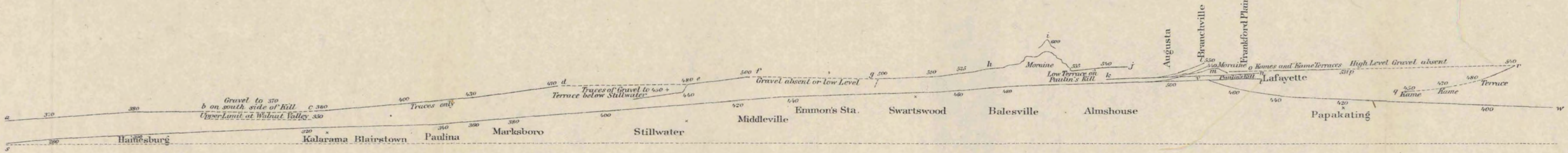


FIG. 2.

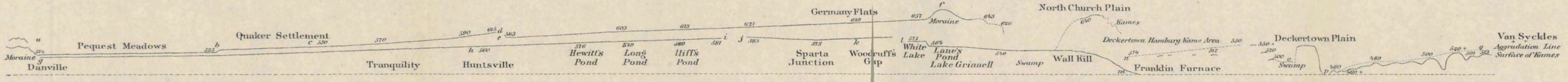


FIG. 3.

general type as along the main valley. No new features are presented, nor are the stages of deposition plainly shown.

Post-glacial erosion.—The amount of cutting done by the Flatbrook in post-glacial time is by no means the same, even in closely adjoining parts of its course. It is manifest from the nature and form of the deposits that they never filled the valley at all points to the height of their highest levels. In some localities they doubtless extended completely across the valley; but often the center of the valley was marked by a line of deep and shallow hollows and basins, along which the drainage established itself when the ice melted. Lakes and ponds occupied these basins. The work of the stream in post-glacial time has been to cut down the divides between them, and to silt up their bottoms, and the amount of vertical cutting has depended solely on the height of barriers between the basins. These may have had varying heights up to 100 feet. Near Flatbrookville the amount of vertical cutting may have been locally as much as sixty feet; near the first bridge above Flatbrookville the maximum measure is seventy feet; a quarter of a mile below the second bridge it may have been as much as forty feet, while near the bridge itself the erosion has not been more than eight feet. From this bridge to Bevans, there has been no erosion. In this part of its course the stream meanders in a broad flood plain, formerly a swamp or lake, which it has been silting up. Midway between Bevans and Layton, the stream has cut a trench seventy-five yards wide and more than twenty-five feet deep, across the barrier of gravel which separated two large kettle holes. Above Layton the maximum cutting has been nowhere more than thirty feet, and in general much less.

Along the Clove brook there has been practically no erosion in post-glacial times. On the contrary the stream has been silting up the marshes along its course.

Local Details in the Delaware Valley.

About Belvidere.—The terminal moraine reaches the Delaware river about two miles below Belvidere. Its greatest height is here 387 feet. To the south the fluvio-glacial gravels rise to about 360 feet in close proximity to the moraine, and stretch far to the southward. North of the moraine an undulating plain of sand and gravel extends north to the Pequest river. That part of this plain which lies south of the L. & H. R. railway varies in height from 315 to 340 feet, while the part to the north is lower. In Belvidere its height is but little more than 280 feet, though east and northeast of the village the gravel is banked against limestone hills to a maximum height of about 440 feet. North of the Pequest, the gravel along the Delaware reaches a height of 320 and 330 feet, while a little east of the Pennsylvania railway it rises to a maximum height of 358 feet. The lower surface (320 and 330 feet) nearer the river is not a secondary terrace, developed from the upper after the ice receded. These facts show that the stratified drift deposits about Belvidere were not built up to a common level, and never had a continuous slope from north to south in the direction of drainage.

Between the moraine on the south and the Pophandusing brook on the north, the surface of the stratified drift is gently undulatory, with a relief of twenty-five feet. The undulations are most marked in the proximity of the moraine. Indeed no sharp line can be drawn between the moraine, which, north of Oxford Church, is largely of stratified material, and the gravel plain to the south. North of the Pophandusing brook the inequalities of surface are still more marked.

Below the level of the stratified drift already referred to, there are two well marked terraces along the Pequest river at Belvidere. The lower one has an elevation of rather less than 260 feet, or about thirty feet above the Delaware close at hand. Water street in Belvidere is on this terrace. The higher terrace is about twenty feet above the first. North of the Pequest it is narrow, but on the south it includes the plain on which Belvidere, as far south as the L. & H. R. railroad, is built. These two terraces are of post-glacial origin, being the work of the present stream. The second terrace represents the flood plain of the Pequest, before the river had cut down to its present level. The lowest terrace is the present flood plain. The gravel plain above these terraces, at an elevation of about 330 feet, well shown between Belvidere and the moraine to the south, and on both sides of the Pequest at Belvidere, appears as a third terrace, but has a different history.

North of the Pequest the topography of the stratified drift above the post-glacial terraces indicates the presence of the ice when its materials were deposited. Here a huge spur or ridge of gravel starts from the plain about three-fourths of a mile south of Hartzell's ferry, and extends southeast nearly to the railroad, partly inclosing a depression twenty to forty feet deep, the position and shape of which precludes the supposition that it is due to post-glacial erosion. It appears to mark the position of an ice block around which the waters deposited the sand and gravel, and built up the plain. This spur of gravel and the accompanying hollow show that the 330-foot plain is not a terrace developed by erosion after the recession of the ice.

Again, along the line of the Pennsylvania railroad for two miles north of Belvidere there are sinks in the gravel plain, and bare ledges of rock at levels lower than that of the closely adjoining gravel deposits. These rock ledges have not been discovered by post-glacial erosion, but were covered and protected by ice when the surrounding gravels were deposited, and so escaped burial.

This conclusion is in harmony with that deduced from the relationship in elevation between the moraine and the gravel train south of it. The fact that the valley train to the south heads in the moraine, shows that it was formed when the ice front stood at the moraine. The irregular topography of the gravel plain north of the moraine implies the presence of the ice, perhaps in the form of detached masses only, when the plain was formed. The fact, too, that the gravel rises to such different elevations on the sides of neighboring hills proves that it was not deposited after the ice had retreated to the "southern valleys of the Catskills."[1]

Had the drainage not been influenced, and locally restrained, by ice still lingering in the valley, the gravel deposits would have been built up to approximately the same level at all points on the same parallel. This is not the case either north or south of Bel-

---

[1]Wright—The Great Ice Age in North America, p. 526.

videre. The gravel reaches very different elevations at different points, and these differences are not the result of subsequent erosion. On one hill it reaches up to 440 feet, on another half a mile distant and a little farther *up stream* it rises to 360 feet only, and on still another in the same latitude it varies from a little above 320 feet to less than 300, and these are the levels of original deposition.

The surface of the highest terrace, that is the original surface of the stratified drift, is generally stony, cobbles eight, ten or even twelve inches in diameter being very common. The composition and texture of the surface material varies notably. In some localities it is sandy, loose and clearly stratified. The sandy surface may grade into a surface covered with loam, and that into one covered with clay with no suggestion of the underlying sand and gravel. This variability of texture of the surface, like the uneven disposition, points to obstructed drainage when the surface was developed.

Over much of the area, exposures are rare. The best are found along the L. & H. R. railway and at gravel pits. In these exposures the uppermost two feet of the material is rather clayey, but the material beneath is clearly stratified. Some of it contains a good deal of clay, so that even at considerable depths it is not clean gravel and sand. In other places, the clayey element is absent save in the surface layer. A very large percentage of the finer gravel is of shale bits, but the lime content is also high. Many pebbles are coated with the lime carbonate, and in some exposures beds several feet thick have been cemented into firm conglomerate. In addition to the Hudson River shale, slate and sandstone pebbles, limestone, Oneida, Medina and gneiss pebbles and cobbles are present, besides some unidentified sandstones and quartzites. All these materials are fresh, and some of them little worn by the water. In some instances the pebbles and cobbles still retain striæ as distinctly as those of bowlders in till. These facts, in addition to those already cited, show that the ice edge was not far to the north when the gravel was deposited. Transportation of the gravel by water even a few miles would have obliterated all striæ, for the striated stones are chiefly of shale and limestone.

The surface layer of the lower (post-glacial) terraces is commonly fine sand, which locally attains a thickness of at least four feet. Beneath the sand, coarse gravel, similar to that of the higher terraces, is found. The fine sand probably represents an alluvial deposit made on each terrace when it was the flood plain of the river. It is, therefore, much younger than the undisturbed gravel which constitutes the main mass of the terrace.

From Manunka Chunk to Columbia.—Opposite Dildine island, below Manunka Chunk, the continuity of valley gravel is interrupted, on the New Jersey side of the river, by a headland of shale. Above this, and a little below Manunka Chunk, the stratified drift appears again as a narrow terrace, which continues to a point half a mile or more above Delaware village. Near Delaware the terrace attains its greatest width, about 700 yards. The surface of the terrace is generally of sandy loam; but exposures indicate that the body of the terrace is composed of coarse gravel. The surface of the terrace is slightly undulatory, and in places it is distinctly higher near the river than along its bluff margin. The most important topographic feature of this part of the terrace is a low broad ridge of gravel, which, a little below Ramseysburg, rises above the general level of the terrace. Towards the south it becomes narrower and higher, rising at a maximum, about fifteen feet above its surroundings. At its southern end, where it is about eighty yards wide, it passes into a confused cluster of knolls and hollows, due in part at least to the failure of the gravel to be built up evenly over a pre-existent, irregular surface. The ridge is probably an alluvial bar, similar to those now forming in depositing streams.

The greatest height of this section of the terrace is at its north end, near Delaware, where it reaches an elevation of 294 feet. This is about forty feet above the river. At Belvidere it will be remembered, the gravel rises, at a maximum, about 200 feet above the river at that point, though its average elevation is 100 feet less. The terrace at Delaware, therefore, is not only lower than that at Belvidere in comparison with the river, but actually lower. Since its surface has not been materially altered since the deposition of the gravel, it is clear that the waters which did the depositing were not the same as those building up the surface at Belvidere. In other words, the deposition at Belvidere, and between Delaware and Manunka Chunk, was not contemporaneous. The gravel about Belvidere was deposited while the ice still occupied the valley just above, while that between Delaware and Manunka Chunk was deposited after the ice had receded to the former place. When the gravel at Delaware and below was being deposited, the river must have been cutting down its channel below the 370-foot level at Belvidere.

The gravel and sand are known to have a thickness of ninety-three feet at one point at Delaware.[1]

About Columbia.—After an interruption of a little more than a mile, the Delaware valley gravel re-appears above Delaware village in a narrow terrace, just below the junction of the Paulinskill with the Delaware. The terrace here has a maximum elevation of a little less than 360 feet, or about ninety feet above the river at this point. It is composed of coarse gravel, and its surface is thickly strewn with cobbles. The surface of a lower terrace, probably of post-glacial development, is sandy.

The stratified drift stretches northwestward from the mouth of the Paulinskill for nearly two miles. In the vicinity of Columbia, its surface is covered with fine sandy loam, varying in thickness, as shown by well borings, from two to ten feet. Some of the loam may be eolian. Beneath the loam there is coarse gravel, occasionally containing bowlders three and four feet in diameter, showing that the edge of the ice was close by when the gravel was deposited. The general level of the terrace about Columbia is a little less than 320 feet A. T. (fifty feet above the river), though it ranges up to 332 feet. It is about thirty feet lower than the kame terraces along the Paulinskill, and is separated from them by a steep slope.

A little more than a mile above Columbia, the terrace rises considerably in height. If the contour map is accurate, the gravel runs up to about 370 feet, or ninety-five feet above the river. At the same time its surface becomes more or less undulatory and stony, bowlders two or three feet in diameter being present.

---

[1]Report of State Geologist 1896, p. 195.

The level of the gravels about Columbia (about 330 feet), taken in connection with the greater elevation of the gravels a mile below (360 feet), a mile above (370), and in the valley of Paulinskill (360 feet), together with details of local topography, suggest that the surface of the terrace about Columbia has been lowered and somewhat modified by erosion since its first development.

On the north side of the small tributary which joins the Delaware a mile and a half above Columbia, the hummocky topography characteristic of deposits of stratified drift made in the presence of ice, is sharply developed. The tributary stream here has eroded a channel thirty to forty feet deep, and over 100 yards wide, since glacial time, and its channel is completely clogged with the large bowlders contained in the gravel, but left behind when the finer material was carried away.

At Browning.—After another short interruption, the gravel re-appears in a well defined terrace in the vicinity of Browning. Its surface is gently undulatory, and has a maximum width of about 300 yards. Its average height is 320 to 330 feet, but along its bluff margin it rises to an altitude of 345 feet. It is forty to fifty feet above the river. In places, the evenness of the surface is interrupted by broad low ridges five to eight feet high, and parallel to the river. Their surfaces are generally strewn with bowlders, some of which are several feet in diameter. They are similar to those formed on the plains of rapid streams carrying an over-load of coarse detritus. Shallow cuts show that the surface of the terrace is composed of fine sand, grading to clay loam. Below, its material is coarser, the gravel containing even bowlders of considerable size. This section of the terrace disappears just below the Water gap.

Between the Water gap and Flatbrookville.—In the Water gap, just above Dunnfield, is a small remnant of a terrace about eighty feet above the river, and just above the Water gap, opposite Labar island, is another small terrace remnant at about the same elevation. From Walker's ferry to Shoemaker's ferry there are no terraces on the New Jersey side of the river which appear to represent fluvio-glacial deposition. At several points there are terraces thirty to thirty-five feet above the river which are still flooded in the highest freshets, and are clearly of post-glacial development. Near Shoemaker's ferry there is a loam-covered terrace about ten feet above the alluvial plain, though not sharply set off from it. This may (?) represent the level of glacio-fluvial deposition. Above this point a well marked knoll of gravel (kame?) rises twenty feet or more above the bluff edge of this terrace.

Near Calno, opposite Poxono island, the lowest terrace forms a broad alluvial plain, above which the gravel rises to elevations of 100 feet above the river, and more than 400 feet A. T. It does not, however, form a well-marked terrace, but has in places a decided kame-like topography. The steep slopes and crests of the knolls are of loose gravel, but much of the surface is compact and till-like in aspect. In the absence of exposures the upper limit of the gravels is located with considerable difficulty. There are probably small patches of gravel above the level of the great mass of the stratified drift. Occasional pits show that the material contains a very large proportion of Medina sandstone, and some limestone.

Opposite Depew's island, the fluvio-glacial terrace is well marked, and has an elevation of 390 to 400 feet (about forty feet above the river). Farther south, near the junction of the road to Millbrook with that to Flatbrookville, the upper limit is difficult of location, the real limit of the river deposits being hidden by wind-blown sand. The surface of the terrace is flat or but gently undulatory, with nothing to indicate that the gravel was deposited in the immediate presence of ice. In places the surface is loamy; in others it is strewn with small cobbles. Occasional exposures show that bowlders two feet in diameter are not wanting. From this point up to the mouth of the Flatbrook there are no terraces on the New Jersey side of the Delaware.

Wallpack bend to Dingman's.—North of Decker's ferry at Wallpack bend, the gravel rises to an elevation of between 420 and 440 feet A. T. (100-120 feet above the river), but the continuity of the terrace is interrupted by erosion gullies. Half a miles to the southwest (up stream), the terrace has a maximum height of only 417 feet. Here the surface is broken by kettles and hillocks with a relief of twenty feet, manifestly not due to erosion. The crests and slopes of the hillocks are thickly strewn with cobbles, the most abundant of which is bluish-gray sandstone, probably from the Hamilton formation. Ice must have been present at this point when the gravels were laid down.

Above Decker's ferry there are two low terraces of post-glacial origin, both of which are flooded. The lowest is narrow, about twenty feet above the river, and represents the height of ordinary freshets. The next is about fifteen feet higher, and is covered only by the waters of the greatest floods.

Just above Bushkill, the gravel terrace is again well developed about sixty feet above the river, and according to the map has an elevation of a little more than 420 feet. Its surface is gently undulatory. The surface material varies considerably in texture, but is rarely clayey. On the Pennsylvania side of the river a well-marked terrace appears to rise a little higher. A little above Smith's ferry, the upper terrace takes the form of a long, narrow ridge, between 400 and 420 feet A. T., separated from the bluff by a depression thirty feet deep. The depression probably represents a former channel of the river before it had been cut down to its present level. Traces of abandoned river beds are also present on the broad alluvial plain below the ferry.

Opposite Buck bar, two miles above Smith's ferry, the alluvial plain is wide and well marked, and, as usual, covered with fine sandy loam. Its surface is more or less strongly ribbed by longitudinal elevations. Traces of gravel occur on the slopes up to about 400 feet.

Below Shapnack island there are, in addition to the alluvial plain about twenty feet above the river, two higher terraces. The lower, of post-glacial origin, is not unlike the alluvial plain in surface appearance, but is separated from it by a steep slope ten feet high. The other has an elevation of a little less than 440 feet (100 feet above the river) and is of coarse gravel. The pebbles are mostly smooth and well worn. Many of them are disk shaped, and some more or less cylindrical. So far as the shapes of the pebbles are concerned, the gravel may have been transported a long distance and have been much worn before deposition.

From Shapnack island to Dingman's there is only a narrow terrace part of the way. Its maximum height is about 450 feet (105-110 feet above the river).

Dingman's to Montague.—Above Dingman's the terraces are better developed than in any other locality on the New Jersey side of the valley above the Delaware Water gap. Next the river near Dingman's, the narrow alluvial plain is twenty-five to thirty feet above the stream. About ten feet higher (390 feet A. T.) there is a loam-covered terrace of post-glacial origin, averaging about 100 yards in width. About ten feet above this is a broad, gently rolling flat, with loose sandy surface, and occasional cobbles and small bowlders. This terrace is about 400 feet in elevation (forty-three feet above the river), and is likewise of post-glacial origin. From its upper edge rises the steep-faced bluff of another terrace, thirty-five to forty feet higher (440 feet A. T.). This terrace has an average width of 125 yards, but varies considerably from point to point. Its surface is thickly strewn with cobbles. Above it a steep slope leads up to the fourth and highest terrace, whose general elevation is 475–478 feet (110 feet or so above the river). The surface of this terrace is sandy, though stones are not rare.

Within a short distance up stream from the beginning of these terraces, the second one above the stream rises irregularly from an elevation of 400 feet to 415–420 feet. The next higher terrace disappears, its place being taken for a short distance by a bench between the level of the two highest terraces, already mentioned. Finally, a mile above the ferry, there are but two distinct terraces, corresponding with the two highest mentioned above, the one at a height of 420–430 feet A. T. (sixty-five to seventy feet above the river) and the other at about 480 feet A. T. (about 120 feet above the river).

At the Fisher school-house, a mile and a half above Dingman's, a recessional moraine lies in the valley, and in this moraine the uppermost terrace noted above has its source. From an elevation of 500 feet at this point, it declines to 478 feet, in a distance of less than a mile. Three and a half miles farther down the river, the highest terrace has an elevation of 451 feet. It therefore declines nearly as much in the first mile below the moraine (500 to 478 feet) as in the next three and a half miles (478 to 451 feet). The rapid rise of the upper terrace to meet the moraine shows that the gravel in this part of the valley was deposited when the ice front stood at the line of the moraine.

For half a mile north of the moraine the upper terrace is present, but declines slightly in elevation. Opposite the lower end of the Namanock island, its evenness is broken by broad depressions, some of which do not seem to be due to erosion. The irregularities of surface are perhaps not greater than might have been produced by the vicissitudes of deposition, with shifting and eddying currents, and by subsequent erosion. The highest part of the terrace here rises in a low ridge to an elevation of 496 feet A. T. The crest of the ridge has bowlders six or eight feet in diameter; but since bowlders of the same size occur in a neighboring ravine, where they have been washed out of the sand and gravel, their presence does not prove that the material of the ridge is not stratified. A little farther north, the terrace is flat and well marked at an elevation of 475 feet.

Opposite the northern end of Namanock island, and thence to Minisink island, the rolling surface of the highest terrace is covered with fine sand. Some of the elevations are low dunes. Not infrequently the knolls are free of vegetation, and the shifting of the sand is now in progress. In some instances the windward sides of the knolls are thickly strewn with pebbles, concentrated by the removal of the sand. The hillocks of sand which have been heaped up by the wind are rarely more than ten or twelve feet high, and are not sharply defined.

Wind-blown sand at higher levels.—East and southeast of the dunes on the terrace is an irregular shaped area extending high up the side of the valley, which is covered with fine sand similar to that upon the terrace. In some places it attains a thickness of six or eight feet. Where best developed it is often heaped into low mounds, though this is not the invariable rule. In other cases it is better developed in shallow depressions than on the slight elevations of the surface. Small patches of sand occur in the adjoining fields beyond the limits of the main area. Where the sand is thin and discontinuous, stones and bowlders appear at the surface, and many of them show unmistakable signs of the peculiar wear inflicted by wind-blown sand.

Montague to Tri-States.—Opposite Minisink island, the Delaware sand and gravel form a narrow terrace at an elevation of about 460 feet. Near the upper end of the island, the terrace widens and reaches an elevation of 500 feet (120 feet above the river). A short distance below Montague, this elevation increases promptly to nearly 520 feet, according to the contour map. On the whole, the surface is even, and shows no sign either of the presence of ice during the deposition of its material, or of wind work since. The surface is generally sandy, but in some places gravel and cobble-stones are common. Just east of this point there is some indication (p. 275) that the edge of the ice halted temporarily in its retreat. It left no moraine in the valley, but if its edge stood for a time at the head of this terrace, the rapid southward decline of the surface, noted above, would be accounted for. This suggestion is strengthened by the fact that when the terrace re-appears to the northward above the Milford bridge, after an interruption at Montague, it is lower (480-490 feet) than at Montague.

At the bend of the river opposite Milford there is a broad alluvial plain twenty to thirty feet above the river, and distinctly higher along the river bank than back from it.

North of North's grist mill the upper terrace is well marked, having an elevation of something more than 480 feet. It is somewhat dissected by post-glacial erosion.

Opposite Quick's island, the general level of the upper terrace is 465 feet (sixty-five feet above the river). Fine sand, probably eolian, reaches higher levels.

A little farther up the river, opposite the lower end of Mashipacong island, several knolls of limestone project above the terrace, which is not so constant in elevation as would be expected of deposits built by free drainage. At a number of points there are low kame-like mounds of sand and gravel banked against the bluffs, ten to twenty feet above the terrace. They are not to be correlated with the terrace in origin, but were probably formed at a slightly earlier time, when ice occupied the valley. The gravel of which they are composed was probably originally deposited in spaces where the ice did not fit closely against the valley wall.

Opposite the lower part of Mashipacong island, the general level of the terrace is about 460 feet, although its upper margin may reach 480 feet, eighty feet above the river. Opposite the upper end of the island, the level of the gravel is less.

From the upper end of Mashipacong island to the State line, the upper terrace is well developed, and rises from an elevation of 480 feet to about 510 feet (80-100 feet above the river). For the last mile and a half below the State line, the terrace differs markedly from most of that farther south. Its surface is broken by sinks and kettles of various sizes and shapes. Many of them are so steep sided, so deep, and so irregular in outline, as to lead to the conclusion that ice blocks were present during the deposition of the gravel. Furthermore, in one instance at least, the slope from the terrace level to the river is marked by undulations and hollows, which are not of erosion origin. Just before the State line is reached, the terrace level is broken by a succession of mounds and kettles. The highest of the mounds reaches an elevation of 531 feet, though its crest is not certainly gravel. On the opposite (southeast) side of the road, there is a finely marked kettle hole of irregular outline about forty feet deep. All these details point to the presence of the ice when the stratified drift at this point was deposited.

The surface material of this part of the terrace is alternately fine sand, gravel and cobble stones, the first named being present over the greater area. The surface material, however, becomes coarser in proximity to the places where evidence of the presence of the ice is distinct.

In the Flatbrook Valley.

Flatbrookville to Bevans.—In the Flatbrook valley,[1] at the village of Flatbrookville there are terraces at about 420 feet A. T., which are continuous with those along the Delaware. On the left side of the brook there is a well-marked terrace at a slightly lower level (404 feet). The terrace material is gravel, composed largely of Medina and Oneida pebbles, though Esopus shale and lime-

[1] The relation between the terraces and the present stream level is shown in figure 1, plate LII, p. 290.

stone are also represented. The hard bluish-gray sandstone so common in the gravel of the adjoining Delaware terrace does not appear here, or, if present, is so rare as to be inconspicuous. Near the school-house, the gravel has been banked against a limestone hill, and much of it has been cemented into a firm conglomerate.[1] This is one of the best exposures of Pleistocene conglomerate in Sussex county.

A little more than a mile above the village, the gravel rises to 448 feet A. T. (ninety feet above the brook) on the right bank of the brook. Depressions and elevations of various sizes affect its surface, tending to obscure its terrace form. This irregularity of surface reaches a maximum just east of the cross roads about two miles above Flatbrookville. Here sharp, winding ridges, strewn with cobbles, inclose irregular-shaped depressions forty and fifty feet deep. The topography is that of a net-work of irregular ridges which branch and cross in the most lawless manner. The area is similar to that which has been described by Shaler and others, as "reticulated kame areas." The highest of the ridges has an elevation of 448 feet A. T., which accords with the height of the better developed terrace down stream. There was evidently a tendency here to build up the deposits to a common aggradation level, but this tendency was opposed, and its consummation prevented, by the presence of ice in the valley. Along the left bank, up to this point, the stratified drift deposits do not form a well-marked terrace, and are often wanting altogether.

The gravel continues more or less interruptedly on both sides of the brook up to the second bridge above Flatbrookville. Occasional spurs of gravel extending out from the side of the valley, and sudden widenings of the alluvial plain, out of all proportion to the size of the brook and the amount of the erosion which it could have accomplished since the ice melted, indicate the presence of ice when the deposits were in process of making. In the vicinity of the second bridge above Flatbrookville, the presence of kames on the flood-plain of the brook, and the occurrence of outcrops of rock in the bottom of the valley in such locations as to forbid the supposition that they have been discovered by post-

[1]This conglomerate was noted by Rogers in his report in 1840, p. 107.

glacial erosion, afford further proof of the presence of ice when the gravels were deposited.

From this point to Wallpack Center, the alluvial plain is wide and somewhat marshy. It is impossible to suppose that the stream has developed this plain since the ice period, especially when the evidence of little erosion below, at the second bridge, is so conclusive. In some cases, also, sink holes affect the slopes of the terraces, bordering the alluvial plain. This of itself is proof that the stream has not excavated the depression at the bottom of which the alluvial deposits lie, unless, indeed, the irregularities referred to are the result of slumping.

Near the second bridge, the greatest elevation of the gravel is 447 feet. At Wallpack Center, the terrace on both sides of the brook is well developed at an elevation of 449 feet, but much of the way between these points the body of the gravel does not reach this level. Though cobbles are more or less common on the surface, much of the material is fine gravel and sand, as shown by the exposures about Wallpack Center.

The aggradation level rises from 449 feet at Wallpack Center to 476 feet opposite the mill pond two miles above, and to about 490 feet at Bevans. The alluvial plain varies considerably in width, widening in places so as to occupy most of the space from bluff to bluff. From Wallpack Center to Bevans, the alluvial plain marks the position of an irregular body of ice, between which and the hillsides the irregular kame terraces were deposited. Just above Wallpack Center, on the right bank, the alluvial plain is bordered by a well-marked kame belt, which, along its bluff margin, passes into a flat-topped terrace. On the left bank the same thing is true, but to a somewhat different degree. The depressions of the surface are not so sharply limited to a narrow belt next the alluvial plain, but are distributed irregularly over the broad terrace, which extends for more than a mile up stream from the Wallpack cemetery.

Opposite the mill pond, about a mile below Bevans, two contrasting types of topography developed under the influence of ice are shown. Just east of the bridge there is a strongly developed kame area, whose knolls and kettles are sharply marked. The vertical relief within narrow limits is thirty to thirty-five feet, the highest knolls reaching an altitude of 468 feet. Here the ice mass, against which the stratified drift was deposited, was so irregular in outline that the deposits were not built up to a common aggradation level, or, if so built up, slumped down into kettles and hillocks on the melting of the ice.

Just north of this area is a broad, flat-topped mound, with an elevation of 476 feet. On the northern side it is being undercut by the brook. Towards the southeast, the steep slopes resemble delta fronts. At other points its steep slopes show signs of deposition against ice. It seems to have been built into a small lake, enclosed, or partly enclosed, by ice walls. When the ice melted, the level top was not destroyed.

A little farther north, on the left side of the valley, the kame terrace forms are well shown. On the whole, the terrace level is distinctly developed. The most significant features here are the sinks on the slopes to the alluvial plain. This area is soon succeeded up the valley by a strongly marked kame area, in which no aggradation level is developed. This is succeeded, in turn, by an area in which the terrace level is marked by small flat-topped plateaus, separated by circular hollows and winding depressions, ten to thirty feet deep. Nowhere are the ever-changing typs of topography, due to stagnant ice, better shown than along the left side of the valley about a mile south of Bevans.

On the right bank of the brook, a few hundred yards south of Bevans, stagnant ice-forms again attain marked development. The terrace is completely broken up into irregular hills and winding ridges, surrounding depressions fifteen to twenty feet deep. The fact that ice controlled the topography, although the gravel was deposited by running water, is written on every curve of the slopes.

At Bevans, the Little Flatbrook and the Big Flatbrook unite to form the Flatbrook. Kame terraces are found in both the converging valleys, but are best developed along the former. These will be considered first.

Between Bevans and the head of Little Flatbrook valley.—Just above the junction of the streams, the valley of the Little Flatbrook widens notably, and the terrace deposits attain their greatest development, with a maximum width of nearly two miles. Within this area, a great range of topography is found, passing from the perfect terrace plain, through the various degrees of pitted plains, to the kame terraces whose flat crests reveal the aggradation level, and finally to kame areas where no two hillocks correspond in height.

The terrace, which, at Bevans, has an elevation of about 490 feet, rises to 512 feet a mile and a quarter up stream, and to 550 feet at Layton. This is a much more rapid rise than for any equal distance at any point farther down stream. With this rapid rise in the height of the terrace goes a notable increase in the coarseness of its material. Near Bevans, the surface is strewn with small cobbles. Up stream, the stones increase in size, and at Layton many of them are twelve or fifteen inches in diameter. There is, however, much fine material associated with the coarse. The occasion of the change of grade, and of the increased coarseness of material, is found in the recessional moraine above Layton, to be mentioned below.

A little northeast of the club house at Bevans, a broad mound of till arises about eight or ten feet above the level of the gravel plain. North of this for nearly a mile, the top of the terrace is level, save for its down-stream slope. Only on its steep slopes are the signs of stagnant ice reflected in the topography. About a mile south of Layton the peculiar hummocky topography is developed in belts on both sides of the alluvial plain. Near Layton, also, are enormous kettles in the plain, a small pond occupying the bottom of the largest.

Midway between Bevans and Layton, where the stream has cut through the portion of the plain which originally separated two large depressions, it has eroded a channel about seventy-five yards wide and at least twenty-five feet deep. This narrow, gorge-like part of the sub-valley, is in marked contrast to the broad, swampy alluvial plains above and below.

A mile above Layton a narrow recessional moraine crosses the valley. This moraine is doubtless connected in time of origin with that in the Delaware valley near the Fisher schoolhouse, although it cannot be traced across the intervening ridge.

From Layton, as already noted, the gravel train rises rapidly to meet the moraine, the rise being more than seventy feet in the last mile. For half a mile above Layton, the gravel terrace is wide and but slightly interrupted by depressions, and its surface is strewn with cobbles and bowlderets. Nearer the moraine, the surface becomes more till-like, being firm and often clayey, and the topography is characteristic neither of till nor gravel. Along the steep slope near the brook, even where the general aspect of the surface is till-like, shallow exposures show stratified drift.

The moraine across the valley marks a definite halting place in the retreat of the main ice mass up the valley. While the ice front remained at this point, and while much stagnant ice, in the shape of more or less isolated blocks, occupied part of the valley below, the great body of gravel between the moraine and Bevans was deposited. Much of that below was deposited earlier.

For some distance above the moraine the gravel deposits are irregular and varied in topographic expression. In places the surface is clayey and more or less till-like, even where gravel and sand are present at no great depth. As nearly as could be determined from the map, this terrace has a maximum elevation of 640 feet, with an average of about 620 feet.

At Hainesville the brook meanders in a wide alluvial plain, which in places is interrupted by swamps. The stream has here an elevation of about 620 feet. Above the alluvial plain rise low mounds and terraces of gravel, many of which have an elevation of less than 640 feet, though in places the sand and gravel extend up to about 670 feet. The best marked terraces are on the east side of the brook, near the Hainesville cemetery.

About a mile above Hainesville, the general level of the kame terrace is 660 feet, but on the west side of the brook there is a series of small irregular knolls of gravel lodged on the steep slope at an elevation considerably higher. Locally this upper deposit takes the form of a narrow terrace; in other localities the knoll form is more conspicuous; and in still other places the gravel seems to be limited to a thin layer over the surface of the slope. This gravel was probably deposited when the ice occupied the bottom of the valley and fitted up against its side; but before a well-marked or continuous terrace was developed, the ice melted away from the hill, and in the wide angle between it and the ice in the center of the valley, the 670-foot terrace was formed. The gravel of the higher knolls contains bowlders and large cobbles, and appears less well assorted than that of the lower kame terrace.

About two and a half miles northeast of Hainesville, a second recessional moraine crosses the valley. This moraine, to be correlated with that near Montague in the Delaware valley, records a second halt in retreat of the ice, during which time the bulk of the gravel, between this point and Hainesville, and perhaps between this point and the moraine above Centerville, was deposited.

On either side of the valley below the moraine, the gravel is disposed in the form of kame terraces, the levels of which rise from 650 feet near Hainesville, to 740 feet at the moraine, the rise in the last mile being forty feet. The rapid rise of the terraces in front of the moraine is to be correlated with the similar but less rapid rise in the terrace level along the Delaware just below Montague. An increase in coarseness of the material accompanies the rise.

Much of the way between Hainesville and the moraine above, the brook flows through swamps, which appear to mark the former sites of stagnant ice-blocks. They are surrounded by stratified deposits, and their outlines are those of the buried ice-blocks, and are extremely irregular. Since the brook rises at about the same rate as the terrace from a height of 620 feet at Hainesville to 700 feet at the moraine, the terraces are nowhere very high above the stream, and the depressions which mar their regularity are not deep, rarely more than fifteen or twenty feet. Just below the moraine the swampy alluvial plain is succeeded by an irregular kame belt, which, in turn, passes into an even-topped, unbroken terrace, 200 or 300 yards in width. Nowhere else is this relationship of forms better shown.

These relations show that a mass of ice still lingered in the valley below the moraine while the moraine was making, and that sand and gravel were deposited about it. The influence of the ice on the topography of the drift is most pronounced in the center of the valley, and less and less toward the bluffs on either side.

North of the moraine is a large swamp, formerly a pond, in which were accumulated considerable beds of shell marl. At the southwest end of the swamp is a group of large kames, whose maximum elevation is over 660 feet. They are separated from the moraine area by a limestone hill nearly free from drift. It is an open question whether they should be considered a part of the moraine area, or classed with the kame terraces above. Their elevation corresponds more nearly with that of the latter. A wide kame terrace limits the swamp on the north.

The average elevation of the terrace above this swamp is between 640 and 670 feet. Over wide areas, the plain character is well developed, although more or less frequently interrupted by depressions, varying in depth from five to thirty feet, and in diameter from two to thirty rods. Occasionally the plain form is almost lost in the complexity and size of the depressions and enclosing ridges.

A mass of stratified drift, with kame topography, forms the divide between the swamp drained by a stream flowing into the Delaware and the swamp in which Clove brook heads. Its topographic expression is in contrast with that of the neighboring kame terrace. Huge mounds of sand and gravel rise in billowy succession thirty and forty feet above the neighboring kettles. Hardly a trace of a common level can be made out. A few of the highest of the kames have an elevation of something over 680 feet. In spite of the difference of the topography, this kame area is not to be separated, either in manner or time of origin, from the neighboring kame terrace. The great difference in topography is believed to be due solely to slightly different conditions of deposition, depending on the amount and form of the ice about which the deposits were made.

The gravel deposits above the moraine above Hainesville are separated in time from those below. This is demonstrated by their differences of elevation on opposite sides of the moraine, those above it being lower. The fact that the kame terrace above the moraine has an elevation of only 640 to 670 feet, while the moraine rises to 740 and 780 feet, shows that the former were made after the ice had withdrawn from the position of the latter.

The surface material of the stratified drift above the moraine varies greatly. In some places it is loose gravel or sand, and in others clay loam, sufficiently compact to bake in the sun. The surface material might occasionally pass for till, particularly where bowlders occur. But exposures never fail to reveal its stratification.

In the Clove Brook Valley.

Along much of its course, Clove brook flows through a wide and somewhat swampy alluvial plain, above which there are more or less discontinuous kame terraces sixty to 140 feet above the stream. They are best developed about the source of the brook, and are continuous with the kame area described above.

The forms assumed by the terraces along this brook are similar to those in the valley of the Little Flatbrook. In places, the tops of the terraces are even and unbroken, and it is only by the topography of their slopes that they can then be distinguished from normal river terraces. In other places, the planeness of their surfaces is more or less interrupted by depressions or they are replaced by a confused plexus of winding ridges, hummocks and hollows. In other places, the deposits are limited to isolated mounds or bench-like hillocks on the side of the valley. The height to which the terraces reach is not constant, though they do not depart widely from an elevation 640 feet. The departures from this level do not appear to be regular, either up or down the valley. Occasionally terraces in close proximity have very different elevations. A notable example is seen on the opposite sides of the small brook which joins Clove brook half a mile from the State line. On one side, the gravel, according to the map, reaches a height of 660 feet, while on the other it is 100 feet lower. This difference in elevation seems to indicate that the two terraces were formed independently of each other. A terrace is often present on one side of the valley and not on the other. The upper surfaces of the terraces do not form a distinct aggradation level, as was the case in the Little Flatbrook valley.

The hillocks vary greatly in the size of the material of which they are composed. Some are mainly of sand and fine gravel, and their surfaces are free from bowlders; others are apparently of coarse material and their surfaces are strewn with cobbles and small bowlders. On the surface of one knoll of fine sand, two bowlders, each four feet in diameter, were noted. At many points along the valley the sand and gravel, though present, form neither well marked kames nor kame terraces, but appear rather as a thin veneer on the hill sides.

In the Big Flatbrook Valley.

The gravel deposits along the Big Flatbrook are less extensive than those along the valley occupied by the Little Flatbrook and the Clove brook. The deposits are by no means continuous, nor, where present, are they always well developed topographically. In some localities it is impossible to classify the drift with any certainty, owing to the absence of well defined topographic forms, and the dearth of exposures.

Where the Milford-Branchville turnpike crosses the brook, half a mile north of Tuttle's Corner, there are well defined undulating terraces, rising about ten feet above the stream on both sides of the brook. The surface is thickly cobble and bowlder strewn, and in places appears till-like. About a mile above, and a little below the next bridge, the topography on the left-hand side of the stream for several hundred yards suggests stratified drift, but the surface is on the whole more till-like.

Half a mile farther up stream there are wide terraces, probably of gravel. They are very stony on the surface, and in some places clayey. Their elevation above the stream is slight. A little east of the next fork in the roads is a small but well marked gravel area. Its surface material is loose and stony. The terrace-like knolls are bordered by a small marshy depression in which an ice block probably lay when the gravel was deposited. About half a mile farther up the valley, along the left bank, is another kame terrace area, at the junction of a small tributary with the Flatbrook. Both the terrace and the kame terrace topography are represented. On the right bank for some little distance above this area, are kame-like mounds which are doubtfully gravel. The surface material is very coarse and somewhat till-like.

Isolated Areas of Stratified Drift.

Half a mile south of Montague there is a recessional moraine. For a short distance south of it, along the road leading to Hainesville, there is a flat-topped deposit of clayey gravel and sand, in the position of an overwash plain. Its extent is small. Half a mile farther south there are limited deposits of coarse gravel, whose topography is slightly kame-like.

On Kittatinny mountain.—Stratified drift deposits on Kittatinny mountain are not common. Culver's gap is occupied by a group of kames, some of which rise thirty feet above their surroundings. These kames are, perhaps, to be regarded as a part of the Balesville moraine, but no other trace of the moraine was found on the mountain. Stratified drift was also noted midway between Culver's gap and Tuttle's Corner, where there are a few small, low knolls of coarse quartzite gravel; a mile southwest of Culver's gap, near the end of the swamp; a mile and a half a little north of east of Tuttle's Corner; and also near Averytown, a mile and a quarter southeast of Hainesville. Besides several hillocks of gravel at this point, there is a narrow, sharply defined, curving ridge of like construction. At its northern end it rises from a wet meadow to a height of fifteen to eighteen feet. Its course is slightly curved, and to the south it abuts against higher land. It is sharply marked and steep-sided throughout its entire length. Its crest is narrow, but at its base it measures forty yards or less. It is twice interrupted by the valleys of brooks which cross it. Including the gaps, its length is about 500 yards. The crest of the ridge, save for the gaps, is gently undulatory. Cobbles are common both on the surface and in the gravel, but bowlders are rare. The form of this ridge is so characteristic that it deserves to be called an esker, in spite of its shortness. Two miles and a half northwest of Beemerville, on the road which crosses the mountain from that village, is a narrow terrace of gravel, facing a small swamp. Where crossed by the road, the gravel is loose and sandy. Beyond the cleared fields it is not easy to determine its limits.

THE TILL OF THE KITTATINNY VALLEY.

THE UNDERLYING FORMATIONS.

The rock formations of the Kittatinny valley are chiefly limestone and shale (or slate), arranged in parallel belts, and these belts are, in turn, roughly parallel to the trend of the valley. The larger sub-valleys are, for the most part, along the limestone belts, which have resisted erosion less well than the shale and slate. The valley therefore affords a good illustration of the dependence of topography on geology. The rock topography of the limestone belts is so different from that of the shale belts, and the difference is of such importance in the disposition of the drift, that some account must be taken of it at the outset.

Limestone underlies the sub-valley extending from Branchville southwest to Columbia, and forms a belt from two to three miles in width. This valley is drained by the Paulinskill. The same sort of rock forms a complex belt across the State, along the southeastern side of the main valley, next to the Highlands. Its maximum width is five miles, but where widest it is interrupted by long, narrow belts of shale inclosed by the limestone. At the north, the limestone of Vernon valley separates Pochunk mountain from the main mass of the Highlands, and at the south the limestone of the Pequest valley almost separates Jenny Jump mountain in the same way. Two smaller isolated areas of limestone occur in Hope and Frelinghuysen townships, Warren county. The limits of the limestone belts are shown on the geological map of the State, and on Plate VII (p. 6). The shale occupies substantially all of Kittatinny valley not occupied by the limestone.

THE LIMESTONE AREAS.

Topography.—The beds of limestone dip more or less steeply, either to the northwest or southeast. The strike corresponds to the strike of the valley, about S. 50° W. The topography of the limestone belts is exceedingly uneven. Ledges and knobs of the

Figure A. Bare limestone knoll near Springdale schoolhouse, south of Newton.

Figure B. Limestone knolls southeast of Newton.

rock often project through the till (Plate LIII), while but short distances from their bases deep wells fail to reach bed-rock, showing that the irregularity of the rock surface is much greater than that of the surface.

Since the surface of the limestone is so uneven, and since the till is in general thin and unequally distributed, the rock outcrops frequently. The outcrops are often considerable ledges or knolls, rising abruptly above the surrounding drift-covered country. They are particularly obtrusive where surrounded by stratified drift, above the level surface of which they rise like islands in a lake. The most conspicuous examples of this sort are found at the Quaker Settlement west of Allamuchy, and between Newton and Springdale. Many of these protrusions of rock are free from drift, or at most have only a few bowlders. The meagre soil between the bare knobs is often sufficient to support but scanty vegetation, and is largely the result of post-glacial weathering. In other cases, the knolls are partially covered by till, above which rock points project. Even where the rock is concealed, the character of the soil often shows that it is but little below the surface. In other regions, where there are no high ledges, the limestone shows itself in numerous small angular projections. Since the beds have a notable dip, the outcrops are usually arranged in lines along the strike of some resistant layer.

The outcrops are always rough, angular and weathered. Striæ are never found on them, and but rarely do they indicate, even by their shape, that they were ever glaciated. So far, indeed, as the shape or markings of the exposed rock surfaces are concerned, it would be impossible to affirm that the region had been glaciated. From the shape of the bosses of gneiss and schist in the Highlands, and from the smoothed and rounded shapes of limestone mounds seen in section under a considerable body of drift, we must conclude that the ice left the knolls and ledges distinctly glaciated and *roche moutonnéed.* We are therefore, forced to conclude that since the last glaciation of the region, weathering has almost completely obliterated the traces of ice work, so far as the exposed ledges of limestone are concerned. Nowhere are more impressive illustrations of post-glacial weathering to be found.

In addition to the angular, warty knolls of rock which appear so frequently, and give the limestone belts a peculiar and unusual topography, the belts are also characterized by undrained depressions, or sinks, formed by the settling of the surface as the rock beneath was dissolved by ground-water. Sinks formed in this way are not to be confused with others, very numerous in this region, formed by the irregular disposition of the drift. Limestone sinks are more or less common over all the limestone area. They vary greatly in size and shape. Some are nearly circular, with steep sides, and depths of twenty, thirty or even fifty feet, while others are shallow, saucer-like depressions, whose diameter is many times their depth. Sometimes the bottom of a sink is swampy, or may even contain a small pond. In other cases there is an opening in the bottom leading down to subterranean passages, into which small streams occasionally flow. A small sink-hole of this kind lies about half a mile north by east of Jacksonburg, Warren county. Into it flows a considerable stream, which can be plainly heard as it dashes down its subterranean course. One of the best marked bowl-shaped sinks lies about three-quarters of a mile northeast of Blairstown, where the road turns south to Paulina. The bottom of this sink, in which there is a small pond, is fully sixty feet below the highest point of its rim. Peculiar significance attaches to it, in that the bottom appears to have sunk five or six feet since the ice melted. This is indicated by an abrupt increase in the inclination of its sides, five or six feet above the bottom.

In some localities where the rock knolls are somewhat evenly till-covered, the combination of sinks and knolls gives something of a moraine topography, but the till-veneered knolls rarely have the flowing contours of moraine knolls.

The warty topography peculiar to the limestone belt is well developed in Warren county between Blairstown and Jacksonburg; north of Cedar lake; north of Paulina; between Blairstown and White pond; three-quarters of a mile north of Marksboro; northeast of White pond, extending north into Sussex county, both east and west of Stillwater; and in the vicinity of Shuster's and Catfish ponds. Good examples are also found half a mile south of Mount Hermon; half a mile south of Swayze's

Mills; three-quarters of a mile west and northwest of Shiloh; from Southtown, northeast through Johnsonburg, and in the same direction beyond Washington (Hunt's Mills) in Sussex county. There are steep ledges at Johnsonburg, and at several places to the northeast. A well at the Johnsonburg hotel within a few yards of the limestone ledge penetrates over forty feet of gravel, without reaching rock. This is an illustration of the extreme unevenness of the rock surface. Another was noted at the corners just west of White pond, where a well penetrated sixty feet of drift, while a few rods distant, at a higher elevation, the limestone outcrops.

With the few exceptions noted, the above localities are in Warren county; but the warty topography is quite as well developed in many parts of Sussex. It is well shown at many points along the road between Swartswood lake and Swartswood station, south of Myrtle Grove, west of Balesville, between Balesville and Branchville, and one to two and a half miles south of the latter place. One of the most extensive limestone ledges in Sussex county extends along the road a quarter to half a mile northeast of the cemetery between Augusta and Branchville.

The same sort of topography is more the rule than the exception along the two limestone belts (sub-valleys) on the southeastern side of the Kittatinny valley. It is conspicuous at many points south and southwest of Newton, towards Springdale and Hunt's Mills, where it is emphasized by reason of the level or gently undulating plain of gravel which buries the ledges up to the level of its surface. Particularly striking examples are found just west of the Springdale school-house; at many points in the woods west of the large swamp between Hunt's Mills and Springdale; and in the area on the west side of the Pequest, half to three-quarters of a mile northwest of Huntsville. Half a mile east of Huntsville, also, the limestone ledges and knobs are very numerous. But in all Sussex county this topography is nowhere better developed than in the area west of Hewitt's pond and Long pond, between Andover Junction, Springdale and Stickle pond, and nowhere can a better idea of it be obtained than along the road crossing this area between Springdale and Andover Junction. In places within this area there are flat and level or gently undulating tracts of sand and gravel built up against the limestone ledges to a definite and nearly constant height. Of drift above this level, there is but little. On the retreat of the ice the rock was left practically bare.

The same topography is developed at several points a mile or two north of Lafayette, and again near the northern end of the swamp which extends northeast of Lafayette. Another belt of it, with outcropping knobs and ledges of limestone every few rods, stretches northward for three miles from a point south of the Harmony Vale schoolhouse. It is well shown west of the numerous ponds lying between Andover Junction and Mulford station, and at frequent intervals for three miles north of North Church, though much of this last area is so wooded that the peculiar topography is not always well seen. A good view of it is obtained along the road from Hamburg to Beaver Run. The same topography occurs at a few other places, the knolls of limestone sometimes being completely surrounded by alluvium, as northeast from Papakating church. From the above enumeration of localities it will be seen that the warty topography is characteristic of the limestone belts as a whole.

General relations of drift to the topography in the limestone belts.—Generally speaking, the lower parts of the Kittatinny valley are covered with stratified drift, and the higher parts with unstratified. The till was doubtless more or less generally present in the sub-valleys of the great valley as the ice retreated; but as the ice melted, its waters, discharging southwestward, necessarily followed the depressions, and either washed away the till or buried it beneath deposits of stratified drift. Since the limestone belts are in general low, a considerable part of their area is covered with stratified drift, which is generally of considerable thickness. Over by far the larger part of the remainder, the till is thin or absent, and the warty topography prevails. In a few small areas the till is so thick as to conceal the rock, and give rise to smooth and undulatory slopes.

SUMMARY OF THE TILL ON THE LIMESTONE AREAS.

So far as it shows at the surface, the till on the limestone of the Kittatinny valley is confined chiefly to the higher parts of the areas underlain by this rock. Even here it is often absent, for the knolls and ridges of limestone are frequently bare. If the stratified drift be looked on as filling the lower depressions in the irregular surface of the limestone, the till is found mainly on the lower part of the remainder. It is most abundant between the knolls and ridges of rock and on their lower slopes, though it sometimes covers their crests as well.

The till varies in character, with its variation in thickness. Where thin, it often so closely resembles the residuary earths arising from the decay of the rock that it is impossible to distinguish between them except by the presence of stony material of foreign origin. Where thin, its color is commonly reddish-brown, ranging to orange and chocolate. The stony matter is largely of angular blocks of limestone, and it is often impossible to say whether they were really ice-carried, or weathered from the outcrops later. Glaciated stones are rare, and the till is not notably calcareous. Such soluble elements as it once had have been leached out. Where the till is thick, on the other hand, its color is lighter, indicating less perfect oxidation; it is calcareous at the depth of two to four feet from the surface; glaciated stones are abundant, and the proportion of stones foreign to the limestone is also greater.

The till of the limestone area is often stony, the bowlders and stones being derived from the Oneida and Medina formations of the Kittatinny range, and from the Hudson River, Trenton and Cambrian formations of the valley. In some localities gneiss bowlders also are abundant. The average of numerous estimates at different points in Warren county gives the following percentages of different sorts of bowlders, none less than one foot in diameter being included:

Oneida sandstone or conglomerate, ...	50 to 60%
Medina sandstone, ...	2 to 7%
Hudson River sandstone, ...	9 to 12%

Limestone,	8 to 20%
Cambrian quartzite,	15 to 20%
Gneiss (except locally),	few.

Similar proportions hold for Sussex county. On the whole the Oneidas are the most conspicuous of the bowlders. They are usually more or less worn, something like a third of them showing distinct evidences of glaciation, either by striæ or planation surfaces. The paucity of gneiss bowlders is readily understood from the direction of ice movement, which was not such as to bring bowlders from the Highlands into the valley. Bowlders of the Highland type are found in the lee of Pochuck mountain, where their presence was to have been anticipated. They are most abundant near the mountain.

The abundance of bowlders and other drift material from the formations of the valley was to have been expected, but the abundance of bowlders from other formations presents a less simple problem. For the quartzite bowlders which are thought to be Cambrian, there seems to no adequate source, for rock which could have yielded them has few outcrops in New Jersey, and these not extensive. For the Oneida and Medina bowlders there are adequate outcrops, though the distribution of bowlders is not always what would have been expected from the position of the outcrops and the direction of ice movement. It should be noted that the preponderance of Oneida bowlders does not mean an equal preponderance of drift material from this formation, for the rock is hard, and masses of it are capable of prolonged wear without comminution. If half the *bowlders* of the valley are from this formation it may not mean that more than five per cent. of the *drift* has the same source.

Owing to the great uneveness of the surface of the limestone, the thickness of the till varies greatly within narrow limits. The known variations are from zero to sixty feet—the latter being the thickness at the corners west of White pond, Hardwick township. Depths of twenty-five or thirty feet may occur in many places, but areas over which such thicknesses prevail are certainly small. Since it is difficult to obtain accurate data as to the maximum thickness, an estimate of the average thickness is apt to be too little, rather than too great; but such data as are at hand indicate that the average thickness of till on that part of the limestone which rises above the level of the stratified drift may be between five and ten feet, and probably nearer the former figure than the latter.

LOCAL DETAILS—TILL ON THE LIMESTONE.

Along the western limestone belt.—On the limestone knolls rising above the stratified deposits of the Paulinskill from Columbia to Blairstown, the till is generally thin and largely of local origin. On the higher limestone hills northwest of the stratified deposits, it is thicker, and foreign bowlders are more common. A huge limestone bowlder, probably glacial, lies on the 476-foot hill just north of Cedar lake.

From Blairstown northeast to Stillwater the warty topography predominates, and the till is present in patches only, though at the five corners just west of White pond a well penetrated sixty feet of drift, probably till, and again along the road a mile northeast of Marksboro, it is over fourteen feet in thickness. Much of it has a dark red or chocolate color, the color of the disintegrated limestone.

Northeast of Stillwater, and again south of Swartswood lake, there are areas in which the till attains a considerable thickness. There are occasional excavations along the railroad where it can be studied, and the roadside cuts afford shallow exposures.

For most of the area east of Swartswood lake, the warty topography (Plate LIII) prevails, and the till occurs in patches rather than as a continuous sheet. Conspicuous bowlders occur (1) near the intersection of the railroad with the first road northeast of Stillwater station, and (2) along the road one-half mile northwest of Emmons station.

Northeast of Swartswood lake as far as Balesville, the limestone belt is knobby, warty, but thinly covered with till. Foreign bowlders, particularly of Oneida and Medina sandstone, are common, and elæolite syenite bowlders from the ledge near Beemerville, are of frequent occurrence. At Balesville, where a recessional moraine three-fourths of a mile wide crosses the limestone belt, the till is thick, and the knob and kettle topography is well developed.

Between the moraine and Branchville, where the limestone belt ends, more than half of its area is covered by stratified drift. Over the remainder the till exists in patches only.

Along the eastern limestone belt.—Near the Delaware, between Belvidere and Buttzville, the eastern limestone belt is covered chiefly either by the moraine deposits, or by stratified drift; but at the limestone quarries near Sarepta a few feet of till not associated with the moraine is exposed. Southeast of Swayze's Mills there are high limestone ledges with hardly more than traces of till between them, but thence east and northeast towards Hope, the till thickens and the rock outcrops are fewer. Nowhere, however, does it conceal the rock for any considerable distance.

Over the limstone area between Hope and Mount Hermon, and thence northeast beyond Feebletown, prominences of limestone are of frequent occurrence. Over the tops of the larger hills the limestone is close to the surface, but does not outcrop in large ledges. The till is frequently of a reddish-brown color, and appears to consist of little but limestone detritus. Elsewhere it is buff colored or gray, and contains a very considerable amount of foreign matter, chiefly Hudson River shale and sandstone and Oneida sandstone.

Southwest and northeast of Shiloh, the till was deposited in considerable thickness against the base of Jenny Jump mountain, and the surface is marked by large bowlders chiefly of limestone, eight and ten feet in diameter. Northwest of Shiloh, and again from Southtown north to Johnsonburg, ledges of limestone are common, and on the whole the till is thin, although there are some areas, notably a mile northeast of Southtown, in which it attains considerable thickness. Fifty per cent. of the foreign bowlders, where present in any considerable numbers, are from the Oneida sandstone, and half as many from the Hudson River formation. There is (or was in 1895) a notable exposure at a pit near W. H. Ackerman's house, northwest of Glover's pond. The bed-rock is a calcareous shale belonging to the transition beds between the Trenton limestone and the Hudson River shale.

The whole mass of the rock has been mashed together, and more or less finely splintered. At first sight the material does not at all resemble till; but foreign stones were found in it ten feet below the surface. Bowlders of limestone and quartzite are said to be found occasionally within the mass. Apparently the ice here did little more than re-work the local material and add a few foreign bowlders. The thickness exposed was twenty-four feet.

The limestone belt east of Jenny Jump mountain is covered mainly by the humus and alluvium of the Pequest meadows, and by stratified drift. Roe and Post islands in the Pequest meadows are apparently of till, but may have rock cores. The ice which

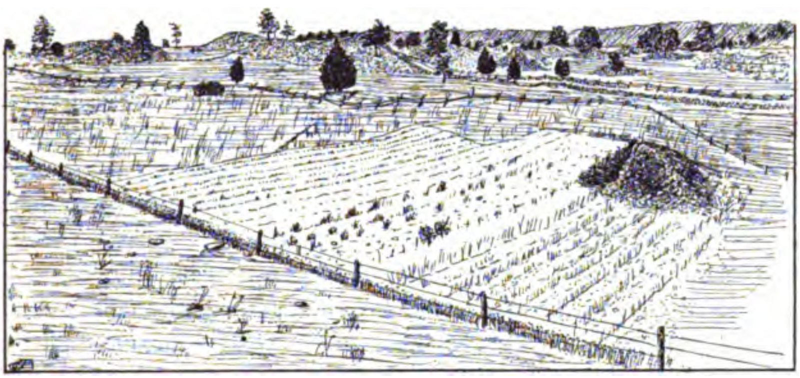


Fig. 68.

Limestone knolls between Allamuchy and Johnsonburg. Drawn from a photograph.

deposited this till had crossed the north end of Jenny Jump mountain, and bowlders of gneiss eight to ten feet in diameter are not uncommon on the surface. The thickness of the till here is in marked contrast with its slight development on the limestone knolls above the plains of sand and gravel at the Quaker Settlement, three or four miles to the northeast.

Between Allamuchy and Johnsonburg, limestone knobs abound (Fig. 68), and the covering of till above the level of the stratified drift appears to be slight, though between adjacent knolls of limestone it may be deep. From Johnsonburg northeast to Hunt's Mills (Washington) the till is thin and mainly of local origin;

but along the road three-quarters of a mile southeast of the Yellow Frame church it is thicker, a maximum depth of thirty-five feet being reported.

Northwest of the large swamp between Hunt's Mills and Springdale, the limestone knolls are practically bare. The same is true of the knolls which rise above the stratified deposits between Springdale and Newton. But on the hills south and southeast of the swamp the till is spread more evenly, and is frequently several feet thick. On the farm of John Wolf, near the south end of the swamp, are several huge bowlders. One of limestone is about 12 x 20 x 15 feet. Another of crystalline rock is 10 x 10 x 12 feet. The large bowlder of crystalline rock lies about 400 yards to the south by west of a ledge of similar rock, from which it may have been derived.

From Allamuchy northeast through Huntsville, Brighton, and Springdale, and thence northeast past Long pond, Iliff pond and Hunt's pond, near Pinkneyville, the till is present in patches only. The most marked exception is just west of Andover, where the till is so thick that the junction of limestone and gneiss cannot be made out. Along the L. & H. R. railway, north of Tranquility, till is exposed to a depth of ten feet. Elsewhere in this vicinity the cuts along this road are in stratified drift.

From Pinkneyville northeast to Lane's pond almost the entire width of the limestone belt is covered by stratified drift. At Lane's pond there is a recessional moraine, north of which the till on the limestone is thin, or wanting, to Hamburg. Apparently the only exceptions are in occasional hollows between the knolls, and on the broad, flat-topped hill a mile and a half southeast of North Church, where it attains considerable thickness. Huge bowlders of gneiss are there abundant. Ledges of gneiss occur a few rods to the north, and three miles to the northeast.

From Newton to Branchville Junction, most of the limestone belt is covered by humus deposits. Between the Junction and Lafayette, the Balesville recessional moraine is conspicuous. For several miles northeast of Lafayette the limestone belt is less rough than is its habit, and over the lower areas the till is frequently somewhat continuous. Exposures four to ten feet in depth occur sparingly along the roads. A limestone bowlder fifteen feet in diameter lies near the road two miles northeast of Lafayette. From Harmony Vale through Beaver Run, and for five or six miles farther northeast, the limestone hills are rough and warty, with here and there thin patches of till, or only a sprinkling of bowlders. Still farther northeast the limestone belt is mostly occupied by the alluvium and humus of the "drowned lands" of the Wallkill. Occasionally rocky, wooded hills rise as islands above the swamp deposits. Scattered bowlders, chiefly Oneida and Hudson River sandstone, are almost the only evidence of drift.

Striæ are rarely seen on the limestone, and never except where the rock has been recently uncovered. In Oxford township, striæ were seen on the rock at the quarries near Sarepta. Their directions[1] are S. 7° E. to S. 3° W.

In the Vernon valley.—This valley, underlain by the limestone between Pochuck mountain on the west and Hamburg and Wawayanda mountains on the east, is narrowest at McAfee, from which point it widens in both directions. A considerable part of the valley is occupied by the humus and alluvial deposits formed in the "drowned lands" of the valley bottom. Stratified drift, particularly in the vicinity of Hamburg, McAfee and Sand Hills station, is another important surface formation. Till covers a larger area than either of the other two, but it is generally thin. Its constitution is determined largely by the underlying rock, and, consequently, it is made up chiefly of limestone; but since the ice moved obliquely across Pochuck mountain into the valley there is much gneiss debris along with the limestone. Towards the northern part of the valley, material from the Hudson River formation becomes more marked. This is due to the shale and slate hills farther north in New York. Oneida and Medina cobbles and bowlders occur on the surface, but not so abundantly as to be always readily found. Such as occur must have come from these formations in New York. A single bowlder from the fossiliferous beds of Wallpack ridge, or its northern continuation, has been seen (Kümmel & Weller) in this valley.

[1]Corrected for magnetic variation.

The till is extremely thin over most of Mine hill north of Franklin Furnace, and ledges of crystalline limestone and intrusive igneous rock outcrop frequently, but northeast of Mine hill and south of Hardystonville the till is thicker. Between Franklin Furnace and Hamburg, the till is massed in a number of elliptical hills which may be drumlins (see p. 91). The number of hills which have the drumlin form is five. In the more typical cases the longer axis is about two, or two and a half times the shorter. The longer axes vary from 600 yards to three-quarters of a mile. The heights are 44, 57, 80, 100 and 128 feet. The longest drumlin—if it is a drumlin—is also the highest, but the second longest is the lowest, so there is no constant relation between length and height. Their slopes are smooth and regular, and in their outline there is nothing to indicate that the rock is near the surface. No outcrops of rock are found on any of them. Their longer axes are parallel to one another, and approximately parallel to the direction of ice movement. In all these respects they resemble drumlins; but it should be noted that the trend of their longer axes is also approximately the same as the strike of the limestone ridges, so that their position cannot be regarded as proof that they are drumlins. While they resemble drumlins, they may be hills of rock only veneered with till. If drumlins, they are the only representatives of the type in the Appalachian province of the State.

There are a number of good exposures of till in the railroad cuts between Franklin Furnace and Hardystonville. Two of the best are a quarter, and three-eighths of a mile, respectively, north of the Franklin Furnace depot. Here the till is clayey, compact, highly calcareous, and contains a large number of finely striated cobbles. Although the matrix is clayey, the till, as a whole, is stony. At the quarries at Rudeville it varies in thickness within short distances from nothing to thirty feet, its upper portion containing some gravel. Limestone bowlders (blue and white), and bowlders from the gneiss, Oneida, Hudson River and Medina formations are all found, the first two in great abundance. The till has been oxidized to a depth of two feet or so, and the layer thus affected is dark brown, the color commonly assumed by the decayed products of the crystalline limestone.

The till is relatively thick over much of the hill north by east of Rudeville, though limestone outcrops are not infrequent.

In the vicinity of McAfee the rock outcrops very frequently on the side hill, but the crest seems more thickly covered. No more than traces of drift can be found on the sharp ridge northeast of the McAfee lime-kilns.

The till attains a considerable thickness on the lower slopes of Hamburg mountain around Vernon, and it is well exposed in cuts along the road to the station. Northwest across the valley there is also a considerable area over which the till is relatively thick for this region, thicknesses of fifteen feet or so being common. Over most of the valley, however, from Vernon to the State line, there is not much drift on the limestone hills. The rock projects above it frequently, and the warty topography prevails, though not to so striking a degree as near Springdale or Harmony Vale.

That there is more till in this region than appears from an inspection of the surface is indicated by a number of exposures along the railroad between Maple Grange and De Kays. The till is exposed to depths varying from four to fifteen feet, and some of the cuts at a depth of fifteen feet do not show the maximum thickness. In these exposures, the till is stony and usually almost entirely of limestone. Much of the material, and in some instances most of it, is angular and unworn, being little more than an aggregation of pieces of limestone. But in spite of the paucity of worn material, striated and polished cobbles always occur with the angular ones, and there is always at least a small amount of ground-up rock. Most of the material is clearly of local origin, yet the presence of the striated and polished material shows that the whole mass was worked over enough to allow the incorporation of a little foreign material into the unworn, or little worn, material of local origin. Further, the angular fragments are often as fresh and firm as the rounded and worn ones. The ice did more than merely knead a few striated stones into a mass of residuary soil. These exposures indicate vigorous rending and tearing by the ice, and the prompt deposition of the material thus obtained. In some of the exposures, however, the matrix is clayey, and the stony material much better worn.

The greatest known thickness of till in this part of the valley is found about a mile west of De Kays, where a well record shows that the drift exceeds forty-five feet in thickness. Another well, a little northeast of Vernon, penetrated thirty feet of drift without reaching rock.

THE SHALE AND SLATE AREAS.

Topography.—Like the limestone, the beds of shale dip at a high angle, either to the northwest or southeast, but the topography of the shale areas is very unlike that of the limestone. This is due primarily to the different behavior of the two sorts of rock when exposed to weathering, and in a less degree to the greater amount of till which is found on many parts of the shale areas. Limestone is more resistant to mechanical agents of erosion, and shale and slate to chemical. As a result, the limestone hills of preglacial time were less effectively reduced by the ice than those of shale. Since the melting of the ice, on the other hand, solution has been much more effective on the limestone than on the shale and slate, and certain other phases of weathering have affected the two formations differently. The bare and probably smooth limestone knolls left by the ice have developed a remarkable degree of angularity of surface, since the ice disappeared, solution and disruption due to changes of temperature, having played important parts in the process. In the case of the shale, solution has been slight, but changes of temperature and other agents of weathering have been effective. The disruption of shale by weathering results in a mass of small fragments, and the topography of the hill which is weathered undergoes relatively little alteration. The disruption of limestone, on the other hand, gives rise to fewer but larger masses, with more important modifications of surface. The fine products of shale decomposition remain to a large extent where formed, and conceal the solid rock. Little fine material results from the disruption of the limestone, the surface of which remains essentially bare. The shale and slate hills, because of their inferior resistance, were more perfectly smoothed by the ice, and their outlines have been changed but little since. Smooth and flowing outlines (background of Plate IV) are therefore as characteristic of the shale hills and ridges, as jagged, angular outlines are of the limestone belts (compare Plates LIII and LIV). Where the shale is deeply covered with till, the topography has the smooth, flowing outlines common to areas where the till is thick. There are, however, several somewhat distinct phases of topography in the shale belts, some of which deserve mention.

While the general topography of the Kittatinny valley is that of a rolling plateau trenched by streams, erosion has gone farther in some regions than in others, giving rise to different topographic results. 1) In some places it has not gone far enough to destroy the old plateau, though it has always gone far enough to obscure it. The plateau character is well seen, for example, north and northeast of Jacksonburg. 2) Many of the minor streams flow for considerable distances parallel to the strike of the beds before joining the main sub-valleys. This arrangement of the streams cuts the plateau into more or less well-marked ridges parallel to one another, and to the strike of the beds; but the ridges are frequently crossed by deep, narrow cloves, through which the smaller streams make their way to the larger. The dissection of the plateau into parallel ridges is well shown east of Beemerville and Coleville, and in the narrow shale belts between the first and second, and the second and third sub-valleys southwest of Sussex (Deckertown). 3) In still other regions the plateau is so much cut up by longitudinal and transverse valleys, that it presents only the appearance of a confused assemblage of rounded hills, whose tops approach a common level. These are the larger features of the topography, and are independent of glacial action.

The details of the topography were determined largely by the ice. The shale belts are pre-eminently regions of smoothed, rounded surfaces. When the ice first withdrew, smooth knolls of polished shale and slate must have been exceedingly common. Between them, and on their lower slopes, was a little till, but their tops and upper slopes were nearly bare, though strewn with foreign bowlders. Not uncommonly these bowlder-strewn rounded knolls of shale are so numerous and so disposed as to resemble, especially at a distance, the knolls and hillocks of a strongly marked terminal moraine (Plate LV). This resemblance is increased when the till between the knolls is so disposed as to form undrained hollows. Though on the whole possessing rounded and flowing outlines, the shale knolls often show sharp projecting points of rock, or bits of angularity, which serve to differentiate them from drift hillocks. A comparison of Plates LIV and LI makes the difference clear.

In some places small shale knolls nearly circular in form, and from five to twenty or thirty feet high, abound. They often occur on the sides and tops of the larger hills, whose outlines were determined primarily by stream erosion. The outlines of the lesser knolls are believed to have been shaped largely by glacial erosion. In other regions the shale elevations are low ridges, instead of knolls. Locally they give the surface a strongly fluted appearance, which is quite unique. One of the most characteristic of such regions is a mile and a quarter southeast of Beemerville, and extends nearly two miles southwest towards Wykertown. Not uncommonly there are small swamps or meadows between the ridges.

Where the till is thick it is sometimes evenly disposed on a rolling surface of shale, and does not greatly change the topography. This type of topography prevails southwest of Newton. In still other regions the till is so thick that the rock is completely concealed, and the details of topography are entirely independent of the rock structure, or if not, the dependence is not evident.

SUMMARY OF THE TILL ON THE SHALE BELTS.

In general the till is thickest on the shale belt between Kittatinny mountain and the Paulinskill-Papakating-Wallkill subvalley. From Culver's pond southwest to Hardwick, in the area in which the plateau-like character of the shale hills is best developed, the till is thicker than in many other parts of the shale areas, and the rock surface most completely concealed. Rela-

Shale hills in the background, with a gravel terrace in the middle distance. Near Fredon, Sussex Co.

Pronounced shale knolls, nearly free of drift. West of Newton.

tively thick accumulations of till also cover that part of the shale belt near the mountain in the northern parts of Hardwick, Blairstown and Knowlton townships.

From Culver's pond southwest to the Water gap, the till is rather thick on the shale at the foot of the Kittatinny mountain escarpment; but from the north corner of Frankford township to the State line, the shale hills immediately at the foot of the mountain are nearly bare, while thicker accumulations of till lie on the hills between Coleville and Clove river. This inequality of distribution of the till at the east base of the mountains is probably connected with the direction of ice movement. To the south, where the till is thicker, it is somewhat in the lee of the mountain as the ice was moving. To the north, where it is thin, this was not the case.

Where the shale belts are comparatively narrow and form sharply marked ridges between the limestone areas, they are, as a rule, but thinly covered with till, and the knoll or ridge topography prevails. Even in these belts, however, as near the Yellow Frame church, where the townships of Green, Stillwater and Frelinghuysen meet, the till locally attains considerable thickness, and expresses itself in the topography by undulations gentler than those produced by the bedded rock.

The average thickness of the till in the shale areas of the Kittatinny valley is probably between eight and twelve feet.

Where present in any considerable thickness, the till on the shale usually has a compact, clayey matrix, containing many stones of all sizes. Sometimes, though not commonly, it is distinctly foliated. Near the mountain, its surface is thickly strewn with bowlders, chiefly from the Oneida and Medina ledges. In other parts of the valley these bowlders, although widely distributed, do not commonly constitute more than one-fourth to one-half of those on the surface, and the proportion is often less. At several places within a mile and a half of the mountain, estimates were made of the cubic contents of the Oneida bowlders lying on the surface or but partially imbedded. These results vary greatly. Stated in cubic feet per 100 square feet of surface, the estimates are as follows: (1) Twenty-seven cubic feet. (2) Eight cubic feet. (3) Sixteen cubic feet. (4) Forty-two cubic feet. (5) Ten cubic feet. These give an average of twenty cubic feet per 100 square feet of surface. There is a belt along the foot of the escarpment between the Water gap and Culver's pond, averaging about two miles in width, over which the Oneida bowlders are essentially as abundant as at the localities where the above estimates are made. At the same ratio, there are within this belt, in round numbers, 278,750,000 cubic feet of Oneida bowlders on the surface or but partially buried. On the assumption that the bowlders are equally numerous at all depths in the till, and that the till in this belt averages fifteen feet (certainly not too great) in thickness, the Oneida content would be 2,090,880,000 cubic feet. This is equivalent to a layer three and eight-tenths feet thick over the entire width of the adjoining Oneida outcrop. It is not meant to imply that these bowlders all came from the New Jersey part of the mountain, for the striæ indicated that the ice movement was so nearly parallel to the escarpment, that most of the bowlders probably came from that part of the mountain somewhat to the northeast of their present location.

The erosion of the Oneida beds was probably much more than that suggested by the above figure, since the bowlders are found, and generally in large numbers, far east of the belt brought into the estimate. To include all the Oneida bowlders of the drift within the State, the above figure (three and eight-tenths feet) should be multiplied by some factor, probably not less than three, and perhaps not less than five. Furthermore, some of the material derived from the mountain, though probably not a very large proportion of it, was reduced to fineness by the glacial grinding, and would not come into the above calculation. Taking all these factors into account, it may well be that the crest of the mountain was lowered on the average as much as twenty or twenty-five feet by the ice. Such calculation has little value save in giving some slight idea of the effectiveness of glacial erosion on such ledges as those of the Kittatinny mountain.

Except near the borders of the limestone belts, the till on the shale is not notably calcareous. Where calcareous matter is present in the till, leaching has generally removed it to a depth of from three to five feet.

Where the rock is near the surface, and outcrops common, the unconsolidated material at the surface is generally composed chiefly of small, angular, unworn shale fragments. It is shown to be drift only by the presence of foreign pebbles or stones imbedded in it, in positions where they cannot be supposed to have been introduced in any way except by the ice. In these cases it seems necessary to suppose that the ice reworked the preglacial residuary soil, added a little, and often very little, foreign material, and then left the product not far from its original position. In other places, the surface layer of broken shale fragments is probably the result of the post-glacial disintegration of the easily disrupted shale, and is therefore not drift, in the proper sense of the term.

LOCAL DETAILS—TILL ON THE SHALE AND SLATE.

The Western Shale Belt.

Knowlton township.[1]—In the northern part of Knowlton township, towards the foot of the Kittatinny escarpment, the till attains great thickness (for this region) and completely conceals the slate save at a few localities. It is here much more bowldery than farther south, owing to the nearness of the Oneida ledges, the greatest source of bowlders for all this part of the State. So numerous are large bowlders towards the foot of the mountain that the land in many places has not been cleared. Near the northern corner of the township a well is reported to have penetrated the till to a depth of sixty feet without reaching rock. This is the greatest depth of till known on the shale.

At the slate quarries[2] at Browning, the till varies in thickness from four to thirty-five feet. The matrix is tough, compact and clayey, but full of stones of all sizes, Oneidas predominating. No limestone was found in it, nor is calcareous matter present in

[1] See also p. 337.

[2] The exposures mentioned here are those which were well seen when the work in this region was done, some years since. Some of them may be concealed at the present time, or so covered with talus as not to reveal their distinctive characteristics.

such quantity as to show itself by the common acid test. The till is gray or buff in color, and the less resistant stones are abundantly striated.

There are deep (fifty to forty feet) cuts in the till along the railroad half a mile below Browning. Here beds of gravel are interbedded with the till. In constitution it is much the same as that at the slate quarries.

At a small slate quarry near the road corners a mile and a half east of Browning, is a small but good exposure. There is another good exposure on the road about a mile northwest of Hainesburg.

Striæ[1] have been recorded in this township as follows: 1) Top of hill northeast of Delaware, S. 27° W.; rock, sandstone. 2) Two and a half miles north of Delaware, on the road, two sets; the main set, S. 33° W.; the secondary set, fewer and less distinct, S. 20° W.; rock, slate and shale. 3) Three-fourths of a mile south of Polkville, S. 28° W.; rock, slate; *roche moutonnée.*

Blairstown township.[2]—Thick deposits of till cover nearly all that part of Blairstown township within this belt. Northwest of Jacksonburg there are a number of rounded shale domes, nearly free of drift, and the shale outcrops frequently along the steep slope above the limestone belt, but the northern part of the township, up to the Kittatinny escarpment, is, for the most part, thickly till covered, the only exception being in the extreme northeastern corner of the township, immediately at the foot of the talus slope. At two slate quarries in the northwestern part of the township, the till is twelve feet and fifteen feet thick respectively. Several wells in the vicinity, sixteen to eighteen feet deep, do not reach the rock. Exposures of six or eight feet along the roads often show no sign of approach to the slate below. The average thickness of till in this part of the township is probably not less than fifteen feet.

Bowlders are abundant over all this area, by far the larger

[1] Corrected for magnetic variation. All the striæ of the township are here brought together, without reference to their position on the particular shale belt under consideration.

[2] See also p. 339.

number being of Oneida sandstone or quartzite. Many of them are five or six feet in diameter. Limestone and gneiss bowlders are essentially wanting, but cobbles of elæolite syenite occur. These came from the ledge northwest of Beemerville. Since the outcrop of this rock is limited in extent, the distribution of fragments from it is significant of the direction of ice movement (p. 105). The till, where exposed, is stony but compact, and not calcareous. Its color is somewhat light and yellowish, rather than brown.

Striæ[1] have been observed in this township as follows: 1) A mile northwest of Mount Hermon, near the road, S. 27° W.; rock, slate. 2) Three-fourths of a mile south of Kalarama, S. 40° W.; rock, slate; striæ indistinct. 3) Three-fourths of a mile southwest of the last, S. 40° W., and S. 34° W.; rock, slate. 4) South of the four corners, about two miles southwest of Kalarama, S. 35° W.; rock, slate. 5) One and one-fourth miles south of Blairstown on the road, S. 38° W.; rock, slate; striæ obscure. 6) One and one-fourth miles northwest of Jacksonburg on road, S. 29° W.; rock, slate. 7) One-fourth of a mile southwest of 6) on road, S. 27° W.; rock, slate. 8) A mile northwest of Walnut Valley, near Yard's creek on road, S. 43° W.; rock, slate.

Hardwick township.—The relatively thick till of the last township is continued into this, and generally conceals the underlying rock. In the northwestern half of the township towards the mountain the till is thin 1) on the steep slopes of some of the deeper ravines; 2) on the hills southeast of Newbaker's Corner, and 3) on the hills south-southwest of Hardwick. In the second locality, rounded hummocks and hillocks of shale, twenty to forty feet in height, are closely associated, with little drift save in the hollows between them. This topography continues for several miles northeast into Stillwater township. Elsewhere on the shale belt the till is thick enough to conceal the rock. In general it has a clayey matrix, and contains many bowlders, a considerable proportion of which are striated. The bowlders increase in size and

[1]Corrected for magnetic variation. All the striæ of the township recorded are here brought together, without reference to their position on the shale belt now under consideration.

number towards the mountain. The till is frequently exposed to a depth of ten feet along the roads.

The following striæ in this township have been recorded: 1) Half a mile southwest of Marksboro, just above the river gorge, on the road, S. 45° W.; striæ very distinct. The greater westing compared with that of the striæ on the other side of the Paulinskill is probably due to the local deflection occasioned by the river valley. 2)* Half a mile northeast of Marksboro, on the railroad, S. 30° W.; rock slate. 3) At the corner south of Shuster's pond, S. 37° W.; rock, limestone. 4) Along the road half a mile southeast of Newbaker's Corners, three sets, S. 4° W., S. 29° W., and S. 39° W. 5)* Along the road a mile northeast of Hardwick Center, S. 53° W.; rock, slate.

In Stillwater township.[1]—The till is relatively thick on the shale hills in the northwestern half of the township, the most important exception being the belt of shale knolls and hills which extends southwest of the lower end of Swartswood lake, towards Newbaker's Corners. Their crests and steeper slopes are practically bare, but there is some till in the depressions between them. Another ridge of nearly bare shale extends for a mile northeast of Hardwick, and there are a number of parallel ridges with very little drift on them a mile or more southeast of Sucker pond. With these and one or two other trifling exceptions the northwestern half of the township is thickly covered with compact clayey, bowldery till. The whole region is very monotonous; a large part of it is wooded; the surface is thickly strewn with bowlders ranging up to six or seven feet in diameter, seventy-five per cent. of them being Oneidas, and exposures are few and never deep. There are no means of determining the maximum thickness of the till. Locally, it is known to exceed thirty feet, and the average probably exceeds fifteen feet.

The following striæ[2] have been recorded in this township: 1)* Fine glacial grooves on the Oneida formation were noted along

*Striæ marked * are exceptionally well shown.

[1] See also p. 341.

[2] Corrected for magnetic variation. All the striæ of the township are here brought together, without reference to their positions on the shale belt here under consideration.

the road ascending the Kittatinny escarpment north of Sucker pond. They are about 140 feet below the crest, and bear S. 49° W. The grooves are from one to two inches wide, half an inch deep, and are nearly parallel to the trend of the escarpment. 2) Near the bend of the road, a mile and a quarter south of Sucker pond, S. 47° W.; rock, slate. 3) Along the road, three-fourths of a mile east by south of 2), S. 53° W.; rock, slate. 4) At the road corners a mile south of the above, and a mile east of Newbaker's Corners, S. 41° W. 5) Along the road a mile south of Emmons station, S. 32° W., and S. 33° W. 6) Along the road one and a half miles southwest of 5), S. 16° W.; rock, shale.

Hampton township.[1]—The same conditions prevail over the higher, broad-topped shale hills of that part of Hampton township lying west of Myrtle Grove. The till is thick, and conceals the rock over wide areas. It is stony, but compact by reason of the clayey matrix. The surface is rich in bowlders, most of which are Oneidas. Among the smaller stones there is a much larger percentage of Hudson River slate and shale. Most of the slate pieces are striated, and a considerable proportion of the harder quartzites are distinctly glaciated. Wells twenty to thirty feet deep do not commonly reach the underlying rock.

The steep slopes of the hill north of Myrtle Grove are till-mantled, but the top is almost bare, the shale outcropping frequently in low knolls or ridges.

Striæ[2] have been recorded from but two localities in this township: 1) Along the road half a mile southeast of Swartswood station, where their direction is S. 40° W.; rock, shale; and the other 2) a mile northwest of Myrtle Grove, on the road, where the direction is S. 30° W.

The Second Shale Belt (From the Delaware to Papakating).

Knowlton township.[3]—Near the Delaware, the area is marked by narrow, steep-sided ravines, not infrequently 200 to 300 feet deep. Till is usually found along their bottoms, but not com-

[1] See also p. 342.
[2] Corrected for magnetic variation.
[3] See also p. 333.

monly on their steep slopes, which are strewn with talus of unworn shale bits. On the flat-topped inter-stream surfaces, the till is fairly well developed, except just northeast and north of Delaware village.

Where present in any thickness, the till is clayey, with stones of all sizes, chiefly from the Oneida and Medina formations. Gneiss debris is nearly or quite absent, as would be expected from the direction of ice movement, S. 27-35° W. In color, the till is grey or buff colored below, but yellowish-brown on the surface, and, except near limestone, is not calcareous.[1]

Although in general the till is bowldery, and has a decidedly clayey matrix, this is not always the case. The most marked exception is along the slope to the Paulinskill, in the vicinity of Warrington, where the matrix is sand. The best exposures are found in a gully a little southwest of Warrington. A similar phase of sandy till is quite commonly found on the steep slopes along the larger drainage lines, above the well-marked deposits of stratified drift.

The average thickness of the till on this shale belt in Knowlton township is probably something more than fifteen feet, although there are but few accurate measurements on which to base an estimate.

Hope township.—Shale occurs in this township mainly in the western part, west of Swayze's Mills and Muddy brook, and again in the northeastern part. Over most of this area the till is very thin, or altogether absent, the only traces of drift on the knolls often being scattered bowlders. The topography is markedly undulatory, the shale knolls being ten to twenty feet high. This type of topography is well shown west of the road leading south from Mount Hermon, and from half a mile to a mile and a half southwest of Swayze's Mills. Where present in any considerable thickness, the till is similar to that of Knowlton township. Its average thickness is probably less than five feet.

Striæ,[2] a mile northeast of Mount Hermon, have a direction S. 28° W. Others on gneiss, on the west slope of Jenny Jump mountain point S. 5° W.

---

[1] For striæ of this township see p. 334.

[2] Corrected for magnetic variation.

Blairstown township.[1]—Over the southern part of this township the till is in general very thin, and rock outcrops, or knolls of rock covered with broken shale fragments, are common. The hummocky shale knoll topography is well developed (1) in the southeastern corner of the township, (2) southwest of Paulina, (3) south of Kalarama and (4) northwest of Mount Hermon. A belt three-quarters of a mile wide, in which the till is relatively thick, extends from a point a mile and a half northwest of Mount Hermon, eastward and northeastward to a point about a mile and a half south of Paulina. Over this area the till is generally clayey and compact, though sometimes gravelly at the surface.

Worn, and more or less distinctly glaciated bowlders up to three feet in diameter, are common on the surface. Of these, Oneidas frequently constitute more than fifty per cent., Medinas about ten per cent., bowlders from the Hudson River formation from ten to thirty-three per cent., while limestones range from two per cent. at some distance from the border of the limestone belt, to twenty per cent. or more, near it. Occasional pieces of black flint and quartz, and bowlders of Cambrian sandstone occur.

A very conspicuous limestone bowlder, 27 x 18 x 10 feet, or the remains of it, is perched on a hill-side on the Cook farm, a mile and a quarter due south of Paulina, near the township line. It is split into several pieces, which still retain their original position relative to one another. Another large limestone bowlder, eighteen feet high, lies on the top of the hill just north of Cedar lake. It is probably a glacial bowlder, but since the underlying rock is limestone, it may not have been carried far.

In a few places the till is slightly calcareous, but in general no reaction could be obtained when tested with acid, even below the zone of oxidation. Within the belt above outlined, exposures six to eight feet in depth are not uncommon, but the maximum thickness is unknown.[2]

Frelinghuysen township.—The northwestern part of this township is included in this shale belt. The till is relatively thick in

[1] See also p. 334.

[2] The striæ of this township are given on p. 335.

the vicinity of the Yellow Frame church (Hardwick church), on both sides of the road leading south and west towards Marksboro, and in a few other small areas. At the church it is more than sixty feet deep. This is probably about its maximum. Over the top and upper slopes of the hill a mile northeast of Kerr's Corners, and on the broad, flat-topped hill a mile northeast of Silver lake, it is deep enough to conceal the rock but probably little more. Its average thickness for the township is probably two to ten feet, but over most of the township the shale outcrops are of frequent occurrence. The undulatory shale knoll topography (Plate LIV), sometimes simulating a terminal moraine in its knobbiness, is well developed (1) near Kerr's Corners; (2) two miles east of the same place; (3) one to two miles northeast of Marksboro; and (4) a half a mile west of the Yellow Frame church.

Bowlders from the Oneida, Hudson River, and Medina formations are common, in the order mentioned, and there are occasional bowlders of Cambrian sandstone and limestone. In general the till is but slightly calcareous. Where thick it is tough, clayey, and contains an abundance of well-worn stones, especially from the Hudson River slate and shale. Where thin, the percentage of unworn shale fragments increases.

The best exposures are found along the roads, (1) a few rods northwest of the Yellow Frame church (ten feet+); (2) half a mile east of Marksboro (twelve feet+); (3) a quarter of a mile south of the same place (four feet); (4) at Kerr's Corners (eight feet+); (5) several exposures near Paulina (six to eight feet); (6) Swayze's hematite mine northeast of Silver lake (twelve+).

Striæ[1] are of rather frequent occurrence in Frelinghuysen township. The following have been recorded:

1) Just west of Kerr's Corners, on road, S. 22° W.; rock, slate. 2)* Three-fourths of a mile east of Kerr's Corners, S. 23° W.; distinct, but not deep. 3)* Three-fourths of a mile north of Kerr's Corners, two sets, S. 10° W., and S. 17° W.; rock, slate. 4) At road corners, one and five-eighths miles southeast of Paulina, S. 19° W. 5) Along the road one-fourth of a

[1]Corrected for magnetic variation.

*Those marked * are exceptionally good illustrations ofstriæ.

mile southwest of Shuster mine, and north of the Swayze mine, S. 19° W.; rock, slate. 6) At the foot of a steep eastern slope, one and a half miles south by east of Johnsonburg, on road, S. 15° E.; rock, limestone. The local deflection from the normal direction is due to topography. 7) Three-eighths of a mile south of the Yellow Frame church, on road, S. 26° W.; rock, slate. 8)* At the road corners one and one-eighth miles southeast of Marksboro, two sets. One set is deep, with grooves, direction S. 23° W.; the other fainter, but seen in the bottom of the grooves of the first set; direction S. 1° E. The second set is younger than the first. 9) By the roadside, a little east of the Marksboro hotel, S. 39° W.; rock, slate. 10)* On the westward slope, a mile northeast of Marksboro, two sets; directions S. 20° W., and S. 33° W. The latter are the better marked, but their relative ages were not determined.

Stillwater[1] *and Green townships.*—The middle shale belt passes through the southeastern part of Stillwater and the northwestern part of Green townships.

West of a north and south line through Hunt's pond the till is thick enough to cover the rock so generally that there are few outcrops. East of this line the till is thin, and in places is represented only by scattered bowlders. The shale knolls, together with the small swamps frequently lying between them, locally give the topography a morainic effect. In the area lying directly north of Hunt's pond, this type of topography is well developed. The knob and hollow type of topography often grades into the fluted type, which is well developed half to three-quarters of a mile west and southwest of Fredon school-house. Over this area the till is probably not more than two feet thick, on the average.

A large limestone erratic, the exposed part of which is 21 x 9 x 6 feet, lies partly buried on the hillside, three-fourths of a mile north of the Fountain house, at Fredon, and the same distance east of Emmons station. It was carried at least two miles, over hills 100 to 150 feet above its present elevation. Just across the line in Hampton township, half a mile south by east

---

*Those marked * are exceptionally good illustrations of striæ.

[1] See also p. 336.

of this bowlder, is one of Oneida conglomerate, measuring 6 x 6 x 10 feet, an unusual size for a bowlder of this rock so far from its parent ledge. From the direction of the striæ, it was transported at least fifteen miles. Several other large bowlders occur in the same vicinity.

East of the north and south line mentioned in the preceding paragraph, the slopes are gentle, and the contours flowing. The topography is in marked contrast with that farther west. Here the till is clayey, compact, and contains a large percentage of foreign material. Striated pebbles, chiefly shale, are abundant. Estimates of bowlders in the fence piles show that the Hudson River sandstone furnished about half of them, the Oneida sandstone rather less, and the Medina sandstone and limestone the small remainder. There is an occasional cobble of elæolite syenite. The till is rarely calcareous to any appreciable degree. There are but few exposures, and eight feet was the maximum thickness observed.

The striæ of Stillwater township are given on page 337. In Green township, striæ a mile and a quarter northeast of Hunt's pond, near the township line, point S. 16° W.

Hampton township.[1]—In Hampton township a belt of shale a mile wide, almost free from till, extends northeast from Fredon to Washingtonville. Bare shale knolls, hills and ridges follow each other in rapid succession. Both the pseudo-morainic and the fluted topography are strongly developed.

East of this belt of bare shale hills and knolls, the rock surface is less uneven, and the till, although not very thick, covers the rock somewhat evenly, and the outlines of the hills are more subdued. This topography is shown southwest of Newton, and on Smith's hill between Newton and Washingtonville. A well in the western part of Newton was reported to have gone down twenty-eight feet without reaching rock. In addition to the Oneida, Medina and Hudson River bowlders, so common to all the drift of the valley, occasional gneiss bowlders occur southwest of Newton.[2]

[1] See also p. 337.

[2] For striæ of this township see p. 337.

The Northern Shale Belt.

Frankford township.—Northeast of Branchville the two shale belts described above unite by the termination of the limestone belt between them. Northwest of Papakating creek—nearly the whole of Frankford township—the till is generally thick enough to conceal the rock. The well defined areas in which the reverse is the case are as follows:

(1) The area enclosed on the west by a line drawn due north from Branchville to the foot of the mountain, and on the east by a line drawn south from a point a mile west of Beemerville and a mile west of Wykertown, to Papakating creek, and then west to Branchville. In the northern half of this area the drift covering is thin and the shale knolls pronounced; (2) the slopes of the hill just south of Branchville and Mt. Pisgah; (3) a belt a mile wide northeast of Wykertown stretching into Wantage township to Woodbourne and Plumbsock.

Over most of the remainder of the township the till is relatively thick. It is best developed east of Long pond, and northeast and east of Culver's pond. Here it is very bowldery and in all respects similar to that found in the western parts of Hampton and Stillwater townships. Large Oneida bowlders are abundant on the surface, and there are a few gneiss bowlders scattered somewhat evenly over the township. Farther south the till increases in thickness toward the foot of the Kittatinny escarpment, but in this township and farther north this condition no longer obtains. West of the south end of Long pond, the shale knolls are nearly free from till, and farther north in Wantage township bare shale knolls next the mountain escarpment are the rule, while the thicker till lies a mile or two to the east.

The greatest known thickness of till for this part of the township was reported from a well at the four corners a mile and a half due west of Branchville. Here it is over forty-four feet thick. Depths of twenty to thirty feet are not uncommon. The best exposure of till is along the road to Culver's gap, where there is a cut twenty feet deep. The till is compact, clayey and yet very stony. Many of the bowlders are distinctly striated, or otherwise glacially marked. The stream here has eroded its channel to a depth of forty-five or fifty feet, and the till probably exceeds that depth.

At a number of points beds of stratified gravel and sand were either seen or reported beneath a layer of till, ten to fifteen feet in thickness.

Over a belt between Beemerville and Wykertown the till is thick and very similar to that already described. Bowlders are, however, less numerous on the surface. It is not calcareous, even far below the zone of oxidation, which is never more than six feet, and generally less.

Striæ[1] from four localities in this township are recorded. They are as follows: 1) Along the road at the foot of the Kittatinny escarpment, west of Long pond, well-marked striæ bear S. 60° W. Less distinctly marked grooves, probably glacial, near by, S. 88° W., and S. 108° W. The latter markings are pointing obliquely towards the steep escarpment. Striæ two miles to the west on the top of the mountain bear S. 38° W., and S. 52°-55° W. 2) Along the road three-eighths of a mile south of Branchville, on the northern slope of the hill, S. 33° W., and S. 40° W., at localities near each other. 3) On the same slope of the hill on the road next west, S. 38° W. 4) Along the road one and three-fourths miles southwest of Beemerville, S. 51° W., and S. 60° W.

Wantage and Lafayette townships.—Wantage township includes the northern end of this shale belt in the State. The following are the areas where the till is thin or wanting altogether: 1) The belt of hills southwest of Woodbourne and northeast of Wykertown. This belt is from one and a half to two miles wide, and is a prolongation of the belt in Frankford township[2]. At Woodbourne, it turns to the east, and passes north of Sussex and extends northeast along the Wallkill to the State line. For part of the distance along the Wallkill it is separated from the alluvial plain of the kill by a well-marked kame belt, whose knolls at first sight somewhat resemble the shale

[1] Corrected for magnetic variation.

[2] See p. 343.

hillocks. Towards the State line, the individual bare shale knolls are surrounded by the alluvial deposits of the Wallkill, above which they rise like islands above a lake.

2) Southeast of Papakating creek a series of high shale ridges extends through the northwestern part of Lafayette and the southeastern part of Wantage townships, as far as Sussex (Deckertown). Over most of this area the till is present in patches only, but that it may be thick in these patches, particularly between the shale knolls, is shown by occasional wells, one of which penetrated forty feet of drift before reaching rock. At the slate quarries north of Lafayette, the till is three to ten feet thick.

3) A belt of nearly bare shale hills and ridges extends from a point a mile and a half north of Beemerville to the State line. It lies immediately at the foot of the Kittatinny escarpment, which, in Wantage township, does not form so marked a ledge as farther south. The shale and slate here extend much higher up the side of the mountain than farther south. The upper limit of the shale is indicated by the upper limit of the cleared land. This belt of nearly bare shale hills is generally a little less than a mile in width, but just south of Coleville it sends out a branch to the eastward, which increases its width at this point to more than two miles. This belt lies just west of a line drawn due north from Coleville.

4) The till is very thin over the region south of Rockport and Mount Salem. In general the rock is covered with a layer of broken, angular and unworn shale, which sometimes contains few foreign pebbles and cobbles. How much of this is till, and how much residuary soil, it is difficult to say. This belt of thinly covered shale extends for several miles towards Sussex on the east side of Clove river.

The best marked area in which the till is thick enough to completely conceal the minor inequalities in the rock surface is a belt two miles or so wide between Coleville and Clove brook, and extending north to the State line. Over this area the till has a very compact, clayey matrix, thickly set with stones and bowlders. It contains only a small percentage of unworn shale fragments. Bowlders up to several feet in diameter are common on the surface. The majority of them are from the Hudson River formation, but about twenty per cent. are from the Oneida and Medina formations. Owing to the large percentage of slate bowlders, striated stones are common, both on the surface and beneath it. Wells ten, fourteen and twenty feet deep rarely reach the underlying rock. The till does not appear to be calcareous, but in the absence of deep exposures conclusive tests were not made.

A mile south of Coleville is a moraine area, a little over a square mile in extent. Here the drift is thick. Another area where there is much drift extends north and northeast of Plumbsock, as far as the Libertyville-Sussex (Deckertown) road. Bowlders of Hudson River sandstone, Oneida and Medina are generally abundant, the former particularly so, and bowlders of gneiss are of occasional occurrence.

The only other area of any size in which the till attains considerable thickness, lies west and northwest of Van Syckles station, and even here the lower slate and shale hills west of the Wallkill, between Van Syckles and Unionville, are but thinly covered with drift. The till here, as elsewhere throughout the shale belt where it has any considerable thickness, is compact. The maximum known thickness is thirty feet. In many places within the area it is much less, and in others it may be much greater.

The cuts exposing the till are mainly along the roads, and are generally shallow and old. One of the best is seven-eighths of a mile west of Quarryville, and another along the railroad about half a mile south of that place. The best exposures in the township are in the vicinity of Sussex. There is a good, though old, cut on Newton avenue, half a mile west of the center of the town, where the till is exposed to a depth of six feet. Some beds of it are slightly gravelly. On Main street, near Munson street, a twenty-foot cut of typical clayey, bowldery till was seen, which is so compact and clayey as to resist successfully the disintegrating action of the frost and rains. It is composed almost entirely of material derived from the Hudson River formation, and there are few of the unworn, angular shale bits so common where the till is thin. Ninety per cent. of the stones are slate or sandstone, some of which are three feet in diameter. Almost the only foreign bowlders are Oneida quartzites. No Medinas, gneisses nor limestones were found. Some of the stones are beautifully striated. The till is of light grey color, except near the surface, where weathering has darkened it.

Striæ[1] have been noted at a few points in Lafayette township and at many in Wantage. In the former, their directions have been recorded as follows: 1) On an outcrop of shale along the road a mile and a half south of Lafayette, S. 35° W.; indistinct. 2) At the road corners a mile south by east of Papakating, S. 18° W. 3) Along the road a mile north of the above, S. 35° W., and nearly parallel to the steep slope of the hills bounding the Papakating valley.

For Wantage township the list is as follows: 1) Along the road in the bottom of the narrow valley a mile and a half northwest of Beaver Run, on the stoss side, S. 21° W. The direction of ice movement does not seem to have been materially affected by the valley. 2) On a low boss of shale near the Papakating creek half a mile northwest of 1), S. 43° W. 3) Along the road half a mile northeast of the above, S. 31° W. 4) At two localities, one and three-fourths miles southeast of Beemerville, half a mile apart, S. 35° W., and S. 45° W.; rock, slate. 5)* Along the road half a mile southeast of Sussex depot, near Mr. Humphrey Marten's house, there is a large, nearly horizontal surface of shale, finely striated and grooved. Directions S. 18° to 26° W. 6) In the field a little south of 5), S. 5° W. 7) About three-fourths of a mile northeast of 5) on the road, S. 21° W. 8) One and one-fourth miles farther north, on the west face of a small shale knob, S. 58° W. This greater westing is probably a local variation due to topography. 9) On the turnpike to Libertyville one and a half miles from Sussex, two localities a quarter of a mile apart, S. 31° W., and S. 35° W. 10) A mile northeast of 9) on the road, S. 44° W.; rock, slate. 11) Along the road between Coleville and Quarryville, one

[1]Corrected for magnetic variation.
*Striæ marked thus * are exceptionally well shown.

and three-eighths miles west of the latter, S. 28° to 33° W. 12) A little more than a mile north of the last, S. 38° W. 13) Half a mile southeast of Libertyville, along the road, S. 34° W.; rock, shale. 14) A mile southwest of Coleville, near the top of a rather steep slope which faces southeast, S. 37° W.; rock, slate. 15) Three-fourths of a mile southwest of the last, close to the foot of the Kittatinny escarpment, S. 36° W. Striæ on the crest above are nearly due west. 16) One and one-half miles north by west of Coleville, at the foot of the Oneida escarpment, S. 48° W., trending obliquely toward the steep slopes; rock, slate. 17) A mile northwest of 16) on the Port Jervis turnpike, and about 100 feet below the summit of the pass across the mountain, S. 42° W. 18) One and five-eighths miles northeast of Coleville, two readings, a quarter of a mile apart, S. 49° W., and S. 28° W. The former is on the top of a shale plateau; the latter, part way down the slope to Clove river. Its more southerly direction is due to the diverting effect of the deep Clove valley. 19) Near Mt. Salem, S. 43° W., and S. 33° W., the latter being a slight local deflection to the south, due to topography; rock, shale. 20) Three-fourths of a mile southwest of the last, S. 36° W.; rock, shale. 21)* Many striæ are found along and near the Mt. Salem-Unionville road near Rockport, S. 38° W., S. 34° W., S. 26° W., S. 28° W., and S. 20° W. were recorded. There is a finely marked *roche moutonnée* just across the State line. 22) Striæ at intervals of three-eighths of a mile, along the road south of Rockport, all point S. 33° W. 23) Half a mile northwest of Van Syckles, S. 25° W.; rock, slate.

The Eastern Belt.

The eastern shale belt extends northeast from near Johnsonburg, in Frelinghuysen township, to a point in the southern part of Wantage township. It is much narrower than the other shale belts, having a maximum width of a little over a mile. Between Johnsonburg and Springdale it is somewhat discontinuous. The till on the shale south of Springdale is generally thin. Where not leached by weathering, it is calcareous, and limestone bowlders derived from the adjacent rock predominate. The

Oneida and Medina bowlders form no more than five or six per cent. of those seen on the surface.

From Davis pond, near Springdale, the shale belt is continuous northeast to its termination, and forms the ridge which separates the sub-valley in which lie Long pond and Germany Flats, from the sub-valley just east of Newton. It includes parts of Lafayette, Sparta and Hardystonville townships. For two miles northeast of Davis pond the hills are almost free from till, and the shale knoll topography is finely developed. It is well seen from the railroad, between Drake's pond and Davis pond. It is also well developed just east of Drake's pond, where the knolls of shale rise ten to fifteen feet above the depressions between them, and often simulate the outlines of the kames around the pond.

To the northeast the till is somewhat thicker, and conceals the rock over the tops of several large hills. One of the best exposures of till (six feet) near Newton, is along the road which crosses the hill half a mile east of Drake's pond. The till is clayey, compact, and contains a large number of striated bowlderets and pebbles. It is less stony than that nearer Kittatinny mountain, Probably sixty per cent. of the stones in the cut are distinctly striated. Most of them are of Hudson River shale.

Along this ridge in Lafayette and Sparta townships the till attains considerable development in places, although shale outcrops nowhere cease to be frequent. On the hill just south of Branchville Junction the till is from five to six feet in thickness, and is clayey and compact. It conceals the rock also on the west side and crest of the ridge crossed by the road from Lafayette to Woodruff's gap, and along the crest of the ridge southwest of Monroe Corner; but just west of that village, the ridge is practically free from drift, and at the northern end of the large swampy meadow west of the ridge, the bare shale knolls are conspicuous. Striated material is common where the till is present in any quantity. A few gneiss bowlders occur at the surface, in addition to those most common to the region, namely, Hudson River, Oneida, Medina, and limestone. The Oneidas are far from being so abundant as farther northwest. The till is generally not calcareous to the depths exposed by the roadside cuts.

LOCAL DETAILS—RECESSIONAL MORAINES.

The Ogdensburg-Culver's Gap Moraine.

Recessional moraines, or moraine-like accumulations of till, have been observed at a number of localities in Sussex county. The most important belt of this sort, extending from Ogdensburg to Culver's gap, has been mentioned (p. 270). Between the points indicated the moraine is, with slight interruptions, well defined. It cannot be traced across Kittatinny mountain, but in the Flatbrook valley a mile above Layton, and again in the Delaware valley near the Fisher schoolhouse, there are narrow but well defined morainal accumulations, which were, perhaps, contemporaneous in origin with the belt mentioned above (pp. 275 and 307).

The average width of the recessional moraine is about half a mile, though it varies from a quarter of a mile or less to nearly a mile. It is generally well developed in the valleys, but absent on the higher ridges separating them.

Like the main terminal moraine, this recessional moraine is, on the whole, more stony and bowldery than the adjoining ground moraine, and much of the material appears to have been partially assorted by water. Its constitution is well illustrated by Plate LVI. Locally, however, the till is as clayey and compact as that of any part of the ground moraine. In places where the surface outside (south) of the moraine is low, it is bordered by plains of gravel and sand. These deposits are described later, under the stratified drift.

At Ogdensburg.—On the east side of Wallkill valley just north of Ogdensburg, there is a small area of slightly morainic topography. The drift is partly gravel and partly till. A quarter of a mile farther north, on the slope of the mountain, the morainic topography is also distinctly developed, though the relief is not great. Some of the knolls are of gravel, while others are probably till. At the northern limit of this area, the sand and gravel knolls predominate, giving the moraine the aspect of a kame belt. The spur or embankment of drift on which part of the village of Ogdensburg stands, and which extends nearly across the valley,

Railway cut through the recessional moraine on the Lehigh and Hudson River road. West of Lake Grinnell.

is not to be regarded as a part of the moraine. Its mode of origin (p. 272) is believed to be quite different from that of the moraine, though it was probably more or less nearly contemporaneous with the moraine.

West of Ogdensburg and across the Wallpack from the great gravel embankment, is a small moraine area, the topography of which is best developed just north of the four corners near the Ogdensburg zinc mines, on both sides of the railroad. The hillocks and depressions are here sharply defined, the relief being twenty feet or so, and the surface strewn with bowlders. Along the railroad there are good exposures, where, in general, the material is coarse and stratified, although locally till-like. The stones are chiefly of gneiss, blue and white limestone, and Hudson River sandstone. Besides these, there are occasional Medina, Oneida and Cambrian sandstones and quartzites.

A large proportion of the material is poorly worn, but much of it is striated. Leaching has removed the calcareous matter from the matrix of the till to a depth of three or four feet, but limestone pebbles and bowlders are found up to the surface. There is no upper gneissic layer referable to superglacial till, as is the case in the deep railroad cut south of Ogdensburg (p. 270). The westward limit of this moraine patch is ill-defined, but traces of morainic topography occur as far west as the four corners half a mile west of the valley.

Lake Grinnell (Lane's pond) to Washingtonville.—There is but little till on the crest of the gneiss hills separating the Wallpack valley from Germany flats, but on the westward slope of the gneiss ridge opposite Lake Grinnell (Lane's pond), the till increases in thickness, and the morainic topography becomes marked. On the east side of the lake the hills and hollows are sharply marked (Plate LI, p. 270), the relief being twenty feet or more. One of the best views of typical moraine topography to be found in the State can be obtained from the west side of the lake, a little north of the ice-houses, looking across the water to the hills and kettles on the opposite side. The surface is thickly strewn with bowlders, some of which are eight to ten feet in diameter. These are chiefly of gneiss, but a few are of limestone.

On the west side of the lake the morainic topography is still bolder, though not so well shown in a general view. A relief of forty to fifty feet is not uncommon, and small kettles five to twenty feet deep occur on the flanks of the larger hills. The surface is thickly bowlder strewn, but limestones instead of gneisses predominate. Cuts along the L. and H. R. railroad give a number of good exposures in the moraine material on the west side of the lake. The material of the different cuts is very diverse. In some it is coarse gravel, including bowlders three to four feet in diameter, poorly stratified and somewhat compact. Others show gravel at one end and till at the other, while still others are composed mainly of stony till with pockets of gravel. The bulk of the material is between these extremes, and perhaps indicates the active co-operation of ice and water. At the north end of the lake, on the west side, the material, judging by surface indications and a few exposures, is almost entirely of sand and gravel, rather better assorted than in the railroad cuts. This part of the moraine is made up chiefly of kames. The moraine borders the lake for its entire length on the west, but on the east the southern end of the lake basin is made by the massive deposits of the overwash plain.

Near Sparta station on the Sussex railroad, the moraine is well marked, and the belt is about two-thirds of a mile wide. Neither the inner nor the outer margin is sharply defined, the morainic topography being best developed in the middle of the belt. West of Sparta station, the outer margin turns sharply northward in crossing the high ridge separating Germany flats from the sub-valley east of Lafayette. On the crest of this ridge, the morainic topography is but feebly developed, and the belt is less than a quarter of a mile wide. Traced down its western slope it widens rapidly, and the topography again becomes distinctive. Between the Fairview hotel and the schoolhouse at Lafayette, the moraine is interrupted by a narrow gravel plain marked by a few knolls. These knolls are best developed near the schoolhouse, where several exposures show loose calcareous gravel.

South of Lafayette the moraine is present on both sides of the railroad. Along the road leading south from the village the topography is well shown, the knolls rising fifteen to twenty feet above the bottoms of the adjoining kettles. A well here penetrated three or four feet of clayey till, containing large bowlders, and then reached loose, shale gravel which could be shoveled "as readily as shelled corn."

The moraine continues west for a mile and a half from the Sussex railroad. It lies just south of the high shale hill west of Lafayette, and just north of the road from Branchville Junction to Washingtonville. Along its outer margin it is not sharply separated from the gently undulating overwash gravel plain, the knolls and kettles of the moraine grading into the lesser undulations of the plain. Many of the moraine knolls near the margin are gravelly, but farther from the margin the material becomes more till-like, and bowlders more common on the surface. The moraine belt has here a maximum width of a little over half a mile. It ends abruptly at the foot of the 754-foot hill a mile and a half west of Lafayette.

Washingtonville to Balesville.—On the west side of the hill just mentioned, the moraine is again found, and extends in a well-defined belt through Washingtonville, Balesville and thence northwest to the foot of the high shale hill north of Myrtle Grove. The width of this part of the moraine is a little more than half a mile, though on the crest of the ridge between Balesville and Washingtonville its width is much less. The moraine topography is strongly developed east of Washingtonville, where the sharp knolls rise thirty or forty feet above their surroundings. It is well seen from the Lafayette road half a mile east of the depot at Washingtonville. Farther east the morainic topography is less distinct. The surface is strewn, though not thickly, with small bowlders and cobbles.

Over the ridge between Balesville and Washingtonville the moraine is narrow and feeble. It is again well developed northwest of Balesville, particularly near the church and in and northwest of the cemetery. Here the hillocks and kettles are sharp and clearly marked, though not of large size. The moraine topography is also well developed along the road a mile northwest of Balesville. The railroad (L. & N. E.) gives a good section through one of the knolls near the mill pond.

Southeast of Long pond.—No trace of the moraine is found on the steep slope up to the shale plateau along the northwestern side of Kittatinny valley. But on the top of the hill it re-appears and extends, with one or two slight interruptions, to the foot of the mountain at the north end of Long pond. Its average width is about one-fourth of a mile. The topography is well developed just south of the point where the road east of Bear swamp crosses it, and again at the northeast end of the swamp. Elsewhere it is weak. Where best marked, the relief is twenty-five feet or more. Bowlders, chiefly Oneidas, are very common on the surface. There are no exposures, but, judging from the surface expression, the moraine is made up chiefly of till.

Near Culver's gap.—In Culver's gap there is an assemblage of drift hillocks, which have the morainic aspect. They are, however, entirely of stratified drift, some of it fine sand, and, considered by themselves, would be classed as kames. It is uncertain whether or not they are to be regarded as a part of the morainal belt. Just east of the gap, and on the north shore of Culver's pond, is a small area in which the morainic topography is distinctly marked, although the knolls are not large. These mounds are of till, and strewn with bowlders. These hillocks are about where the moraine should be, for it would be expected to turn to the northward, as the mountain is approached.

In Flatbrook valley.—No trace of the moraine belt was found on Kittatinny mountain north or west of Culver's gap, but since all this region is heavily covered with thick underbrush, detailed examination was not attempted. A narrow moraine belt, however, crosses the Flatbrook valley a mile north of Layton. Its chief development is on the eastern side of the valley, but small patches of morainic topography occur on the western side as well. In the bottom of the valley it is largely of stratified drift, and the knolls are sharply marked. On the eastern side, a morainic belt a quarter to a third of a mile wide extends northeast obliquely up the side of the valley. From an elevation of 600 feet in the center of the valley it rises over an 823-foot hill, three-quarters of a mile to the northeast. On the top of this hill the topography is characteristically developed. It dies away on the slope of the hill to the east of the Hainesville-Tuttle's Corner turnpike, about a mile and a quarter south of the former place. The material is chiefly till on the higher parts.

The belt cannot be traced continuously across the ridges separating the Flatbrook valley from the Delaware valley. A few small patches of morainic topography, in the line which the moraine belt should occupy, are to be seen on the western side of the valley, making possible the connection from the one valley to the other.

In the Delaware valley.—A mile and a quarter north of Dingman's ferry a narrow moraine belt rises above the terrace level of the Delaware gravel (see p. 300).

Influence of Topography on the Course of the Moraine.

Between Ogdensburg and Culver's gap the moraine swings southwestward something like three and a half miles in crossing Kittatinny valley, and in the Delaware and Flatbrook valleys it lies several miles north of the latitude of Culver's gap. This change in position represents the effect of the high escarpment and plateau of Kittatinny mountain lying slightly athwart the direction of ice motion. The influence of topography upon the advance of the ice is also well shown by the position of the moraine west of Kittatinny mountain. The ice extended farther south, and was more vigorous in its action, in the valleys than on the hills. This inequality in the ice front must have been farther increased as the ice melted, since there was less to melt on the hills than in the valleys. In the case in hand, the edge of the ice on the ridge between the Flatbrook and Delaware valleys must have been about a mile and a half farther north than in the valleys on either side.

Other Minor Moraines and Morainic Areas.

Northeast of Augusta.—A mile northeast of Augusta, a narrow morainic belt crosses the Papakating valley. It lies just south and southwest of Frankford plains, and extends farther southwest in the center of the valley than on the side. The topography is distinctly developed near the road corners a mile southwest of the Frankford plains church. Here there are knolls and hollows having a relief of ten to thirty feet. Shallow cuts show that much of the material is till, and the surface, which is thickly bowlder strewn, corroborates the conclusions drawn from the cuts. On the east side of the valley the morainic belt rises ten to twenty feet above the stratified deposits in the valley. Bowlders are common on the knolls, but in this part of the belt many of the hillocks are of stratified drift. The belt is nowhere more than three-eighths of a mile wide, and its length is about a mile and a quarter. There are no other moraine belts in the adjoining valleys to be correlated with this.

Near Libertyville.—About a mile north of Libertyville, Wantage township, there is a moraine area about a mile square. Its limits and its topography are not always sharply marked. Bowlders are abundant upon the surface. There are no other morainic areas near, but the area is quite well in line with morainic accumulations across the mountain near Montague, and it is, perhaps, to be correlated with them.

LOCAL DETAILS—DISTRIBUTION OF BOWLDERS IN KITTATINNY VALLEY.

Of Oneida conglomerate and sandstone.—That bowlders from the Oneida formation should enter into the till of the southern part of the Kittatinny valley is not strange, since the direction of ice movement was here less westerly than the trend of the valley. The general direction of movement in the latitude of Flatbrookville should have carried them at least as far out into the valley as Jenny Jump mountain. But at the north end of the valley it will be remembered that the movement of the ice was rather more westerly than the trend of the mountain (Plate VIII). The presence of the Oneida and Medina bowlders in the northern part of the valley is, therefore, not to be explained in the same way. The problem here is similar to that presented by the Green Pond mountain conglomerate bowlders in the Newark valley, though there is an additional alternative here.

Theoretically, the bowlders from the Oneida formation might have got out into the valley at its north end, 1) by descending the east face of the Kittatinny range under the influence of gravity before the last glacial epoch. In this case the ice found them in the valley, and since in the valley its movement was in general less to the west than the axis of the valley, its tendency was to carry them obliquely across it. 2) The bowlders might have been carried out into the valley by an ice sheet earlier than that which made the conspicuous deposits of drift. In this case the movement of the earlier sheet was less westerly than that of the later in this latitude. 3) The bowlders may have been brought in from New York, where the outcrop of the Oneida formation is farther east, and where the direction of ice movement was less to the west. It is possible that all three of these alternatives coöperated, for it is well nigh certain that there were bowlders at the east base of the Kittatinny escarpment when the ice came in, and it is certain that the Oneida formation lies farther east in New York than in New Jersey, and there is no doubt of more than one glacial epoch. The first of these alternatives seems inadequate, for gravity never carried the bowlders far beyond the base of the mountain, certainly not far enough in this State, for the ice of the last glacial epoch to have carried them to the points where they now occur. The course of the ice which crossed the Kittatinny range from the west between the bend of the Delaware at Flatbrookville and the Water gap, was not such as to allow it to reach the Highlands. Whether the movement of the ice across the Oneida formation in New York was in such a direction as to account for the distribution of these bowlders is not definitely known. Into the account must be taken the fact that similar bowlders occur miles beyond the terminal moraine of the last glacial epoch, in the extra-morainic drift, and even up on the Highlands beyond the valley. It seems on the whole probable that some of the bowlders were carried well east of the Kittatinny range by the ice of an epoch which antedated that during which the moraine was made, and that the last ice sheet re-worked this old sheet of drift so far as it covered it.

Of the Elæolite Syenite.—A mile and a quarter northwest of Beemerville are a number of ledges of elæolite syenite. They occur on the face of the eastern slope of the mountain, between the Oneida ledge and the slate and shale below. The outcrops occur at frequent intervals for a mile and three-quarters along the mountain face. Fragments of this rock are readily recognized in the drift. Since it occurs in no other part of the State, and since its outcrop in this vicinity is limited in extent, its distribution in the till is significant of the direction of the ice movement. Fragments of this rock have been found in the drift more than twenty miles to the south and southwest of the outcrop. The area within which they have been seen is approximately bounded by a line drawn from the outcrop, south by southwest to a point a mile and a quarter east of Washingtonville, then southwest to a little east of Hewitt's pond, Green township, then west to the foot of the mountain, and thence northwest along the Kittatinny escarpment (see Fig. 29, p. 106). One small cobble was found in the northern part of Blairstown township, another in the western part of Hardwick. With these exceptions, fragments of the syenite were not observed south of the latitude of Middleville, although careful search would probably result in the finding of a few. North of the latitude of Middleville, which is about thirteen miles from the outcrop, bowlders and cobbles are more common in the drift, but they nowhere become so abundant as to obtrude themselves upon the notice. They increase in size towards the parent ledge, in the vicinity of which they are sometimes four or five feet in diameter. So far as observed, they are not equally distributed, but show a disposition to be aggregated in belts transverse to the ice movement. Even within these belts they are not very abundant. One of these belts, about a mile in width, extends east and west of Middleville. Another extends west of Myrtle Grove. A third area in which they are more than ordinarily abundant lies east of the northern end of Culver's pond. The reason for this distribution is not apparent. So far as known, these belts are not lines of heavy accumulation of till, and so they can hardly be taken to represent a pause in the retreat of the ice sheet.

It is significant that stones from this outcrop were not carried farther south. The rock is not especially resistant (for igneous rock), and it is hardly to be doubted that its comminuted products went farther than recognizable fragments. The distribution of the syenite is an illustration of the general fact that masses of rock, which is not exceptionally resistant, do not suffer extensive transportation in the bottom of the ice without being ground to fineness.

The distribution of the syenite illustrates also the spreading of the ice. Near the ledges, the fragments are confined to a narrow zone within which the bowlders are relatively abundant. West of Beemerville this zone is not more than a mile wide. In the latitude of Culver's pond, a little more than four miles south of the nearest syenite ledge, the zone is about four miles wide. In the latitude of Balesville its width is nine miles. According to the distribution of these erratics the direction of ice motion must have ranged from S. 12° W., to S. 46° W. (corrected). These figures fall within the limits of the numerous striæ recorded in the valley.

In addition to the area outlined above in which the syenite occurs, a few bowlders of the same sort of rock were noted in a locality so significant as to deserve separate mention. The syenite outcrops are 100 to 150 feet below the summit of the Oneida ledge. Along the road across the mountain northwest of Beemerville, many bowlders of syenite were noted at an elevation 100 feet higher than the nearest outcrop, and a quarter of a mile distant in a due westerly direction. If these bowlders came from the northernmost outcrop, their line of motion was S. 48° W. If they came from this ledge, they may be no more than thirty feet higher than their source, but to reach their position they must have passed over a hill about 100 feet higher than the ledge whence they were derived.

A number of syenite bowlders, one three feet in diameter, were found on the westward slope of the mountain three-fourths of a mile from Beemerville. They lie S. 62° W., to S. 69° W. of the northernmost outcrop, and a mile from it. There are no considerable elevations between their present position and the ledge. A short distance northwest of the ledge of syenite, striæ were found bearing S. 93° W., or 3° north of west. These striæ and others in the vicinity, together with the syenite bowlders west of the crest of the mountain, prove that in this vicinity, at least, the direction of ice motion at the crest of the mountain was more to the west than the trend of the mountain, and that on the east side of the range, ice from below the crest passed over the crest to the westward slope. Except at the localities just mentioned, and a doubtful cobble in the gravel at the mouth of the Flatbrook, syenite fragments were not found on the west slope of the mountain.

THE STRATIFIED DRIFT OF THE KITTATINNY VALLEY.

Stratified drift of all sorts, mainly gravel and sand, does not occupy more than one-tenth of the surface west of the Highlands and north of the terminal moraine. Most of it is confined to the larger valleys, the general courses of which are parallel to the Kittatinny mountain.

The stratified drift of the Kittatinny valley takes on, at one place or another, essentially all the phases assumed by drift deposited by water. These various phases, together with the conditions under which they arise, have been detailed in chapter IV of this volume. The especially striking feature of this phase of the drift in the Kittatinny valley is the frequency with which it is disposed in the form of kame terraces.

The *distribution* of the stratified drift shows that when it was deposited glacial drainage followed the present valleys. This places the origin of the stratified drift at a time subsequent to that of maximum glaciation, after the ice had so far disappeared as to free, or partially free, the valleys. The *disposition* of the stratified drift shows that remnants of ice still existed in the valleys when the stream deposits were made. This has led to the conclusion that bodies of ice lay in the valleys after the intervening ridges were free from it. The presence of the ice in the valley bottoms caused the drainage to flow along the sides of the valleys somewhat above their bottoms (Fig. 33, p. 121), the stream being held in on the one side by ice, and on the other by the slope of the valley. The drift deposited by such streams was left on one or both sides of the valley somewhat above its bottom. If the ice in the valley persisted until glacial drainage ceased to flow through it, the bottom may have been free from stratified drift when the ice disappeared, even though there were abundant deposits on the slopes above. Where the ice disappeared from the valley before glacial drainage ceased to flow through it, stratified deposits were often made in the bottom of the valley later than those on the slopes above (Fig. 69).

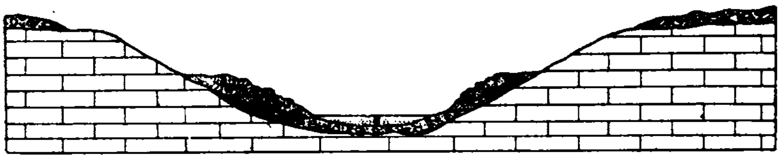


Fig. 69.

Diagram illustrating kame-terraces, with sand and gravel (a) deposited in the bottom of the valley after the departure of the ice.

Stratified drift deposited on the slopes of a valley, rather than on its bottom, should be especially characteristic of mountain valleys. It should be at its best in such regions as the northwestern part of our State, where the relief is great, and where the valleys in which the ice tongues lingered were the valleys through which the glacial drainage flowed.

The kame-terrace deposits generally increase in elevation northward, that is, in the direction whence the aggrading waters came. This is true even in the northward sloping valleys. In such valleys the tendency was to form temporary lakes, as the ice blocked their lower (northward) ends. Beds of clay deposited in standing water are occasionally exposed in the valleys, and are evidence that such lakes existed.

Deposition of stratified drift in the valleys north of the moraine doubtless began as soon as the ice began to retreat. The deposits made at any stage occupied the valleys between the moraine on the south and the edge of the ice on the north. As the ice retreated, the deposits of sand and gravel were extended northward, the newer deposits being added to the older ones up stream, as illustrated by Fig. 38, p. 127.

The aggradation level, represented by the terraces in each valley, is liable to interruption. Above an interruption, the new aggradation level, if one appears, is lower than that farther south. The new level slowly rises northward for a greater or less distance, to be in turn succeeded by another and lower level. This relationship indicates that the kame terraces were formed by southward flowing streams, but that the gravels of the successive areas where the aggradation levels are discordant were deposited at successive intervals, the deposits of the lower levels and more northerly latitude being formed after those farther south. The points of interruption are points where the edge of the ice stood for some time, long enough for the deposition of heavy beds of gravel below. The relations of the successive sections are illustrated by Fig. 38. The terraces below (to the left of) 1, were developed before the ice receded beyond (to the right of) 1, perhaps while it stood at that point. The ice then receded more or less promptly to 2, and the gravels between 1 and 2 were deposited, but without immediate regard to the deposits below 1. The deposition of stratified drift in the valleys probably continued as long as glacial drainage flowed through them.

In the following pages the stratified drift of the Appalachian province is described by drainage systems.

STRATIFIED DRIFT OF THE VALLEY OF PAULINSKILL.

Summary.

Disposition.—As in other valleys of the Appalachian province, stagnant ice in varying amounts remained in the valley of the Paulinskill while the gravel was being deposited. The presence of the ice is shown (1) by the various types of kame and kame terrace topography; (2) by the wide, swampy flood plain, which is not the result of post-glacial erosion; (3) by the occasional outcrops of rock near the bottom of the valley below the level of the gravel deposits, but in positions where post-glacial erosion could not have discovered them, and (4) by the kettle-like depressions in the slopes of the terraces where they rise above the flood plains. Where the ice was present in quantity, there are well-marked kames and kame terraces along the sides of the valley, and where for short distances it was wanting, the gravel was spread more generally over the whole valley, developing valley plains out of which the river has since cut normal river terraces.

Well-marked kames, kame terraces and other forms due to the presence of ice where the gravel was deposited occur near 1) Hainesburg; 2) between Blairstown, Jacksonburg and Kalarama; 3) near Swartswood station; 4) a mile northeast of Swartswood station; 5) a mile southwest of Balesville, and 6) between White and Shuster ponds, in a tributary valley. Above the moraine belt at Balesville the kame topography is marked at points some distance back from the stream, whereas immediately along the kill, the deposits form a low, level, broad terrace. This latter was probably formed later than the kame terraces and after the ice had disappeared from the valley.

Broad terraces, showing little influence of the ice, occur above Columbia, at Walnut Valley, above and below Stillwater, between Augusta and Branchville, and east of Augusta.

The profile of the surface of the stratified drift of the valley is not continuous. Its discontinuity is such as to show that it was not deposited contemporaneously throughout the valley. Rather was it deposited in sections, beginning at the lower end of the valley, after the manner illustrated by Fig. 38 (p. 127); that is, the upper surface of the stratified drift of the valley is not a continuous aggradation plain.

The profile shown in Fig. 2, Plate LII (p. 290), shows the elevation attained by the highest terraces in the valley, and the present slope of the stream. It is to be understood that terraces made while ice still occupied the axis of the valley do not, at all points, reach the maximum aggradation level shown in the figures. The most important of the localities where they fall below the general level for considerable distances are indicated. As shown by this profile, the upper limit of the gravel rises from about 360 feet at Columbia, to a point a mile and a half above Hainesburg, where a maximum height of 380 feet is reached. For two miles above this point in the vicinity of Walnut Valley, the gravel does not reach above 370 feet, and the general level of the broad Walnut Valley plain is less than 350 feet. Near Kalarama it again attains an elevation of 380 feet, and ascends by a very constant gradient of about fifteen feet per mile, to an elevation of 470 feet a mile above Marksboro. For the latter half of this distance the valley is narrow, and occasional patches only of gravel are present.

For two miles below Stillwater, the gravel deposits are abundant, but most of them are below (440 feet or less) the Marksboro level. Here and there traces of gravel appear at elevations of about 460 or 470 feet, the proper aggradation level. Near Stillwater, the terraces rise by a somewhat abrupt slope from 440 to 470 feet, and then less rapidly to 480 feet. Near Middleville, the gravel attains a height of 500 feet, but a little farther up stream, according to the topographic map, it does not rise higher than 480 feet. For some distance above Emmons station the gravel is absent, but when it again appears it has an elevation of 500 feet or more, and rises rather rapidly to about 540 feet at the moraine near Balesville.

North of the moraine, there are kame terraces at 540 feet back from the stream, but along the stream the terraces have an elevation of only about 500 feet. The higher gravels disappear near the Almshouse, a mile northeast of the moraine, but the 500-foot terrace continues up the kill nearly to Lafayette. A corresponding terrace extends up the tributary valley to Branchville, where it reaches an elevation of 570 feet. A continuation of the same low terrace extends northeast from Augusta to the small moraine below Frankford plains.

History of deposition.—From the profile (Fig. 2, Plate LII) of the higher terraces, something concerning the history of the deposits can be made out. The gravel below Walnut Valley was probably deposited while the ice edge stood at the Valley; and that between Walnut Valley and Stillwater, while the edge of the ice stood a little below the latter place. There is nothing, however, apart from this disposition of the gravel and sand, to suggest these halts of the ice. The stratified drift between Stillwater and the moraine at Balesville, was deposited while the edge of the ice lay in the position of the moraine, which marks a definite and probably a more protracted halt of the ice. The high level kame terrace north of the Balesville moraine was clearly built around ice blocks, and is of later origin than the moraine itself.

The lower terrace has little of the topography indicative of the presence of ice, and was formed later than the higher terraces, and after the ice had disappeared from this part of the valley. The small moraine northeast of Augusta marks a second halt in the retreat of the ice front, and the stratified drift below stands in the relation of a valley train (p. 124) to the moraine.

Constitution.—The finer parts of the stratified drift of the Paulinskill is made up chiefly of shale and limestone, while the coarser part contains much material from the Oneida and Medina formations. The proportions of shale and limestone vary as the kill flows from the one formation to the other, but shale generally predominates. Much of the gravel is clayey, rather than loose and sandy. Its uppermost part is generally sufficiently clayey for agricultural purposes, and the gravel below affords good under-drainage.

In size, the material varies from sand to large cobbles. The fine and coarse materials are in general more or less intermingled, though there are localities where the one or the other predominates. There is, on the whole, no marked diminution in the size of the material towards the lower end of the valley, a condition of things to be expected under the conditions of deposition sketched above.

The gravel is well exposed between Columbia and Hainesburg along an incomplete railroad grade, at Blairstown, along the railroad above Marksboro, and at Stillwater in the abandoned railroad cut.

Post-glacial erosion.—The amount of post-glacial erosion along the Paulinskill varies greatly within narrow limits. In the narrower parts of the valley, as above Marksboro, and at Emmons station, gravel deposits are absent. If they ever existed in these localities to the height of the aggradation level, the stream must have lowered its channel fifty or sixty feet. But there is no positive evidence that stratified drift was ever present here. In a few localities, positive evidence of a moderate amount of erosion is found. Jacksonburg creek, below Blairstown, has trenched the Paulinskill gravels to a depth of twenty-five feet, making a valley more than 200 feet wide. On Blair's creek, above Blairstown, the vertical cutting has been locally about forty-five feet. Above Paulina the Paulinskill itself has cut thirty feet in till, and a mile and a half above Stillwater a small tributary has eroded a channel twenty-five feet deep and 150 feet wide in the gravel deposits. Below Emmons station the kill has lowered its channel thirty-five feet, and at Balesville the moraine has, in places, been trenched to a depth of forty feet, whereas near Augusta the maximum cutting has not been more than ten feet. At other localities, as above and below Stillwater, and at Yard's creek near Hainesburg, there has been no post-glacial erosion, but filling instead.

Local Details.

Columbia to Blairstown.—The deposits of stratified drift along the Paulinskill between Columbia and Blairstown are somewhat extensive, and better developed on the northwest side of the river than on the southeast. In the vicinity of Walnut Valley and Jacksonburg, the belt of stratified drift is something more than a mile wide, though in the latter place its continuity is interrupted by ledges of limestone which rise above it.

Just above Columbia, near the junction of the kill with the Delaware, the terrace of stratified drift has an elevation of 360 feet, and is ninety feet above the Delaware at this point. Its surface is commonly strewn with cobbles, although in places it is loamy. Its topography varies from planeness to notable undulatoriness. A few exposures along the line of the L. & N. E. railway show that the gravel is poorly assorted and rather clayey. Several limestone hills poorly covered with till, rise above the gravel deposits.

Between Columbia and Hainesburg there is little gravel on the left side of the valley. What there is, is generally at low levels, but about a quarter of a mile above the station at Warrington, the sand and gravel rises in a terrace-like kame against the hill side to a height of 370 feet.

At Hainesburg the stratified drift attains an elevation of nearly 380 feet, and is eighty feet above the river. In this vicinity, the influence of the ice on the disposition of the drift is well shown. The tendency of deposition was to build a plain, having a slight slope down stream; but the presence of more or less ice in the valley prevented the perfect development of the plain. The deposits were made around and over the ice, and when the ice melted, it left the drift in irregular forms. Kettles ten, twenty and even thirty feet in depth are common. One of them near the schoolhouse at Hainesburg, contains a small pond. This topography continues in good development nearly two miles above Hainesburg. In the tributary valley of Yard's creek, a mile northeast of Hainesburg, the stratified drift reaches up to 420 feet, but in the main valley as far as Walnut Valley, the terrace level does not rise above 380 feet.

At Walnut Valley the topography developed by stagnant ice is generally absent. The terrace plain is broad and flat, or but gently rolling. The material is fine gravel and sand, and bowlders and cobbles are absent from its surface. The general level of this plain is between 340 and 360 feet, a little less than the elevation farther down stream. The filling below probably antedated that at Walnut Valley, by some short period of time.

South of Walnut Valley, on the left side of the Paulinskill, the surface of the stratified drift has an elevation of about 340 feet, but a few mounds rise above this level to nearly 370 feet. Near Kalarama, a high limestone hill projects well above the level of the stratified drift. Along the railroad, the material of the stratified drift is seen to be mainly sand and fine gravel. It forms a smooth-surfaced, gently sloping plain, with a maximum elevation of about 380 feet. Near the river, the topography shows the influence of ice, and there the material is coarser. Just above Kalarama station, kame-terrace forms are well shown on the hillside.

On the right side of the Paulinskill, from a point a mile northwest of Kalarama to Blairstown, the kame-terrace topography is again finely developed. The outline of the stratified drift is irregular, owing to the irregular outlines of the limestone hills against and around which it was deposited. The topography is extremely varied. Unbroken plains, pitted plains, undulatory areas, even-crested winding ridges, mounds and deep depressions, follow each other in rapid and apparently orderless succession.

Over the whole tract, however, the aggradation level is well marked. Numerous limestone hills rise above the gravel deposits which surround them, and it frequently happens that the gravel does not rise to the same height on all sides of the protruding hill. Not infrequently it varies as much as thirty feet in narrow limits. So far as can be determined from the contour map, the old aggradation surface reaches an elevation of rather more than 420 feet, a mile west of Jacksonburg. At Jacksonburg, however, it apparently fails to reach a height of 400 feet. At Blairstown it rises to something over 400 feet. These irregularities are ascribed to the influence of the ice, the edge of which was inconstant in position.

Exposures near Blairstown afford good opportunity to study the constitution of the gravel. There is a deep cut along the road to Jacksonburg, near the old creamery. Here fully thirty feet of sand and gravel were exposed in 1894. In general the material is coarser towards the top. In size, it ranges from sand to cobbles six inches in diameter. Of the pebbles over two inches in diameter, three-fourths are from the Oneida and Medina formations and most of the remainder from the Hudson River sandstone. There are a few limestone pebbles, and the gravel is distinctly calcareous. Of the fine material, the Hudson River shale constitutes a much larger percentage. This gravel is cross-bedded. Another good exposure is on the road to Kalarama, just south of Blairstown. Where exposed (in 1894) it is horizontally stratified, and somewhat clayey. The material ranges in size up to cobbles four to five inches in diameter, with occasional small bowlders. Of the material as a whole, the Hudson River shale and sandstone was estimated to constitute half.

The gravel terrace is well developed north of the village in the vicinity of Blair hall. Here limestone knolls rise above the terrace plain, and sharply defined depressions, probably marking the position of buried ice blocks, sink beneath it.

Blairstown to Marksboro and above.—Between Blairstown and a point two miles below Stillwater, stratified drift has but slight development. Small kame terraces occur, now on one side of the stream, and now on the other, but their extent is nowhere great. They are best developed just above Marksboro, where they reach an elevation of seventy to seventy-five feet above the stream (460–470 feet A. T.) and in places form distinct benches, well up on the valley slopes. The influence of the ice in determining their form and position is shown by the kettles which interrupt the evenness of their surfaces and by the undulations of the steep slopes.

The railroad cuts above Marksboro give the best exposures in this vicinity. The most noteworthy features of these cuts are the large bowlders imbedded in the gravel, some of which is cemented into conglomerate.

Along Blair's creek.—A glance at the map will show that in addition to the drainage along the present course of the Paulinskill, there was a considerable discharge of glacial waters along a low line a little north of White pond, through Blair's creek, and into the Paulinskill at Blairstown. The gravel deposits along this line are much more extensive than those along the Paulinskill between Blairstown and a point two miles below Stillwater. As is abundantly shown by the constitution and topography of the deposits, they were not made independently of the ice, although clearly enough deposited by running water.

In this valley, the gravel deposits form well-marked terraces on both sides of the stream, from Blairstown nearly to Hardwick Center (Slabtown). The gradient of the creek is much greater than that of the terraces. Just above the mill pond at Blairstown, the latter have an elevation of about 410 feet, and the former of 360 feet. At the first bridge, a mile above, the terrace and creek are 430 feet and 407 feet, respectively, while near Hardwick Center they have altitudes of 482 feet and 460 feet. The finer material of the terraces is largely Hudson River shale and sandstone. Just north of Blairstown it constitutes more than three-fourths of the deposit. Farther up stream the surface is thickly strewn with cobbles. Of those between eight and twelve inches in diameter, Oneidas are by far the most abundant.

The gravel along Blair's creek extends nearly to Hardwick Center. Here the main line of glacial drainage did not follow the course of the creek, but came down from the northeast. For a short distance, gravel deposits are wanting or doubtfully present, but about a mile northwest of White pond there is a gravel area which extends northeast to Shuster pond and Paulinskill. Its outline is exceedingly irregular. The gravel winds in and out between the islands and peninsulas of limestone. The boundary does not follow a contour strictly, although it does not, so far as appears from the map, rise much above 500 feet, and many limestone knolls below that height are not covered by the gravel.

The surface of this area is generally rather clayey and firm, but it is marked by great numbers of cobbles and pebbles. Some knolls, however, are loose and sandy. Topographically the surface varies considerably. In places the gravel takes the form of more or less flat-topped terraces on the sides of the limestone hills. These often inclose or partially surround irregular depressions, some of which contain ponds. But this flat-topped character is not the general rule. Mounds and hillocks are common, and in places the kame topography is strongly developed. Yet the crests of a sufficient number of these mounds and terraces approach a common level, to establish a general aggradation level, above which a hillock of gravel rarely rises. The presence of the numerous kettles, of terraces facing more or less irregular depressions not due to erosion, the presence of knolls of limestone, free from gravel, and slightly covered with till, *below* the general level of the gravel, indicate the presence of irregular masses of ice during the deposition of the gravel.

One arm of this gravel area extends as far north as Shuster pond, along the east side of which ill-defined terraces are present. Another area extends eastward to the Paulinskill, reaching the stream about two miles above Marksboro. At this point the gravel deposits along the stream have a maximum elevation of only 460 feet, which is twenty to forty feet lower than the elevation of much of the gravel farther south.

Stillwater to Emmons Station.—From a point about two miles below Stillwater, to Emmons station, gravel deposits are developed along the Paulinskill, being most widespread about Stillwater. They occur also in the tributary valleys at elevations equal to or greater than the height of the terraces along the main valley. Between the two roads which cross the kill, one and a fourth and one and three-fourths miles respectively, below Stillwater, the terrace is well marked, being best shown southeast of the stream, where it has an elevation of about 460 feet. Its surface is clayey, except on the steep slopes, and its material, largely of Hudson River shale and slate, is not coarse. One or two limestone knolls rise above the level of the terrace. Nearer Stillwater, the gravel is better developed on the right side of the stream, where the height of the main terrace is about 440 feet. This level is maintained to Stillwater, where the surface rises abruptly twenty feet. Topographically, the broad terrace below Stillwater at 440 feet might be a secondary terrace, carved out of the higher, but such an amount of post-glacial erosion appears excessive in this situation. The abrupt rise of the terrace at this point might be thought to be a delta front, but the existence of a temporary lake is not otherwise indicated. Half a mile north of Stillwater there is a deep kettle in the terrace, containing a pond of considerable size. Apart from this kettle, there is little in the topography to suggest the presence of ice when the sand and gravel were deposited.

The best opportunity for studying the constitution of this part of the Paulinskill gravel is in the old railroad cut near Stillwater, where loose sand and gravel are exposed to a depth of twenty feet. The gravel is fine, and composed largely of Hudson River shale and sandstone. Owing to the predominance of shaley material, the pebbles are markedly disk-like. Of cobbles over four inches in diameter, those derived from the Oneida formation are most abundant. The gravel is not highly calcareous, though the underlying rock is limestone. Here, as elsewhere, the stratified drift contains a larger percentage of material foreign to the formation on which it lies, than does the till of the same region.

South of Middleville, the gravel terrace reaches an elevation of 500 feet. Here the depressions in the terrace plain and the configuration of its slopes indicate the passive co-operation of the ice in the fashioning of the deposit. The gravel is here rather coarse, cobbles being numerous on the surface. Kame terraces extend slightly above Middleville along the valley of Trout brook.

Between Middleville and Emmons station, the gravel does not form extensive terraces, although they are clearly marked in several places. Their maximum height is about 500 feet. For a part of the distance, at least, the gravel probably originally filled the valley to the height of the terraces, but some of it has since been carried away.

Swartswood to Balesville.—Above Emmons station the gravel is absent for more than a mile. Here the river flows through a remarkably straight, narrow, steep-sided valley, the bottom of which it has filled, to a considerable depth, with alluvium. About a mile below Swartswood, the stratified drift appears again at an elevation of a little over 500 feet. Its topography indicates that ice was present when it was deposited. Its continuity is somewhat interrupted by hills of limestone which project through it, and it is not always disposed in the form of a terrace.

Above Swartswood station, gravel deposits are more considerable, and the terraces are present on one side of the stream or the other as far northward as the recessional moraine at Balesville. Between Swartswood station and the Paulinskill, stagnant ice topography is fairly well developed, and on the terrace to the northeast, sinks ten to twenty feet are common. But the best examples of the peculiar interrupted terrace topography. resulting from the deposition of gravel and sand around and among more or less isolated blocks and masses of ice, is to be seen on both sides of the stream above the bridge a mile above Swartswood station. Here kettles twenty-five, thirty and even forty feet deep are common. Limestone knolls nearly bare of drift not infrequently rise above the general level reached by the gravel.

On the left-hand side of the stream, a line of deep sinks lies along the bluff margin of the terrace, the terrace forming a ridge between them and the stream. About half a mile below the moraine, on the right-hand side of the kill, near the house of Mr. Carpenter, the gravel stretches back for some distance from the stream. It winds in and out between the limestone ledges, its upper limit following approximately the 525-foot contour line, but departing from it notably in some instances. In this region, also, limestone ledges outcrop at low levels in such positions as to lead to the conclusion that they were covered by ice when the surrounding deposits of stratified drift were made.

The material of this part of the Paulinskill gravel is similar to most of that found elsewhere. The bulk of the coarser material is Oneida sandstone and conglomerate, while Hudson River shale and sandstone predominates in the finer parts. It contains but little limestone, in spite of the fact that a belt of limestone lies along the right bank of the river. The smallness of the limestone content is accounted for partly by the fact that the ice movement was here nearly parallel to the strike of the beds, and partly by the fact that the neighboring belt of limestone is narrow, and extends but a short distance up the valley, so that the ice which reached this area and supplied the material of the terraces had passed over but little of this sort of rock compared with the amount of shale and slate which lay in its path.

Near the moraine at Balesville, the gravel reaches an elevation of about 540 feet, but there is here no such rapid increase in the gradient of the terrace as in the valleys farther east, or as in the Delaware and Flatbrook valleys (pp. 300, 307, 309).

Balesville to Branchville.—For a short distance above the moraine, the gravel deposits are somewhat extensive on the west side of the stream, but nearly wanting on the east. Stagnant ice forms of various types are well developed. The terraces do not rise more than twenty feet above the kill, and in some places even less. The kame terrace topography is wanting along the stream, although strongly developed at higher levels and farther back from the river. The probable explanation of this is found in the fact that glacial drainage continued along the bottom of the valley after the ice had melted, and the lower deposits, made later than the higher, are without the impress of the ice.

The kame terrace topography back from the river varies considerably. Just north of the moraine the gravel plain, although distinctly shown, is much broken by kettles. In the forks of the roads, rather more than a mile north of Balesville, the topography is very undulatory and broken, with hardly a trace of an aggradation level. Farther north, near the almshouse, the topography is also strongly kame-like, and the hillocks are large and massive. Still farther north, along the tributary to the Paulinskill, there are more or less distinct terraces at somewhat lower levels.

Augusta to Branchville.—A short distance west of Augusta a wide tributary valley from the north joins the valley of Paulinskill. Extensive deposits of shale gravel are present in this valley as far up as Branchville, a distance of a mile and a half. The terraces are broad and even, and in general show few indications of the presence of ice while the drift was being deposited. In places, however, their evenness of surface is interrupted by undulations. They do not rise more than fifteen or twenty feet above the stream; but as the gradient of the stream is high, they rise from an absolute elevation of about 500 feet near Augusta, to about 550 feet at Branchville. The plain is most regular and unbroken near the cemetery midway between Branchville and Augusta, but kame terraces are strongly marked along the narrow side valley northeast of that point.

The constitution of the gravel is much the same as that in the main valley farther south. Here, however, occasional pebbles of gneiss occur. The material becomes coarser toward Branchville.

Augusta to Lafayette. —Near Augusta, the Paulinskill leaves the strike valley which it occupies below this point, and follows a transverse valley almost at right angles to its lower course. This transverse valley extends southeast to a point a little beyond Lafayette. The strike valley, however, continues northeastward to Sussex (Deckertown), and is occupied by the Papakating creek. The divide between the creek and a small tributary to the Paulinskill is about half a mile east of Augusta, at a height of about 500 feet.

Stratified drift is present in both the transverse valley followed by the kill, and in the larger strike valley, the most extensive deposits being directly east of Augusta. The plain of gravel here is nearly a square mile in extent, but its continuity is broken by the alluvial deposit along the depression followed by the railroad, and by a high hill of rock and till which rises about 100 feet above it. The surface of the plain is rather even, and it slopes gently to the southwest.

A small moraine crosses the valley at the northern edge of this plain a mile or so north of Augusta. In front of the moraine the surface is strewn with large cobbles, but the gravel decreases notably in size to the southward, and at the kill small pebbles only, appear at the surface. Standing in the relation indicated to the recessional moraine to the north, this plain partakes of the nature of an overwash plain or a wide valley train.

The southern part of this plain is continuous with the interrupted terraces along Paulinskill, toward Lafayette. The lack of continuity of the terraces here does not appear to be due altogether to erosion. Their disposition and relations indicate that the valley was partly occupied by ice when the gravel was deposited. Strongly marked stagnant ice forms are present at one point a little back from the kill.

A mile south by east of Augusta, on the left-hand side of the stream, the gravel was deposited around hills of shale. Over much of this area, the topography reflects the influence of the ice around and on which it was deposited. A part of this area may be taken as a type of that member of the series of stagnant ice forms, in which the plain is almost lost in the number and size of the depressions. Only narrow terraces and winding ridges indicate the old aggradation level.

Half a mile northwest of Lafayette, and again at Lafayette, are small terraces, whose elevation approaches 560 feet. These are strictly local in their development. The evidence is clear that they are not erosion remnants of a once more wide spread plain at that elevation.

Above Lafayette, the Paulinskill is commonly bordered by broad, swampy areas. The gravel deposits which in places border these areas will best be considered in another connection.

STRATIFIED DRIFT IN THE PAPAKATING VALLEY.

Papakating creek has its source in a swamp at the foot of Kittatinny mountain a mile north by west of Beemersville. It flows in a general southerly direction, more or less across the strike of the slate, for five or six miles. At the Frankford plains it enters the wide strike valley extending from Augusta to Sussex, and changes its course from southeast to northeast.

Summary.

From the moraine northeast of Augusta to its junction with the Wallkill, the Papakating creek is bordered by kames and kame terraces. Typical stagnant ice forms occur near Armstrong station (pitted plain and confused mass of kames), near Papakating (large massive kames), and southeast of Woodbourne (kame terraces). Just north of the moraine at Frankford plains is a glacial delta, built in a temporary lake or pond, which was partly confined by ice walls, at an elevation of 525 feet. This origin of the plain is indicated by its topography rather than by its structure, since the latter is not exposed.

In addition to the stagnant ice forms indicated above, which occur at high levels, there are clayey, slightly stony terraces along the creek at low elevations, which in some cases at least (Roy station) are composed of clay. For most of its course, the creek is bordered by a wide alluvial plain.

That the gravel deposits of this valley were made when the ice filled its center and lower parts at many points is shown (1) by the topography of the deposits; (2) by their position high on the sides of the valley; (3) by the wide and somewhat swampy flood-plain, not of post-glacial development; (4) by the bare rock outcrops and deposits of till along the bottom of the valley below the gravel deposits, where their surroundings are such as to forbid the supposition that erosion has removed overlying stratified deposits; and (5) by the existence of well-marked kames in the valley at elevations of 450 to 480 feet, while the general aggradation level of the valley deposits is considerably higher.

The profile of the deposits in this valley is shown as a continuation of the section of the Paulinskill deposits (Fig. 2, Plate LII, p. 290). The Papakating valley drains northward. As the ice retreated northward and down this valley, the drainage must have been either (1) contrary to the slope of the land, or towards and under the ice (very improbable); or (2) ponds must have been formed in the valley in front of the ice, the overflow escaping to the south. The slope of the surface of the deposits of stratified drift shows that the drainage was to the southwest. Facts already cited indicate that a large part of the valley was occupied by stagnant ice. Ponds, if formed, must have been long and narrow, and in general situated between the ice and the sides of the valley. The topography of the high level deposits themselves, with the exception of the delta at Frankford plains, does not indicate that ponds had any considerable development. Some of the clay in the lower terraces may have been deposited in temporary lakes.

History of deposition.—The following appears to be the history of ice retreat and gravel deposition in the valley of Papakating creek: 1) A stage of comparatively rapid retreat of the ice from the position of the moraine northeast of Augusta, to a point a little above Papakating, followed by the formation of the gravel deposits between these points at elevations of 525 to 531 feet; 2) a probable second stage of rapid retreat of the ice, and then a pause, during which the deposits from near Roy's station to near Woodbourne were formed, represented by the aggradation level ranging from 450 to 540 feet. The rapid rise from 450 to 540 may be accounted for by the abundance of material brought down by the Little Papakating at this point. As will be seen later, deposits at harmonious levels extend up the Little Papakating some distance above Woodbourne.

Post-glacial erosion.—Post-glacial erosion along the Papakating has been almost nothing, though here and there the creek has lowered its channel a few feet. Where the Little Papakating crosses the high terraces southeast of Woodbourne, it has cut a valley eighty to 100 feet deep and 200 yards wide, in post-glacial time.

Local Details.

There is but little stratified drift along the upper course of the creek. Two miles southwest of Beemerville, low kame terraces of coarse, poorly rounded, and poorly assorted, shaley gravel rise not more than twenty feet above the stream. About a mile and a half east of Branchville, kame terraces having a maximum elevation of about sixty feet above the stream are present on both sides of the creek.

Frankford plains.—Just south of Papakating creek, where it enters the longitudinal valley, there is a high, flat-topped deposit of sand and gravel known as Frankford plains. The steep slope of its free borders shows no sign of having been built against ice. On the contrary, it possesses both the outline and the slope characteristic of the front of a delta, and this the plain is believed to be. The front slopes vary in height from fifteen to thirty or forty feet, being highest on the northeastern side of the plain, near the church, where the water into which the delta was built was deepest. The surface of the plain is very even, but rises gently towards the west and northwest. Near its margin on this side, it becomes slightly undulatory, and this topography probably marks the position of the edge of the ice when the delta was made. Coarser material appears with the undulatory topography.

The top of the plain has an elevation of about 525 feet, and, if it be a delta, there must have been standing water at about this elevation. Such a pond need not have been of long duration, and its area need not have been much greater than that of the delta. On the west side, the delta was built against a hill which limited the water in that direction. A little south of the plain, a recessional moraine (p. 355) crosses the valley, with an elevation of more than 530 feet, save where it is cut through by a tributary to the Papakating. This moraine was probably the confining barrier on the south side of the lake. South and southeast of the plain, and on the other side of the creek, the gravel and sand deposits rise to about the same height as the top of the delta plain. Their topography indicates that the ice was instrumental in determining their form, but they may have antedated the lake. Beyond these deposits rise high ridges of rock, so that drift or rock confined the lake in this direction. To the northeast, the retreating ice front must have been the confining barrier for the lake.

Between Frankford plains and Roy's station.—East of Frankford plains and just south of Armstrong station on the L. & N. E. railway is a marked group of kames. The highest have an elevation of about 520 feet, but the ice about which the kame materials were deposited was so irregular that even the suggestion of an aggradation level, which is often afforded by the flat tops of a number of kames at a common level, is not present. The hillocks are massive, and separated from one another by deep depressions, a vertical relief of forty feet or more being found within narrow limits. The gravel is composed chiefly of Hudson River sandstone and greywacke. Quartzite (mostly Oneida) and limestone also occur. In size the gravel ranges from small pebbles to cobbles.

Northeast of the above kame area, and separated from it by a narrow strip of till, is another plain of sand and gravel. This plain, however, differs from the Frankford plain in that its steep slopes and top bear the impress of the ice. The evenness of the plain-like top is broken by sinks and small kame areas, whose vertical relief varies from ten to thirty feet. Save on the sides of these kettles, and on the steep outer slopes, the surface is till-like, but the topography clearly establishes the stratified nature of the material. Adjoining this deposit of sand and gravel at lower levels, are areas of till. Glacial drainage flowing freely through the valley would have buried them, in aggrading the valley to the height of the gravel plain. The surroundings of the till areas are such as to preclude the supposition that an overlying cover of sand and gravel had been carried away by erosion. There can be no doubt, therefore, but that ice partly filled the valley when the gravel deposits were made, and prevented the till areas from being covered by the stratified drift.

South of Papakating station there is a well-marked kame area consisting of a few large, massive kames surrounded by smaller hillocks, and an undulatory deposit of fine sand. The maximum elevation is 531 feet, which is but little higher than the top of the gravel plain to the southwest (up the valley). The gravel is largely of shale, sandstone and greywacke (Hudson River), with some Oneida quartzite and occasional gneiss pebbles. Lower, poorly defined terraces are present in places along the stream.

Between Papakating and Roy's stations, the railroad makes a cut in one of the lower terraces. Its surface, which is twelve or fifteen feet above the rock, and distinctly separated from the alluvial plain, is hard and clayey, but it is more or less strewn with water-worn pebbles. In the cut, the pebbles are seen to be limited almost entirely to the upper layer, a foot or two in thickness. Beneath it is tenacious clay, almost, but not altogether, free from pebbles. It is not distinctly laminated, nor is it calcareous. It is possible that many of the lower terraces, whose surfaces are usually clayey, are composed of similar deposits. Such deposits of clay show that drainage was not free when they were made.

Half a mile south of Roy's station, is a poorly defined gravel terrace at an elevation of about 520 feet. Below the terrace, the slope of the valley is thinly till covered, and rock outcrops frequently. The terrace marks a point where the ice in the valley did not fit closely to the valley wall, and in the angle between the two, the gravel was deposited.

Roy's station to Sussex.—From near Roy's station to Sussex, deposits of stratified drift are not present on the east side of the Papakating. Kame terraces occur, however, on the west side at various elevations. Near Roy's station there are well-marked single kames at elevations not exceeding 450 feet. About a mile northeast, there are well-marked kame terraces between hills of shale. They have a maximum elevation of about 470 feet. Still farther northeast the gravel deposits become more massive, and reach greater elevations. A mile southeast of Woodbourne, where the Little Papakating joins the larger creek, the stratified drift forms broad, massive terraces about 120 feet above the brook. There is some difficulty in reconciling the heights of the different parts of the terraces as given by the topographic map, with determinations made by means of the hand-level. The terraces, however, seem to have an elevation of about 540 feet. Just north and east of the four corners, near the junction of the creeks, are two massive kames of loose sand and gravel. In height, the larger approaches the elevation of the neighboring terraces. Northward, the distinctive terrace topography disappears, but the gravel seems to extend as far as the upper Woodbourne-Sussex (Deckertown) road.

IN THE VALLEY OF THE LITTLE PAPAKATING.

The Little Papakating is formed by the union of several small streams from the steep eastward slope of Kittatinny mountain north of Beemerville.

Summary.

North of Beemerville kame terraces, presenting the various types of topography developed by deposition against ice, border the broad alluvial plain of the Little Papakating creek. At the Beemerville cemetery the stratified drift forms a flat-topped plain with few kettles, but farther north the kame terrace topography is strongly marked. These terraces are from 760 to 780 feet A. T. Another and lower set (720 feet) of kame terraces occurs near Plumbsock. These two levels do not grade into each other. East of Plumbsock kame terraces extend, with but slight interruption, almost to the Woodbourne schoolhouse. West of the brook two terrace levels are shown, one at 660 and the other at 630 feet. The upper aggradational level is represented by narrow terraces and isolated mounds, while the lower is more continuous. Both were developed while ice remained in the valley. The deposits of the upper level antedate those of the lower, and represent a period when the ice filled more of the valley.

East of Woodbourne, terraces have an elevation 560 to 570 feet A. T., 100 feet below the upper level of the Plumbsock area. These several levels of stratified drift in the valley of the Little Papakating do not grade into each other, and their great discordance is proof of independence of origin. They may or may not have been contemporaneous, but they were not made by waters flowing freely down the valley. Although the kame terrace topography is not of a strong type, the evidence is complete that ice clogged the valley while the terraces were being formed. The elevation of the kame terrace along the Little Papakating at Woodbourne (560 feet) connects it with the terraces southeast of Woodbourne (540-550 feet), in the valley of the Papakating.

Constitution.—The gravel is chiefly shale and sandstone, with a variable content of Oneida and Medina pebbles. The material is of all sizes up to cobbles. In some areas fine material predominates, while in others coarse and fine are associated. The lower terraces are commonly of finer material than the upper.

clearly marked levels. The upper (660 feet) is represented by narrow terraces, and more or less isolated mounds of loose gravel. The lower (630 feet) is more continuous than the upper, and its surface is more clayey. Since shallow and more or less circular depressions mark the surface of the lower terrace, it can hardly be assumed to have been carved by erosion from the higher. Since the upper level is represented only by narrow disconnected terraces, and isolated, flat-topped mounds, it would seem that the ice must have almost filled the valley when the gravel of the upper terrace was deposited, while the lower terrace was formed a little later, after the ice had so far melted as to occupy but little more than the depressions, the bottoms of which are now the valley swamps. The lower plain is best shown near the house of W. D. Haggerty. Here a well-boring penetrated sixty-five feet of stratified drift, most of which was fine sand.

The Woodbourne area extends from the creek a mile east of Plumbsock, to the Woodbourne schoolhouse, a distance of about a mile. It lies mainly on the northeast side of the creek. It has an altitude of about 560 to 570 feet, and is, therefore, between sixty and seventy feet lower than the lower plain of the Plumbsock area, and nearly 100 feet lower than the upper terrace. It cannot, therefore, be considered as a part of the Plumbsock area, although it was probably formed under similar conditions. This area is generally flat and terrace-like. The kame topography is nowhere developed, though some small, sharply marked kettles, and the general arrangement of the terraces around the irregularly shaped alluvial plain, indicates the presence of some ice, when the stratified drift was deposited. The terrace is best developed about an eighth to a half mile north of the schoolhouse. Here it forms a broad level plain with a maximum width of nearly half a mile. From the map it would appear to rise rapidly to an elevation of over 600 feet, but according to measurements with a hand-level, the elevation is not more than 580 feet. The surface is somewhat cobble strewn, but no bowlders are present. It has the clayey surface characteristic of stratified drift made up largely of shale.

The terraces of this area are not more than fifteen or eighteen feet above the brook. In places they have been undercut by the stream, and erosion slopes developed. Stream erosion, however, does not seem to account for the irregular outline of the alluvial plain, for its sudden widenings and narrowings, for the sinks which occasionally occur on the slopes of the terraces, nor for the fact that only where the alluvial plain is very narrow, or where the present course of the stream is close to the terrace, are there normal erosion slopes. All these phenomena are accounted for, if ice was present in the axis of the valley when the deposits were made.

At Woodbourne, the gravel deposits are absent for a short distance, but they re-appear about a quarter of a mile east of the Woodbourne schoolhouse, at an elevation of about 560 feet, and are, therefore, to be correlated with the terraces above Woodbourne. They are fairly well developed, although in places their continuity is broken by erosion gullies. Although they have very nearly the same absolute elevation as those above Woodbourne, yet because of the greater depth to which the stream has here cut in post-glacial time, they are much more conspicuous topographic features.

STRATIFIED DRIFT IN THE VALLEY OF CLOVE RIVER.

Summary.

The Clove river joins the Papakating creek from the north at Sussex (Deckertown). Gravel deposits occur more or less continuously on one or both sides of its valley for several miles north of Sussex. Generally they reach down to the alluvial plain, but occasionally the gravel forms small terrace-like patches on the side of the valley well above the alluvial plain. Evidence is not wanting that the deposits of this valley, like those of all the other valleys of the region, were made when more or less ice remained. The discontinuity of the terraces, their occasional occurrence high on the valley sides, the topography of the steep slopes of the stratified drift, the deep sinks, and the kame-like topography which is often present, is the basis for this inference.

Well defined kame terraces and stagnant ice forms are found in the valley of Clove river, (1) along the Sussex-(Deckertown) Montague turnpike, a mile and a quarter above Sussex; (2) at the Clove cemetery, two and a half miles above Sussex, and (3) a third of a mile above the cemetery. Isolated mounds and small terraces occur at numerous other points along the brook, either in the bottom of the valley or high on its sides.

The gravel of the valley is chiefly of Hudson River shale, and sandstone. In places it is slightly calcareous. This is shown chiefly by the calcareous incrustation which sometimes coats the pebbles. In general, the surface is rather clayey, although waterworn pebbles are often abundant. It is rarely loose and sandy, save on the crests of the knolls and on the steeper slopes. Near Sussex are several exposures of lacustrine clay in a terrace a few feet above the brook.

The upper surface of the stratified drift of the valley does not possess a continuous aggradation level. Near the Sussex turnpike the terraces reach an altitude of 550-560 feet; at Clove, the level is a little over 540 feet; and about the same height is attained a mile and a quarter farther north. Although these elevations do not agree very closely—the first being too high, and the last not high enough—accurate leveling might show that the disconnected terraces are less discordant than they appear on the map.

The amount of post-glacial erosion along the Clove river is inconsiderable. It probably nowhere exceeds fifteen feet in vertical measure, and is usually much less.

Local Details.

On the outskirts of Sussex there is a well-marked terrace about thirty feet above the stream. It is in part, at least, composed of clay deposited in standing water. The uppermost foot or two is stony, the stones being small and waterworn. Beneath this there is four to five feet of clay, interstratified with layers of fine loamy silt. The silt layers are thicker than those of clay, though both are thin, so that the deposit is distinctly laminated. There were formerly clay pits near the old mill pond, from which considerable clay was dug for the manufacture of bricks. Clay apparently forms the material of the terrace as far north as Fuller's mill. The same terrace is continued northward from Fuller's mill, but the material is more stony. On the opposite side of the stream is a terrace at about the same level, but in the absence of exposures, its constitution was not determined. The elevation of this clay deposit is about 460-480 feet, forty to sixty feet greater than that of the clay near Roy's station. The explanation of these clays is to be found in obstructed drainage. Clove river has its outlet into the Wallkill, but after the Clove valley was free from ice, the valley of the Wallkill farther north was still occupied by it, and standing water in the valleys above the obstruction, was the result.

Near Fuller's mill, small gravel deposits occur as ill-defined terraces at heights eighty to 100 feet above the stream. North of the Milford-Sussex pike, on the west side of the stream, the gravel deposits form a conspicuous kame terrace, which the contour map fails to show. It rises abruptly 100 feet above the alluvial plain. The stream is cutting laterally into its face, and the slope is as steep as the loose gravel will lie. Back from this steep face, the surface is flat, or rises slowly towards the hills, against which the terrace material was deposited. Its bluff margin appears to have an elevation of about 550 to 560 feet, and its valley margin one of 540 feet. The evenness of the top is broken by depressions. A gravel pit in one of the lower knolls near the outer face of the terrace shows the material to be rather coarse gravel, composed almost entirely of Hudson River shale and sandstone. A few of the pebbles are coated with calcium carbonate, but no limestone pebbles were found.

On the east side of the stream opposite this terrace there is but little gravel. A low terrace corresponding to the clay terrace below Fuller's mill is present, but it is composed of earthy gravel. Here and there on the hillside above the plain are small, ill-defined terraces of gravel, formed where the ice did not fit closely to the hillside. Farther north, the terrace is somewhat better developed on the east side of the stream than on the west.

One of the best exposures along Clove river is near the schoolhouse two miles north of Sussex. The gravel is exposed to a depth of about fifteen feet. Ninety to ninety-five per cent. of the material is from the Hudson River formation, either shale, slate, or sandstone. There are a few Oneidas and Medinas. No limestone was found, although some of the shale pebbles are incrusted with calcium carbonate. The lime, however, may have been derived from the Hudson River sandstone, some beds of which are calcareous. A striking feature of the gravel of this cut is the slightly irridescent bronze color of the shale pebbles. This coloration has been noted in other localities. Its significance, if it has any, is not known. The whole mass of gravel is earthy. The pebbles are often coated with clay, and the whole made compact by a clayey matrix. This exposure is typical of a large part of the shale gravel of Sussex county.

At Clove, two and a half miles north of Sussex, kame terraces are well developed. In and about the cemetery the topography is strongly kame-like, undulations of twenty feet being common. The aggradation level is here a little above 540 feet. For a mile above Clove, the gravel is present in varying amounts and at varying elevations. Well-marked terraces and characteristic kame topography are, however, absent.

About a mile and a quarter above Clove, a flat-topped, slightly triangular, spur-like mass of gravel projects out into the valley from the west. The material seems to have been deposited in a crevasse in the ice.

Deposits of gravel occur along the stream for more than three miles above Clove. They occur either as isolated mounds or discontinuous terraces. In general, their elevations accord with one another, and with those of the higher terrace below Clove, indicating that the deposits were not entirely independent of each other in origin. Deposits of equal volume were not made all along the stream, owing to the obstruction caused by the ice. Because of the rapid rise of the bed of the stream northward, the terraces are not so high above the stream as the corresponding terraces nearer Sussex.

STRATIFIED DRIFT IN THE VALLEY OF BEAVER BROOK.

Beaver brook heads in a swamp near Kerr's corners. Its course is southwestward, through Silver lake, Hope and Sarepta, to the Pequest river, a short distance above Belvidere. Stratified drift occurs in its valley almost continuously from the Pequest to Hope, but above that point it has little development. The gravel is composed largely of shale bits, and is more or less clayey. Its surface is generally clayey, save on the crests of knolls and steep slopes. Although there are no considerable exhibitions of the peculiar topography developed by the deposition of gravel against ice, as in the case of some of the other valleys of northwestern New Jersey, yet evidence is not wanting that this valley, too, was somewhat obstructed by ice during the deposition of its stratified drift. There are traces of an aggradation level at an altitude of 440 feet north of Silver lake, at 415–420 feet two miles above Sarepta, and at 360 feet at the moraine below Sarepta. Nothing in the deposition of this drift affords evidence that the ice front halted in its retreat through the valley.

The inner margin of the terminal moraine touches the brook about a third of a mile south of Sarepta. In the angle between Beaver brook and the Pequest, the moraine is largely of gravel (kames), and the topography resembles that assumed by gravel deposited around standing ice, where an aggradation level is not well developed. This part of the moraine complex was probably formed by the action of streams issuing from the somewhat irregular margin of the ice. Between the moraine and Sarepta, the gravel forms wide, flat-topped terraces, whose elevation is a little less than 380 feet. In places they are gently undulatory, but not markedly so. Above Sarepta, the gravel assumes the form of kame terraces, or of kame areas.

Midway between Hope and Sarepta the area of stratified drift widens out, forming a broad undulating terrace on the north side of the brook, at an elevation of about 380 feet. On the opposite side of the stream, however, the gravel reaches an elevation of nearly 420 feet, and the topography is somewhat kame-like. Excavations show a fine, clean, clayless gravel, composed mostly of shale.

Half a mile south of Swayze's Mills, on Honey run, a tributary of Beaver brook, are deposits of clayey shale gravel, of kame-like habit. They have an elevation of about 410 feet, and are nearly surrounded by humus and alluvial deposits, above which they rise but a few feet. Still farther north, on Muddy brook, half a mile south of Mount Hermon, are small, terrace-like forms which probably were built between ice blocks.

Between the junction of Honey run with Beaver brook and Hope there are no prominent deposits of gravel. The alluvial plain is wide. Bordering it is a low terrace of varying width, which is probably of stratified drift. The relations of the terrace to the alluvial plain, particularly near Hope, suggest that the gravel was deposited around ice which occupied the low ground of the alluvial plain. Since the melting of the ice, the stream has partially filled the depression thus formed.

Between Hope and Feebletown, small terrace deposits of clayey gravel occur on the borders of the swamp through which the stream flows. At the northern end of Silver lake there is a gently undulatory terrace plain of gravel, rising above both the swamp and alluvial plain on the west, and the till on the east. It is thus distinctly set off topographically from its surroundings. No gravel deposits are found along Beaver brook above this terrace.

STRATIFIED DRIFT OF THE PEQUEST SYSTEM.

Summary.

Distribution and history.—The stratified drift in the Pequest and adjoining sub-valleys is more extensive than in any other valley system of the Appalachian province. The deposits were formed under varied conditions. In many places the topography and the disposition of the stratified drift are such that the history of its deposition can be readily made out. The accompanying profile (Fig. 3, Plate LII) gives a generalized view of the slope of the deposits, and the present drainage lines between Danville and Sussex (Deckertown). This profile helps to the understanding of the history of the deposition.

The terminal moraine occupies much of the valley between Danville and the Delaware. Between Pequest furnace and a point a mile south of Townsbury the moraine lies north of the valley, but previous to its formation, the ice advanced temporarily to Oxford or beyond. As this protrusion of ice melted, and while it still occupied a part of the valley, the gravel deposits between Oxford and the moraine were formed, and disposed under the influence of ice. Its influence on the disposition of the drift is best seen in the high-level, terrace-like ridges near the Warren county poorhouse, probably formed in crevasses. All the stratified deposits north of the moraine were of slightly later origin.

At Danville the moraine formed a dam across the valley at an elevation of about 550 feet. This dam brought a shallow lake into existence over the area of the Pequest meadows and the Quaker Settlement, as far northeast as Tranquility. Its maximum length was about eight miles and its greatest width two. At the Quaker Settlement the lacustrine deposits consist of fine sand and silt, ranging up to an elevation of about 550 feet, or a little less. When these deposits were made the ice had withdrawn some distance to the northward, and there is little evidence that even isolated ice blocks remained. Lacustrine deposits doubtless underlie the humus of the Pequest meadows.

Small kames of coarser materials, and of different lithological constitution, rise to heights not exceeding twenty feet above the general level of the lacustrine deposits, which they antedated, and by which they were partly buried. Knobs of limestone, practically bare of drift, rise above the general level of the plain, and probably constituted islands in the lake.

The glacial drainage which poured into the Pequest lake entered from two main lines. One was along the valley followed in part by the Pequest river, through Huntsville, Andover Junction, Pinkneyville and Germany flats to the Wallkill valley near Hamburg. The other main line was along the valley of Bear creek, through Johnsonburg, Hunt's Mills, and thence to Newton. These two belts of stratified drift are connected by a narrow cross belt between Springdale and Huntsville. The profile given on Plate LII, Fig. 3, follows the line first mentioned.

As is there shown, the deposits rise somewhat regularly and gradually from an elevation of about 550 feet at the upper edge of the Settlement to a height of 615 or more near Huntsville. Just above Huntsville the high terrace (615-620) plays out against the hillside.

Above Brighton a new terrace level appears at 583 feet, and extends north through Springdale to the plain southwest of Newton, where its altitude is 630 feet. The same level also extends northeast to Germany flats, rising steadily in that direction. The ending of the higher level near Huntsville and Brighton, and the beginning of the lower terrace to the north, point to two stages in the formation of these deposits. During the first stage the edge of the ice lay near Brighton, though there is no recessional moraine. At this time the gravel below Brighton and Huntsville was deposited. Somewhat later, after farther retreat of the ice, the deposits north and northeast of Brighton were made. According to this interpretation, the gravel deposits from Brighton and Huntsville to the Pequest meadows were made at about the same time, those of the Settlement being lake deposits, and those between the Settlement and Brighton, the deposits of streams.

The second section of the stratified drift, from Brighton on the south to the recessional moraine on the north, likewise seems to be a unit. It rises steadily from an elevation of 583 feet near Brighton to 660 feet at the outer border of the moraine at Lake Grinnell, the rise being essentially regular. It should be remembered, however, that the line in the profile (Fig. 3, Plate LII) does not always represent the actual surface of the terraces, but rather the original aggradation level which is found by combining the adjacent maximum elevations of the terraces.

The moraine at Lake Grinnell marks a well-defined pause in the ice retreat. While deposits were doubtless being made along the valley outside the ice during its retreat from Brighton to the moraine, the leveling up of the valley to a common aggradation level, probably occurred while the edge of the ice was making the recessional moraine. Large ice blocks still lay in the center of the valley, and the stream deposits were made around them. The sites of the largest of these blocks are now marked by the ponds and marshes from Andover Junction to the moraine. Long pond is reported to have a depth of more than 100 feet.

For a mile above the moraine, massive kames and kame terraces border the stream. They may have been contemporaneous with the moraine in origin, but probably were formed a little later.

South of Johnsonburg, in the second main belt of stratified drift above the Pequest Meadows, the deposits of gravel and sand form a broad plain having an elevation at its lower end of about 550 feet, but rising northward to 580 in the vicinity of the village. The aggradation level ascends northeastward along Bear creek, reaching a height of about 632 feet in the vicinity of Huntsville. Still farther northeast it attains an elevation of 639 feet, but still farther north it appears to be slightly less. Per-

Fig. 70.

Kame terraces south of Drake pond, near Newton.

haps the gravel, from near Hunt's Mills to a point below Johnsonburg correspond in time of deposition to the gravels from Brighton southwest; while the gravels between Hunt's Mills and Newton, with an aggradation level between 620 and 640 feet, correspond in time of origin to those between Brighton and the moraine in the other valley. Data are, however, not definite enough to warrant positive assertion.

Types of topography.—Broad plains formed in standing water are represented by the Quaker Settlement plain. Terrace plains slightly pitted with kettles, but in general having the configuration of normal stream deposits, occur along the Pequest, and on the line of the L. & H. R. railway, southwest of Huntsville. The greater part of Germany flats shows the same type of topography, but here the plain is interrupted by extensive ponds and swamps. The same type of topography occurs south of Johnsonburg and north of Springdale, though the surface here is less even. Kame terraces, comprising kettles, winding ridges, and narrow terraces bordering the rock hills, are well developed east of Huntsville and Brighton, about White, Hewitt, Long, and Drake ponds (Fig. 70). This type of topography was developed where drainage was interfered with by residual bodies of ice which occupied parts of the valley, after the main front of the ice had receded to the north. Between the northern end of Bear swamp and Newton, *via* Muckshaw pond, a distance of over three miles, various types of topography resulting from the deposition of stratified drift against ice, occur. Large kettles and flat-topped kames are common. Over much of this area, also, limestone bosses project through the gravel plain.

Near Brighton, there are good examples of bare rock ledges at levels lower than the gravel deposits, and in localities where erosion cannot be supposed to have removed the stratified drift. The ledges must have been covered by the ice when the gravel terraces about them were deposited. Near Hunt's Mills, also, the stratified drift is surrounded by irregular hills of limestone, and knolls of rock project up through it.

Discordance between glacial drainage and present streams.—The disposition of the stratified drift shows that the glacial drainage did not altogether conform to that of the present time. The glacial streams flowed southwest, as is shown by the slope of the deposits they made. In some localities the present streams flow in directions opposed to this slope. This is shown on the profile (Fig. 3, Plate LII). The southwestern part of Germany flats is drained by a branch of the Pequest, whose headwaters are just above Iliff pond. The central part of the flats is drained by two streams, one flowing southwest, the other northeast. The upper part of Germany flats drains into the Wallkill in a direction contrary to the slopes of the terraces. These streams were located not by the slope of the surface of the terraces, but by the slope of the lowest passages along the valley, at the time the ice melted.

The present drainage would doubtless have corresponded with that of glacial times, if masses of ice had not lain in the axis of the valley while the deposition of the gravel and sand was going on. The melting of the ice at a later time interrupted the southward slope which existed while the ice masses remained, and the streams adjusted themselves to the new slopes.

Constitution of the gravel.—The bulk of the gravel in the Pequest system was derived from the Hudson River formation close at hand. Limestone pebbles and cobbles are abundant in some exposures, but their abundance is variable. The larger stones are mainly from the Oneida and Medina formations, especially the former. A few gneiss pebbles also are present. The gravel is generally well water-worn, but striated cobbles are not entirely absent. Occasional masses of till are included in the gravel, but such occurrences are rare. In size, the material varies from fine sand to coarse gravel, layers of extreme diversity being often closely associated. Where the topography is irregular, the materials are likely to be coarser and less well assorted. Over much of the area the surface is clayey. The greatest known thickness of the gravel is forty-five feet, at which depth its bottom was not reached.

Post-glacial erosion.—The greatest amount of post-glacial erosion in the region is where the Pequest river crosses the moraine between Danville and Townsbury. The vertical cutting does not exceed forty-five feet, and may be a little less. The width of the gorge is between 100 and 200 yards. Above the moraine, the Pequest and its tributaries have done no considerable cutting. Locally the erosion may amount to a few feet, but for most of their courses the streams have been silting up the swamps and ponds along their courses.

Local Details.

Belvidere to the Pequest meadows.—Between Belvidere and the mouth of Beaver brook, the course of the Pequest river is through deposits of stratified drift which belong to the Delaware valley as much as to the Pequest, and are described in that connection. From Beaver brook to Pequest furnace, the stream flows through the terminal moraine, composed in considerable part of stratified drift. Between Bridgeville and Buttzville, the stream is bordered by low terraces, which were probably developed after the ice departed.

At Pequest furnace the moraine swings out of the valley and lies on the northern side of Mt. Mohepinoke, but at Townsbury it re-enters the valley, and extends down stream a mile below the village. Evidence is not wanting that at some time, perhaps immediately preceding the formation of the moraine, a body of ice advanced down the valley from Townsbury as far as Oxford. As this ice melted from the hill-side against which it abutted, kame terraces were formed in favorable localities between the ice and the valley wall. The most marked examples are the high terraces (520 to 540 feet) near the Warren county poorhouse, nearly two miles south of Townsbury. A third of a mile north-east of the poorhouse, a broad, flat-topped ridge, fifty to eighty or ninety yards wide, rises twenty-five to thirty-five feet above the surrounding deposits of stratified drift. Kame-like knolls are associated with it on the northeast, while on the northwest there are broad terraces with pitted surfaces. This ridge may represent a crevasse filling.

In addition to the high terraces near the poorhouse, and the crevasse deposit just mentioned, several kame-like mounds rise above the general level of the stratified deposits. They are taken to represent accumulations at the margin of the ice at localities which, for reasons now unknown, were favorably situated for receiving deposits.

The stratified drift of the valley is continuous from the moraine south of Townsbury, to Pequest furnace, and the northern edge of the meadow near Oxford. With the exception of the higher points already noted, the general level is 500 feet or less. The surface is everywhere more or less undulatory, probably the result of remnants of ice which still lingered in the valley, when the gravel and sand were deposited.

Near the moraine, the stratified drift is traversed by a number of old drainage lines, marked, aside from their topography, by great numbers of bowlders. All these abandoned channels can be traced in either direction to the present channel of the Pequest.

Between Townsbury and Danville the terminal moraine occupies the valley, filling it to an average height of between 540 and 560 feet.

Pequest lake.—Between the Pequest meadows and Townsbury, the river flows through a post-glacial valley cut in the moraine. The depth of the post-glacial cutting can be determined approximately. If this post-glacial valley were filled, the conditions which existed at the time of the withdrawal of the ice would be reproduced. At that time the lowest point in the crest of the moraine was between 540 and 560 feet A. T. Since this is somewhat higher than the area of the Pequest meadows (514 to 531 feet) it follows that a lake must have existed north of the moraine when the ice first withdrew. If the surface of the lake had an elevation of 550 feet, its maximum depth could not have exceeded thirty-six feet, plus the depth of the filling which the lake area has since received, a filling accomplished partly while the lake was in existence and partly since. Its maximum length was not more than eight miles, and its greatest width not more than two. This extinct lake may be called *Pequest lake.*

The lake came into existence when the ice withdrew from the moraine. Its surface was lowered as the outlet across the moraine at Danville was deepened, and it ceased to exist when this outlet was lowered to the level of the meadows. Since the cutting of the outlet through the moraine was probably rapid, the life of the lake was short. Owing to its shallowness, its comparatively small size, and its short life, shore features were not developed. This lake bed was recognized as early as 1880 by Prof. Cook.[1]

From Pequest meadows to the Quaker Settlement.—From the northeastern edge of the Pequest meadows, stratified drift can be traced, with slight interruptions, for several miles. In general it forms two, and sometimes three, parallel belts. The main belt lies along the northeast-southwest valley followed in part by the Pequest river, and passes through Huntsville, Andover Junc-

[1]Annual Report State Geologist 1880, pp. 32-73.

tion, Pinkneyville, to Germany flats. The L. & H. R. railroad follows the natural grade established by the deposits along this line of glacial drainage. The second belt is along the valley of Bear creek, a tributary to the Pequest, through Johnsonburg and Hunt's Mills, and thence along the low land to Newton. These two belts are connected by a narrow cross belt between Springdale and Huntsville.

The area of stratified drift lying northeast of the Pequest meadow and west of Allamuchy, is known as the Quaker Settlement, or simply as the Settlement. The general level of this area is about 550 feet, although in places it falls a little below 540 feet. Its lowest parts are more or less swampy. Above the humus deposits, the surface is gently undulating, and composed of fine, yellow sand, which in places approaches a silt. The sand is likely to be a little coarser on the crests of the swells than elsewhere. Pebbles are few and small, and often altogether wanting. Most of the few which do occur are of shale, though there are occasional limestones and gneisses. The depth of this deposit is not known. The deepest wells do not go down more than twenty feet, and do not reach the bottom of the sand, which, at a depth of five or six feet, is described as "quick."

In the shallow depressions between the swells, the surface is generally covered with black-loam, composed largely of vegetable matter. Where not ditched and drained, these depressions are somewhat marshy. The humus layer is rarely more than three feet thick.

The plain is interrupted by elevations of two sorts, namely, protruding masses of limestone, and small kames. The former are of various heights and sizes, and essentially free of drift. The kames are rarely more than ten or twenty feet high, and are composed of material much coarser than that of the plain. The kame material is in general poorly rounded, poorly assorted and poorly stratified. Most of it is limestone and chert, but shale, Hudson River sandstone, Oneida and Medina quartzite and sandstone and gneiss are also present.

Excavations in the fine sand of the plain are not common. The best exposure was found near the Long Bridge depot on the L. and H. R. railroad. Here the sand is composed chiefly of quartz grains and fine bits of shale, the upper two and a half feet being discolored by the oxidation of the iron in the sand. The fact that the sand is partly of gneissic origin (the quartz having been derived from the gneiss) would imply a ferruginous content sufficient to cause the observed amount of discoloration. Lime carbonate appeared to be wholly wanting.

The kames were formed before the development of the surrounding plain, the material of which partly buries them.

The plain rises slowly to the northeast, towards Tranquility church. Near the Tranquility stock farm it has an elevation of about 560 feet. As this elevation is approached, the material changes from sand to fine gravel. So far as determined the fine sand does not extend much above 550 feet, the height of the moraine at Danville, and the maximum elevation to which the moraine dam could have held a lake in the low country to the north. The fact that the fine sand and silt deposits are limited, so far as known, to the area which the lake might have covered, lends further support to the theory of its existence.

Between Johnsonburg and Newton.—Northeast of the Pequest lake, from Johnsonburg through Hunt's Mills (Washington) to Newton, there is a considerable belt of stratified drift along a line of glacial drainage.

Bear creek, the tributary of the Pequest which drains Hunt's pond, is joined by another stream about a mile south of Johnsonburg. In the angle between these streams is a broad plain of fine gravel. Its surface is but slightly broken by shallow depressions or low knolls. Its elevation near its southern margin is 550 to 560 feet, but it rises gradually to about 580 feet near Johnsonburg. The topography and disposition of this drift do not indicate the presence of ice in quantity during its deposition. A mile southeast of this plain, and half a mile south of the Johnsonburg-Allamuchy road, the topography characteristic of deposits made by water under the influence of standing ice is well shown. The wide areas of low, swampy land adjacent to these and associated terrace deposits are not due to post-glacial erosion, and probably indicate areas where ice stood when the deposits of stratified drift were made.

Terraces of stratified drift, presenting to a greater or less extent the topography of kame terraces, are present along the stream at Johnsonburg and for a mile above. The present course of the stream was probably located by a line of sinks left when the ice blocks, which occupied them, melted, after the deposition of the material of the terraces. A number of limestone ledges rise above the plain, but the gravel is often thick close to them. The well at the Johnsonburg hotel, within two or three rods of the point where the gravel abuts against a limestone ledge, penetrated more than forty feet of stratified drift without reaching its bottom.

The main train of gravel along Bear creek is continuous with the plain south of Johnsonburg. The gravel forms terraces twenty-five to thirty feet above the stream. Both circular and elongate depressions occur in these terraces, but they are rarely more than five or ten feet deep. Towards Hunt's Mills, the outline of the area of the stratified drift is exceedingly irregular, owing to the outline of the surrounding limestone hills, to the numerous bosses of limestone which rise above the plain, and finally to the humus filled hollows in the plain itself. In general the topography of the terraces has the undulatoriness characteristic of deposits built against ice. Striking examples of such topography may be seen three-fourths of a mile due east of Hunt's Mills on the road to Huntsville. The surface material of the terraces is generally rather loose and gravelly, though this is by no means universal. The gravel is rather fine (pebbles mostly under three inches.) Fully nine-tenths of the finer material was derived from shale, and the thin, disk-shaped bits are sometimes firmly imbedded in a clayey matrix, even where the material is clearly stratified. Between Hunt's Mills and Johnsonburg, the surface of the stratified drift has a gradient of about eighteen feet per mile, while that of the present stream is about sixteen feet.

A little more than a mile east of Hunt's Mills are extensive kame terraces at the southwestern extremity of the swamp which stretches northeast to Springdale. These terraces, although continuous with those along Bear creek, are now drained by another tributary of the Pequest, which flows to the northeast, but the glacial stream which deposited the drift probably flowed to the southwest. For much of the distance along the margin of this swamp, stratified deposits are wanting, but towards its northern end there are kame terraces at about the same height as those near Hunt's Mills. From this point they extend northeastward to Newton. The aggradation level, which in general is well shown, has an elevation of between 620 and 640 feet between the swamp and Newton.

The stratified drift about Newton has a most irregular outline, the result of the character of the pre-glacial topography. The underlying rock is limestone. In pre-glacial times, stream erosion and solution by ground water had developed deep and tortuous valleys, and probably undrained hollows. The stratified drift was deposited in the depressions, and around the hills and knolls (Plates LVIII and LIX in pocket). The result is that the outline of the gravel area is approximately the outline of an area bounded by the 630-foot contour. The hills and knolls of limestone which limit the deposits of stratified drift, or which rise as islands above its level, appear on every hand, and are nearly bare. To cultivate them is impossible, and they are usually left in timber where there is soil enough for trees to get a foothold. The gravel areas, on the contrary, furnish good agricultural land. Along this belt, therefore, the limit of stratified drift is essentially the limit of the cleared land, though this is not the case where the gravel is bordered by shale instead of limestone.

Various types of topography are represented in the different parts of this area. North of Springdale, along the road to Newton, the gravel forms a broad level or gently sloping plain, with its surface rarely relieved by shallow depressions or gentle swells. About midway between Springdale and Newton, the plain becomes pitted by depressions, large and small, the largest being the "Devil's hole," on the Babbitt estate. Still nearer Newton, the gravel forms narrow terraces against the sides of the hills, and flat-topped winding ridges of about the same elevation. Inclosed by the terraces and ridges are irregular depressions and sinks. These sinks often have a linear arrangement, and are separated from one another by ridges of gravel, somewhat lower than the bordering terraces. In the southern part of Newton, the topography of the gravel deposits is kame-like, hillocks and kettles having a relief of twenty-five feet following each other in rapid succession, without apparent tendency to approach a common level.

This same undulatory topography, with here and there a small terrace showing the aggradation level, is well developed in the vicinity of Drake pond, southeast of Newton (Fig. 70, p. 393). The pond lies in a large kettle, which probably marks the former position of an ice block. The inequalities in the outline of the ice at the time the stratified drift was deposited, are reflected in the topography of the sides of this basin. Topography resulting from stagnant ice is also well shown along the narrow belt of gravel between Drake and Stickle ponds. The characteristic narrow terraces, flat-topped mounds and ridges are also well shown around Muckshaw pond, which, like Drake pond, lies in a hollow occupied by an ice block, while the surrounding stratified drift was deposited. Kame terraces are also well developed two miles southwest of Muckshaw pond.

Shallow road-side excavations, a few sand and gravel pits. and the cuts along the Sussex railroad near Newton, afford opportunities for studying the composition, size, amount of wear, and oxidation of the gravel. The bulk of the gravel is composed of shale, sandstone and greywacke derived from the Hudson River formation. Limestone pebbles and cobbles are abundant in some places, but are almost entirely absent in others, while many of the larger cobbles are of Oneida quartzite and Medina sandstone. Gneiss pebbles are present, although not in great numbers, and not in every exposure. The gravel is generally well worn. Striated cobbles are present, but not abundant. At a few localities, notably near Drake pond, masses of till are included in the gravel. The material varies considerably in size. In some exposures fine sand, or even silt, is inter-stratified with moderately coarse gravel; in others there is much greater uniformity. There seems to be some relationship between the strength of the kame topography and the coarseness of the gravel, the coarser material going with the rougher topography. Cross-bedding is common. Oxidation has usually penetrated to a depth of three or four feet, as shown by the discoloration of the surface layer, and, where the body of the gravel is calcareous, by the absence of lime carbonate from the discolored portion.

Over much of the area the surface is clayey. This is particularly the case in the broad hollows of the plain, and less commonly of the surface of the terraces. In the depressions, the clayey nature of the surface might be regarded as the result of the wash of the finer material from the slopes above. The clayeyness of the higher surfaces seems, however, to be connected with the closing stages of deposition.

The maximum depth of the gravel of this area is not known, since the deepest wells rarely reach its base. The greatest known thickness is forty-five feet, but at this depth the bottom of the gravel was not reached.

Between Quaker Settlement and Germany Flats.—A second considerable belt of stratified drift extends northeast from the Quaker Settlement to Germany flats and beyond. Its easy grade is followed by the L. & H. R. railroad, as far as the north end of Germany flats. Through a part of its course, the belt is partially separated by long, till-covered hills into two or three narrow belts.

From Quaker Settlement, kame terraces occur along the Pequest, with some interruption, as far as the mill-pond at Tranquility. The topography is in places very undulatory, with a relief of twenty feet within narrow limits, while in other localities, an aggradation level is well developed, at about 560-570 feet. This is well shown near the mill-pond. The gravel of these kames and kame terraces is coarse, and composed largely of limestone. In places along the river the low terraces (below 540 feet) of sandy loam are correlated with the sands and silts of the Settlement plain.

From the Tranquility mill-pond to Huntsville, the stratified drift forms wide, gently undulating terraces on both sides of the river. On the right bank, the terrace is about twenty-seven feet above the stream, and higher near the stream than back from it. Two terraces are present on the left side of the valley for some distance below Huntsville, the higher being about thirty-five and the lower about twenty-five feet above the stream.

The best exposure of these gravels is at a pit on the right side of the valley, nearly a mile below the mill-pond at Huntsville. Save for a surface layer of clayey gravel, the material is loose sand and fine gravel, distinctly stratified. The beds dip 30° away from the brook. The gravel is rather fine, though cobbles are not wanting. Among the pebbles, limestone is most abundant, and Hudson River shale and sandstone next. Bits of gneiss, chert, and sandstone and quartzite from Kittatinny mountain, make up the remainder. The finer material is mostly from the shale. As a whole, the gravel is fresh and unweathered. Notable oxidation, and leaching of lime carbonate have affected the gravel to the depth of two or three feet only from the surface.

A second belt of stratified drift stretches southwest from Huntsville along the line followed by the railroad. Its surface is generally level, or but gently undulatory. Near Huntsville station, however, it is broken by several large depressions twenty to thirty feet deep. The general level of the plain near Huntsville station is between 610 and 615 feet, and it declines slightly to the southwest. Several cuts along the railroad show that the gravel is very largely of limestone, but that shale, gneiss, Oneida quartzite and Medina sandstone are present. The surface is sometimes loose and gravelly, and sometimes firm and clayey.

A third belt of gravel terraces is found along the stream at the foot of Allamuchy mountain northeast of Tranquility. These terraces are continuous to the southwest with the low plain of the Settlement. The topography varies somewhat in different parts of the belt. It is generally nearly level, or but gently undulating. Locally it is interrupted by small sinks, and towards its northeastern limit, east of Huntsville, kame-terrace topography becomes marked. Buckmire pond occupies one of the largest of the numerous depressions. East of Huntsville the gravel attains a maximum elevation of 620 feet, although the general level of the plain is a little less. The surface declines to the northwest, and near the Tranquility church the terrace has an elevation of about 585 feet.

Between Huntsville and Brighton, and southeast and east of these places, the deposits of stratified drift wind in and out between the limestone hills, their upper surface being limited approximately by the 650-foot contour. Depressions in the surface are common, and in places the flat-topped terrace topography gives place to an orderless succession of hillocks and hollows characteristic of kame areas. This type of surface is well shown a fourth to a half mile southeast of Brighton. Turtle pond lies in one of the large depressions, probably the site of an ice block, when the gravel was deposited. In the same vicinity are other proofs that the stratified drift was deposited about lingering masses of ice. Close to the margin of the swamp (an ice-block depression) are numerous outcrops of rock. Near them, but at higher levels, are the terraces of stratified drift. The stream appears to have done no post-glacial cutting, and so cannot have uncovered the exposed rock. It appears therefore that when the gravel was deposited, the ledges were covered by ice, and therefore not buried by the stream deposits.

A gently ascending plain of sand and fine gravel extends north from Brighton for nearly a mile, divided by the swampy, alluvial plain of a tributary to the Pequest. Its continuity is also interrupted by several limestone ledges, nearly free from drift, which rise above it. Its elevation is slightly less than 590 feet, about twenty-five feet lower than the kame terraces south of Brighton. It is nearly level, being interrupted by only a few shallow sinks. It must have been formed under conditions of somewhat freer drainage than the kame terraces near Brighton, and perhaps a little later. This terrace is continued along the right bank of the Pequest for a mile south of Springdale. The gently undulating plain, which stretches north from Springdale to Newton has an elevation but slightly greater, although it rises gradually to the northward. This belt of stratified drift shows that one line of glacial drainage was along the low land south of Newton, by way of Springdale, to Brighton. Another glacial stream branched from this a little north of Muckshaw pond, and flowed southwest towards the swamp between Springdale and Hunt's Mills. Whether the gravel deposits in the vicinity of Hunt's Mills (p. 400) and to the southwest were formed by the same glacial river, and are contemporaneous with the deposits southwest of Muckshaw pond, is a little uncertain. Their corresponding elevation suggests community of origin.

Gravel deposits continuous with those which extend north from Brighton are found between the limestone hills in the vicinity of Davis and White ponds, one to two miles north of Andover Junction. The gravel here forms kame terraces, the surfaces of which are more or less broken by depressions. The ponds occupy the largest of these depressions, and the gravel forms narrow terraces around them. The surface is generally clayey, and the gravel is largely of shale. The plain, where best marked east of Davis pond, has an elevation of about 605 to 608 feet. At one point a well eighteen feet deep reaches the underlying rock, but in many places the gravel is much deeper.

A narrow, steep-sided valley extends northeast from Andover Junction. About a mile south of Pinkneyville it broadens very considerably, attaining a maximum width of a mile and a half north of Woodruff's gap. The striking feature of this valley is the string of long, narrow ponds and swamps which it contains, extending from Andover Junction to Monroe, a distance of more than ten miles. In the narrow part of the valley, below Pinkneyville, the ponds are larger and more numerous than in the wider part. These ponds, even where the valley is narrowest, are generally surrounded by stratified drift. In one or two localities the rock slope of the valley forms a part of the shore of the pond, but this is the exception rather than the rule. The gravel about the ponds generally assumes the form of narrow, undulatory-topped terraces, twenty to twenty-five feet above the water. The steep terrace slopes are often undulatory. A series of ice blocks probably lay in this valley in the depressions now partially filled by the waters of the ponds and the humus of the swamps. Between these blocks of ice, and between the ice and the valley walls, the stratified drift which now forms the terraces bordering the lakes, was deposited by the waters of the melting ice. The knobs and hollows on the face of the terrace reflect, in some measure, the irregularities of outline of the blocks of ice.

Between Hewitt's pond and Long pond, the terrace has an elevation of 595 feet; on the west side of Long pond it rises to 603 feet; near Iliff's pond, still farther north, to about 615 feet; and at Howell's pond to 619 feet. The gravel is well exposed in a number of railroad cuts along the east of Long pond and the west side of Iliff's pond.

Germany flats.—The broad gravel and sand deposits northeast of Pinkneyville are known as Germany flats. The topography is that of a broad, level or but gently sloping plain, the surface of which is interrupted by irregular and more or less connected depressions, twenty feet or so below the general level, and occupied by swamps or ponds. Occasionally the surface becomes slightly undulatory. The steep slopes surrounding the marshy depressions often show the irregularities impressed upon them by the ice against which they were built. This topography is well shown in the vicinity of Woodruff's Gap station (House's corner), on the slopes above the swamp followed by the railroad. It can also be seen at almost any point between Sparta Junction and Lake Grinnell (Lane's pond). Between these points the railroad follows a line of kettle holes, marking the location of ice blocks.

The elevation of Germany flats increases to the northeast, and reaches a maximum near Lake Grinnell (Lane's pond), where the plain joins the recessional moraine (p. 351), crossing the valley at this point. Near Pinkneyville the general elevation of the plain is 600 feet, although the gravel rises twenty feet higher on both sides of the valley. Near Sparta Junction, the general level is 615 feet, and near Woodruff's Gap station 618 feet, though the maximum height on the west side of the plain is nearly 640 feet. Near the southern end of White lake the plain has an elevation of 632 feet, and from this point it rises to 657 feet at the moraine a mile distant. That part of the plain which lies south and southwest of White lake is fifteen to twenty feet higher than that part immediately west of the lake. The two levels are separated from each other by a sharply marked escarpment of fifteen to twenty-five feet, which faces northward. It is probable that the edge of the ice was at the line of the escarpment during the deposition of the stratified drift to the south, and that after the ice had withdrawn somewhat to the north the lower terrace was formed. Near the moraine the gravel of the plain is coarse, though finer than the material of the moraine itself. The material decreases rapidly in size with increasing distance from the moraine, and near Woodruff's Gap station, less than three miles from the moraine, it has become fine gravel and sand. The pebbles are chiefly of gneiss, limestone, flint and chert, Hudson River shale, slate and greywacke, Oneida quartzite and Medina sandstone, in varying proportions. In a cut on the east side of White lake, the gneiss and limestone are the most abundant constituents. In a cut southwest of Woodruff's Gap station, the gneiss was estimated at about sixty per cent. of the whole, the Hudson River bits at about twenty-five, and the Oneidas at about ten. Limestone is not at all abundant, although the gravel is slightly calcareous below the zone of weathering, which has a thickness of three to four feet. Farther southwest, at other cuts, the limestone is again abundant, constituting a third of the gravel. At a railroad cut near Mulford station, the gravel is chiefly of shale, though at a pit near by, limestone is very abundant.

West of Sparta Junction, and again northwest of Woodruff's Gap station, limestone knolls project up through the gravel. In other places, the rock outcrops at levels below the plain. In some of these cases, at least, the rock was never covered by the gravel, and must have been protected by ice when the gravel was deposited.

Between the escarpment of stratified drift southwest of White lake, already mentioned, and the moraine west of Lake Grinnell, the plain has an average elevation of less than 620 feet. Much of the surface is clayey and in places till-like. This is particularly true of the point of land which projects between White and Mud lakes. It is believed, however, that in spite of the till-like aspect of the surface, the material is stratified. This belief is based (1) on the topographic continuity of the area of till-like surface with areas of stratified drift at the same level; (2) on data from borings made in the midst of this area; and (3) on the fact noted in many places that loose, stratified gravel often has a clayey surface coating, not unlike till in texture.

The moraine which crosses the valley at Lake Grinnell marks a definite pause in the retreat of the ice, that is a position where forward motion was counter-balanced by marginal waste. The lake basins along the line of Germany flats are hollows occupied by stagnant ice when the terrace plains were formed. The line marking the junction of the moraine and the outwash valley plain must have been, for a time, the line of separation between living ice to the north, and stagnant ice to the south.

The general southward slope of the terraces about Germany flats shows that they were formed by glacial drainage flowing southward. The present drainage, however, is in several directions. Southwest of Pinkneyville, Iliff's, Long and Hewitt's ponds are drained by a stream flowing southwest, a tributary to the Pequest. Howell's pond has no outlet. From Howell's pond to Sparta Junction, the southern third of Germany flats, the drainage is to the northeast, contrary to the general slope of the terraces. The middle third of Germany flats is drained by two streams flowing southwest. Near Sparta Junction they unite with the one from the southwest, draining the southern third of the flats, and flow northwest, out of the Germany Flats valley, into the Paulinskill at Branchville Junction. The northern third of the plain, including White lake, Mud lake and Lake Grinnell, drains northeast into the Wallkill. Here present drainage is in striking discord with that of the glacial time.

Between the recessional moraine and Monroe.—Between the north end of Lake Grinnell and Monroe are massive kame terraces. They are best developed on the east side of the stream, and in places attain an elevation of eighty to 100 feet above the bottom of the valley. Their maximum altitude is about 660 feet. This is about the same as the maximum height of Germany flats south of the moraine. The line which separates this area from the moraine on the west side of Lake Grinnell is somewhat arbitrary, since that part of the moraine is largely of sand and gravel, and the two areas are not sharply differentiated topographically.

There are good exposures near Gunderman's mills at the north end of Lake Grinnell, and along the railroad. Nearly half of the gravel is of limestone, a fourth of gneiss, and half as much of shale and greywacke. The material is in general coarse, cobbles twelve inches in diameter being common. Great masses of the gravel have been cemented by calcium carbonate into firm conglomerate. Near Monroe the material is much finer.

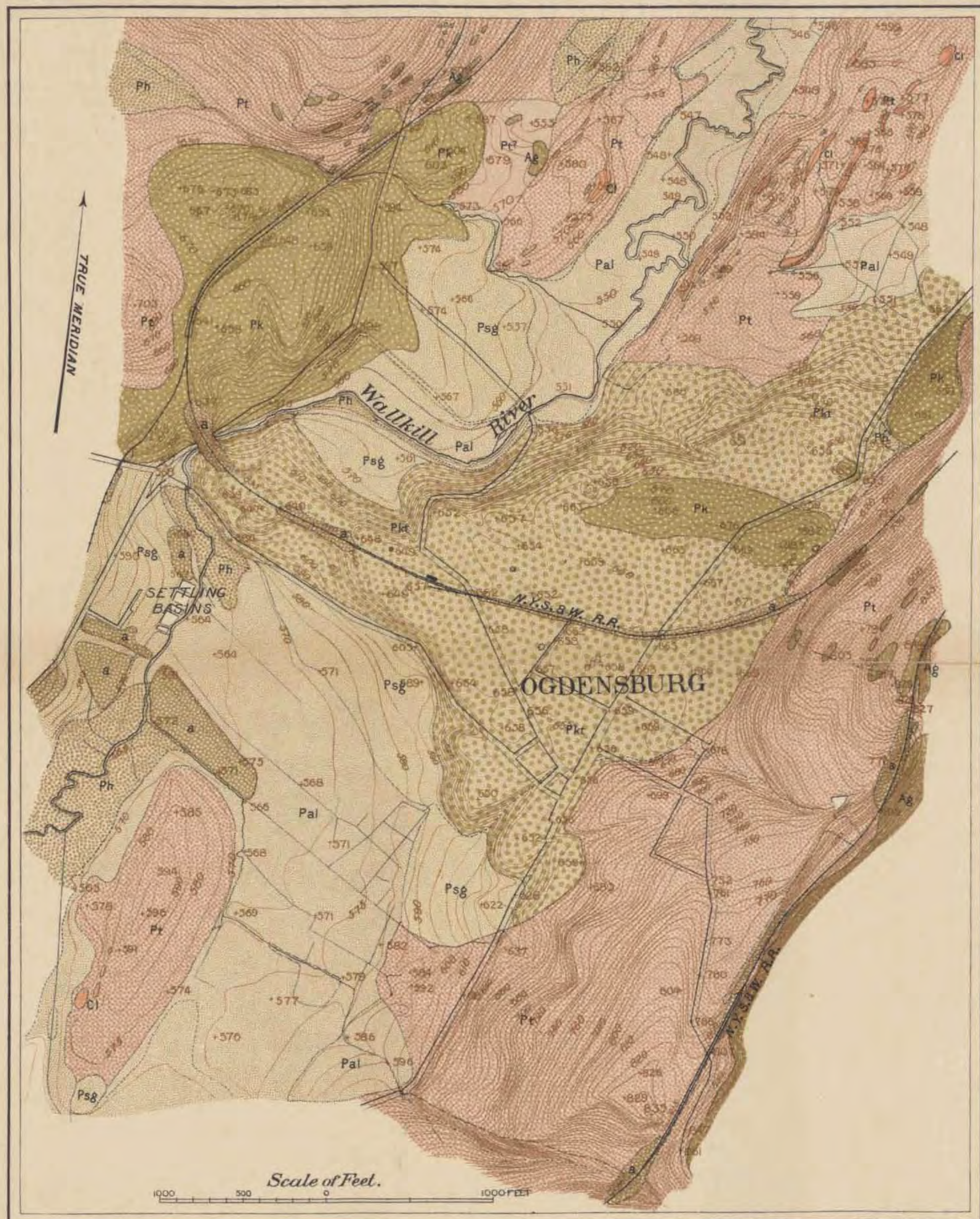
STRATIFIED DRIFT IN THE VALLEY OF THE WALLKILL.

Summary.

The Wallkill valley contains less stratified drift than any other important valley of northwestern New Jersey, though some interesting and striking types of this phase of the drift are found.

The river may be said to have its source in the swamp southwest of Sparta. At Sparta there are large massive kames rising sixty to 110 feet above the stream. Much of the material of these kames is coarse and but slightly water worn, some of the stones still retaining striæ. At Ogdensburg a huge triangular embankment of stratified drift crosses the valley, its base resting against the east bluff (Plates XXXIII and LVII). Its crest has an altitude of about 660 feet, and is 100 feet above the valley to the south. The free end of the embankment does not now reach the western side of the valley, and the evidence seems to indicate that it never did, or at least that it never did at the level of the present crest. This embankment of drift is believed to have been deposited in a huge crevasse in ice which had lost its motion before the deposition took place. The material is plainly stratified, and on the whole is well assorted, although large bowlders occur at all depths.

West of Hardystonville and extending beyond North Church is a glacial delta (Plates XXX, XXXI, p. 120, also Fig. 43, p. 158). It is a flat-topped plateau of sand and gravel a mile and three-quarters wide and five-eighths of a mile long, with an average elevation of 630 feet. Its southern and eastern margins are lobate, with characteristic delta fronts, which in places are 100 feet high. The surface of the delta is plane, but rises gently northward, grading in this direction into a series of kames. On the northern side of this delta and in the closely adjoining region are the most massive kames of Sussex county (Plates XXX and XXXI). Individual kames attain a height of 140 to 150 feet, and the kame topography is well defined. This kame area extends some distance northeast of Hamburg.



LEGEND

RECENT

a — Artificial

PLEISTOCENE

Pal — Alluvium

Ph — Humus

Pt — Till

Pt? — Probably till

Psg — Unclassified Stratified drift

Pk — Kames and kame areas

Pkt — Kame terrace

CAMBRIAN

Cl — Limestone non-crystalline

PRE-CAMBRIAN

Ag — Gneiss and crystalline limestone

Geology by Henry B. Kümmel

A. HOEN & CO. BALTIMORE.

THE SURFACE GEOLOGY NEAR OGDENSBURG

The conditions controlling the deposition of the gravel must have been very different on the two sides of the delta. On the south it was built into water standing at an elevation of from 620 to 630 feet. On the north the material was deposited against the irregular front of the ice which bounded the lake on this side. Except for the delta, shore features are absent, and the existence of the lake must have been brief.

Two small gravel plains between Hardystonville and Franklin Furnace, at 640 and 660 feet respectively, resemble glacial deltas, but the evidence is not conclusive.

A narrow kame belt extends for several miles north from the North Church delta and its associated kame area. This kame belt varies in width from 200 or 300 yards to three-fourths of a mile. It is made up of large single kames, kame terraces, and assemblages of small knolls. Its aggradation level is not well marked. So far as can be made out, it rises from a height of 514 feet at its southern end, near the delta plain, to 550 feet south of Papakating cemetery a mile and a half south of Sussex. Its southern end is, therefore, more than 100 feet lower than the delta plain just south of it. The topographic relations of this kame belt indicate that it was formed after the retreat of the ice from the delta. The plain and the kame belt are shown in profile in Fig. 3, Plate LII (p. 290).

A short distance north of the kame belt just mentioned is the small delta plain at Sussex (Deckertown). Extending north from it is a second kame belt bearing the same relationship to it that the first kame belt does to the North Church delta. The Sussex plain has an average elevation of 535 feet. Its southern margin is lobate, the lobes resembling delta fronts, and rising eighty to 100 feet above their surroundings. The top of the plain is not distinctly that of a delta, being somewhat pitted by kettles. The northern border of the plain has a topography which shows that its materials were deposited against the ice. The plain is like that at North Church in many respects, but is less well developed.

The narrow kame belt which extends for three and a half miles north from this plain is composed of a succession of large and massive kames, surrounded and connected with each other by smaller hillocks. An ill-defined aggradation level is discernible, rising from 460 feet near the delta to 520 feet near its northern limit. The material of the kames was probably deposited somewhat later than that of the delta, as in the preceding case. The Sussex (Deckertown) delta and the kame belt north of it are shown in the profile (Fig. 3, Plate LII).

West of this kame belt is an irregular body of stratified drift, the most significant part of which is found a mile west of Quarryville, where an embankment of gravel similar to that at Ogdensburg, though on a much smaller scale, juts out from the hillside. Like the greater embankment which it resembles, it is probably a crevasse filling.

The deposits of stratified drift on the east side of the Wallkill are of small extent and of little importance. The only exception is the embankment jutting out from the hillside three-fourths of a mile north of Independence Corner. It projects into the valley for half a mile, and from its free end a narrow belt of kames extends to the southwest for about the same distance, forming a right angle with the main mass. Like other similar embankments this is believed to have been formed in a crevasse in the ice.

Local Details.

Sparta to Ogdensburg.—The Wallkill river may be said to have its source in the swamp southwest of Sparta. A few kame-like knolls of sand and gravel occur on the eastern side of this swamp, and a few mounds, wholly or partly of stratified drift, rise above the humus deposits of the swamp. There is, however, little stratified drift above Sparta. At this point there is a considerable kame area, extending from the northern end of the swamp, northeast beyond the railroad, and including the hill of gravel north of the depot. Its continuity is interrupted south of the depot by a hill of limestone thinly covered with drift. Towards the village, the limits of the area are indefinite, due partly to grading. Elsewhere they are clearly marked.

Within this area, a number of massive kames rise to heights sixty to 110 feet above the swamp. Between them, and on their flanks, are smaller hillocks separated by undrained depressions. The vertical distance between the hillocks and depressions is often twenty to thirty feet. This area is a good example of strongly marked kame topography.

The surface material of the sharper knolls is generally, though not always, loose sand or gravel. Cobbles and even bowlders are sometimes common, one of the latter being eight feet in diameter. A very noticeable proportion of the surface material is little worn.

The best exposure is near the depot. Here the railroad has cut across the end of a large kame, giving a section thirty to forty feet deep. All sizes of material are present, from fine sand to bowlders five or six feet in diameter. The large bowlders occur not only on the surface, but also below. Gneiss is the most abundant constituent, and constitutes fully half of both the large and small material. Limestone, chiefly of the blue variety, is the next most abundant constituent, forming about a third of the whole. The Hudson River, Medina and Oneida formations are represented more meagerly. Where the cut is fresh enough to show the structure, the beds dip toward the end of the kame. The depth of the oxidized surface layer varies from two to six feet. This layer, here as elsewhere, shows no sign of stratification, and has the distinctive characteristics neither of stratified drift or till. The fact that the leached and oxidized surface layer is usually co-extensive with the layer in which stratification does not appear, whereas the unoxidized and unleached part below is usually clearly stratified, indicates that weathering has destroyed the bedding.

Although there can be no doubt but that the material of the kames was water-deposited, it is equally clear that much of it was not carried any great distance by the water. Considered as a whole, the gravel is poorly rounded. This is true, particularly of the coarser materials. It is also true that many of the cobbles and bowlders, particularly of limestone, still retain their glacial markings, apparently undimmed. These could not have been carried far by water in company with the hard pieces of crystalline rock and quartzite.

The great range in size of the material in these kames, its poor assortment, its slight wear and the absence of any semblance of a common summit level, all indicate the immediate proximity of the ice, when the kames were made. A kame area of this sort probably represents a halting place of the ice in its retreat, but a place where the marginal accumulations were of stratified drift, rather than till. A kame belt, therefore, has much the same significance as a moraine.

From a point just north of Sparta to Ogdensburg, the Wallkill flows through a marshy alluvial plain, which locally has a width of half a mile or more. Along this part of its course the river has been silting up its valley in post-glacial times. A few small kames and kame terraces occur at several points along the sides of the valley, some distance above the alluvial plain, the best developed being on the east side of the valley a mile and a half south of Ogdensburg.

The Ogdensburg embankment.—At Ogdensburg a great triangular embankment of stratified drift extends nearly across the valley from the eastern side (Plates XXXIII and LVII). This peculiar feature has long attracted attention. It was referred to in the *Geology of New Jersey,* 1868; in the Annual Report of the State Geologist for 1878, and was described at some length in the Annual Report of the State Geologist for 1880. "It is a conspicuous feature of the landscape, and affords beautiful views of the valley both to the north and to the south. And it serves as an embankment for the New Jersey Midland railroad (the N. Y., S. and W.), crossing the valley of the Wallkill. Its (average) height is 660 feet above the sea and 100 feet above the meadow level along the kill. The village of Ogdensburg stands partly on its eastern end. Its length, measured in a straight line directly across the valley, is three-fourths of a mile. Its breadth may average a quarter of a mile."[1] At its eastern end, where it joins the slope above the embankment, it has a width of nearly three-fourths of a mile, but at its western end, near the Wallkill, its width at the summit is only two or three hundred yards. The apex of the triangle is close against the

[1]Annual Report for 1880, p. 51.

western side of the valley, leaving but a narrow passage for the Wallkill. If the embankment ever extended across the valley, a lake must have existed in the valley to the south. The amount of post-glacial erosion is not easy of determination, because of the modification of the surface by railroad grading; but as nearly as can be made out, the maximum amount of post-glacial cutting does not exceed twenty feet. It can be affirmed with some degree of certainty that the embankment never extended entirely across the valley at its maximum height. If the filling at the west end of the embankment was twenty feet above the present stream channel, a shallow lake existed south of it, extending three or four miles up the valley. If such a lake existed, the Wallkill drained it as it lowered its channel across the west end of the embankment.

Exposures are common on the southern slope of the embankment near the western end. The deposit as a whole is of stratified drift, though the material is locally ill-assorted. The gravel is coarse, although fine sand is present. Bowlders ten feet in diameter occur, and those less than five feet are hardly rare, either at the surface or below it. Many of them are striated.

The crest of the embankment is nearly plane, though in places it is gently undulatory. Its general slope is westward. In contrast with the top, the steep slopes are marked by shallow kettles and low knolls, which give a clue to the origin of this remarkable feature. Slopes with such topography could only be formed where the drift was deposited against the ice. The topography and constitution of the embankment, together with its position directly athwart the course of drainage, leads to the conclusion that it was probably formed in a wide crevasse in the ice which formerly occupied the valley. The bowlders were probably in the ice, and were set free and incorporated in the gravel, as the ice melted, and while the deposition of the gravel was still in progress. The ice could have had little or no motion at the time of deposition or later, or the regularity of the deposit would have been destroyed. This ice is, therefore, thought to have been essentially stagnant.

The gravel of the embankment is composed chiefly of gneiss and limestone (both blue and white), with a considerable content of Hudson River sandstone. The gneiss is estimated to constitute about forty per cent., the limestone slightly less, the slates and sandstones a fourth as much. The Oneida, Medina and Cambrian formations are represented, and there are also flints and occasional pieces of zinc ore. The large bowlders are chiefly of gneiss and limestone. Towards the eastern side of the embankment the gneiss content seems to increase somewhat over the limestone.

Weathering, oxidation and leaching have affected the surface layer to a depth of about three feet. Great masses of the gravel have been cemented by calcium carbonate into conglomerate, the best exposures of which are near the western end of the embankment.

Ogdensburg to North Church.—From Ogdensburg to a point north of Franklin Furnace there is little drift of any sort in the valley of the Wallkill. The low hills of limestone along the valley are but thinly covered with till, and the rock outcrops frequently. A few small knolls of sand and gravel were noted on the west side of the valley.

Between Franklin Furnace and Hardystonville are two or three sand and gravel areas, which, although not strictly along the Wallkill, may be mentioned in this connection. The first of these is half a mile northwest of Franklin pond, and half a mile east of the Buckwheat mine. Here the gravel forms a small plain with several distinct lobes. Its elevation is rather less than 660 feet. The lobate front slopes resemble delta fronts. The gravel is loose and mainly gneissic.

About a mile north of this area is another similar sand and gravel plain of about the same elevation. Its margin is lobate, and its slopes resemble delta fronts. The material is loose and sandy with some gravel. The material is chiefly gneissic, but is highly calcareous. This plain has been dissected by a small stream to a depth of over forty feet.

In many respects these two plains resemble glacial deltas, but their topography is hardly decisive, and the structure is nowhere well enough shown to warrant positive conclusions. At one point steeply dipping beds were noted, but they were inclined obliquely to the margin of the lobe, and no top-set beds could be made out. The height of these plains is about the same as that of the embankment at Ogdensburg. If that embankment originally stretched across the valley, a lake might have been formed between it and the ice front farther north, and in this lake these plains might have been formed. But there is no positive evidence that this was the case, and, as already stated, the weight of evidence seems to be against the extension of the embankment across the valley. It is possible that ice temporarily completed the obstruction.

Just southwest of Hardystonville is a high kame which possesses more than ordinary interest. The railway cut shows it to be made up chiefly of interbedded sand and gravel, the beds of which dip northward at an angle of about 30°. Most of the gravel is rather fine, but cobbles are not uncommon, and bowlders five or six feet in diameter occur. Much of the gravel is poorly rounded, though striated pebbles are rare or wanting. The gravel is chiefly of limestone and gneiss. At the south end of the cut, layers of clay underlie the sand and gravel, and grade upward into them. The clay is slate colored, compact and "fat," and dips with the sand and gravel. Its thickness is at least fifteen feet. The laminæ exposed when the section was seen were not crumpled, and, except for their high dip, showed no signs of having been disturbed since deposition. It is probable that the clay beds were originally horizontal, and that the disturbing force was the ice. In any case the clay was deposited in standing water, which was perhaps the same as that in which the North Church delta was built.

Half to three-quarters of a mile southeast of Hardystonville, and northward to Rudeville, are a number of small areas of sand and gravel, which have something of the kame or kame terrace topography. The areas are at various elevations, and do not seem to be connected in origin. The gravel is largely gneissic, and the surfaces of the kames are often cobble strewn.

The North Church delta and associated kames.—Across the Wallkill from Hardystonville is a high, flat-topped delta plain of sand and gravel, which extends as far west as the old North church (Plates XXX and XXXI; also Fig. 43, p. 158). Stretching northward from this plain for ten miles is a narrow belt of kames. The relationship of the kame belt to the plain, and of the various parts of the former to each other, will be indicated below.

The North Church delta plain is a striking feature. Its greatest width from east to west is a little more than one and one-fourth miles. Its greatest length from north to south is five-eighths of a mile. Its average elevation is 630 feet above the sea, and it rises from twenty to 100 feet above its surroundings. The top of the plain slopes gently from north to south, its planeness being interrupted only by a few shallow depressions.

Along its southern and eastern margins its outline is lobate and its slopes steep. The outline and the slope of the front are such as are characteristic of deltas. The height of the abrupt slope varies notably, because the surface on which the plain was built was uneven. Near the North Church schoolhouse, where the plain borders the swamp, the steep slopes are nearly 100 feet high. To the east the height decreases as the surface in front of the plain rises, until at a point north of Franklin Junction the front slope rises no more than twenty feet above the surface outside. But the front is here just as clearly constructional as is the higher escarpment farther west. The lobes of the plain are clearly outlined, and the re-entrant angles are well defined. Still further east and northeast, the height of the slope is again greater though it nowhere equals that near the North Church schoolhouse.

Nowhere along the lobate margin of the south and east front of the plain, with one exception, are there kames or sinks such as characterize the slopes of stratified drift deposited against ice, and such as are found on the northern face of the plain. Near the schoolhouse, however, there are a few small irregularities of slope on the sides of a wide re-entrant angle. These may be due to slumping.

The surface of the plain is strewn with cobbles and smaller pebbles, with rarely a small bowlder. The surface is generally coarse and loose, though in a few places the soil is clayey. Limestone constitutes nearly half of the gravel, and gneiss is the next most abundant constituent. In the finer parts there is much shale. The internal structure is nowhere well exposed. Sandy silt covers the low ground in front of the western end of the plain.

The northward slope of the plain is very different in topography and outline from the southern. Here the plain breaks up into a succession of hillocks and kettles at a level lower than the top of the plain. Some of the kettles are eighty feet deep. Nowhere else in Sussex county are kames developed on such a massive scale as on the northern flank of the North Church plain and in the closely adjoining area to the north. Unfortunately, much of the area is covered with timber, and a good view of the whole assemblage of hills and hollows is impossible. Bowlders and large cobbles are much more abundant on the surface of the kame area than on the plain itself, though the material of individual kames is often fine gravel or sand.

It is evident that the conditions which obtained on the north flank of the plain while the drift of the plain was being deposited, were totally unlike those on the southern. The steep slopes and lobate margin of the plain on the south, point to the conclusion that the North Church plain is a glacial delta, built out into a temporary lake, whose waters had an elevation of 620 to 630 feet. The knolls, ridges and kettles of the northern slope indicate deposition against an ice front of irregular outline. There can be no doubt that the margin of the ice was at the line of these kames when the delta plain was formed, and constituted the barrier which held in the lake on the north. With drainage blocked in this direction, the water about North Church would to-day find its lowest outlet to the southwest, *via* Lake Grinnell and Woodruff's gap, to the Paulinskill, at a level a little below that at which the North Church lake was held. The obstruction which held the lake up to the level of 620 to 630 feet was probably the recessional moraine (p. 350) about Lake Grinnell, the site of the lake being then occupied by an ice block. In the upper Wallkill valley, the Ogdensburg embankment may have hemmed it in on the south, or the waters may have extended up the valley to the vicinity of Sparta. The clay near Hardystonville, already mentioned, was probably deposited in this lake.

Northeast of the delta plain, and separated from it by a narrow valley in which there is little drift of any sort, is a conspicuous area of kames. The area is noteworthy both for the massive size of two of its individual kames and for its wonderfully sharp kame topography. The two massive kames are flanked by many smaller ones. On its southern side, the larger of the two rises 140 to 150 feet above its surroundings. Its slopes are regular and symmetrical, unmarked by minor irregularities. On its northern flank, however, and just southwest of the Hamburg station of the L. & H. R. railway, is a small but complex area of pronounced hillocks and kettles. This particular spot affords an exhibition of the most striking kame topography in Sussex county (Plates XXX and XXXI, p. 120). The kettles are nearly circular, and their rims are practically unbroken. The hillocks are equally perfect in their dome-shaped outlines. The relief is often forty feet. Measured from the top of the large kame to the bottom of the nearest kettle, the relief is nearly 100 feet. This kame area is continued northeast across the river in the southern part of Hamburg. It is marked by massive hills of stratified sand and gravel, in which bowlders are more or less abundant. Between the massive hillocks are sharp, irregular depressions and kettles. These massive kames indicate the positions of at least a temporary halt of the ice, during its retreat. This area extends toward McAfee valley, and is more or less continuous with deposits between McAfee and the State line, to be described later.

The best exposure in the kames of this vicinity is in the railroad cut of the L. & H. R. railway a little northeast of the station. Large bowlders are not uncommon, but in exposures nearer the L. & H. R. depot, the material is a fine sandy silt. Much of the coarse material is poorly rounded. A large proportion of it is limestone, with gneiss the next most abundant constituent.

The Sussex (Deckertown)-Hamburg kame belt.—This kame belt extends from the northern edge of an alluvial plain near the kame-marked slope of the North Church plain, northward to the gravel plain east of Sussex. It lies entirely west of the Wallkill, but for much of the distance not in its immediate valley. The greatest width of the belt is more than half a mile, but its average width is not more than half as much.

There is little trace of an aggradation level in this belt, though the tops of the higher knolls approach a common plain, which rises slightly northward. West of Hamburg, near the southern end of the belt, the principal hills have heights of 514, 501, 504 feet. Three-fourths of a mile to the north, the summits of several large kames are above 500 feet. Within the next mile and a half, five or six kames have elevations of between 500 and 520 feet, but none reach 540 feet. Half a mile south of the Sussex cemetery, near Papakating church, several kames rise above 540 feet. Near here, the gravel is massed against the hill-side in a terrace which is nearly 560 feet above the sea. In the immediate vicinity of the cemetery, and near the railroad, the kames do not rise above 510 feet.

Between the larger kames of this belt and on their flanks, are smaller knolls, and depressions. In parts of the area, the large kames are somewhat separated from one another, and on all sides rise from low surroundings. In these cases the relief is not infrequently eighty feet. Occasionally several kames are ranged in line, suggesting an interrupted esker. More commonly they are closely aggregated. Locally the gravel is built against the hills forming terraces, but this is not the rule. More commonly there is a marked depression between the knolls of gravel and the till-covered hills on either side.

The relationship in position between this kame belt and the North Church plain suggests a genetic connection between them. This kame belt has the same position in regard to the plain, as does the "feeding esker" to some of the Massachusetts sand plains.[1] The position of the kame belt in regard to the sand plain may indicate that the kames were built along the course of the stream, which, at its mouth, formed the delta plain.

The kame belt was probably developed after the front of the ice had retreated from the north margin of the delta plain, but while some ice still lingered in the valley. This is indicated not only by the position of the kames relative to the delta plain, but by the fact that the kames are considerably lower than the delta.

This kame belt affords the best opportunity known in Sussex

[1]Davis. Proc. Boston Soc. Nat. Hist., Vol. XXV. pp. 318-35, 1892,

county for studying the effect of change in the surrounding rock on the constitution of the stratified drift. It is bordered on the east by limestone hills, which are nearly free from drift. Limestone also borders it on the west, save for a mile near its north end. The contact between the shale and the limestone crosses the kame belt obliquely near the Papakating cemetery. The northern extension of the gravel area towards Van Syckles is on shale. Exposures at intervals of a mile give an opportunity for noting the change in the constitution in passing southward from the shale area to the limestone.

A mile southeast of Sussex the material as seen in a railroad cut in the kame belt is fine gravel, with sand and occasional bowlders. Of the pebbles under one and one-half inches in diameter ninety-five per cent. or more are of shale, while shale cobbles comprise about sixty-five per cent. of the coarser material. At the road corners a mile or more due south of the above cut, and three-fourths of a mile south of the contact of limestone and shale, the shale constitutes seventy-five per cent. of the finer material and a much smaller proportion of the cobbles than at the first exposure. The loss in shale is made up almost entirely by a gain in the limestone content, the other constituents being about the same. At a third exposure, a mile south of the second, where the drift is on the limestone, something more than fifty per cent. of the finer material is shale, and twenty-five to thirty-three per cent. of the cobbles over three inches in diameter are of limestone, whereas at the first exposure the limestone cobbles do not comprise over eleven per cent. of the whole.

At a fourth pit, a mile south of the last, and likewise on limestone, fifty to sixty-five per cent. of the cobbles are limestone, as are also one-half of the pebbles from one-fourth of an inch to an inch in diameter. The shale still constitutes more than fifty per cent. of the finest gravel. In less than three miles, therefore, after leaving the shale, the material of the stratified drift changes from a gravel in which fully ninety-five per cent. of the finer and sixty-five to seventy per cent. of the larger fragments are from the Hudson River formation, to that in which fifty to sixty-five per cent. of the cobbles and fifty per cent. of the small pebbles are limestone, while only in the finest material does the shale predominate.

The Sussex (Deckertown) Delta.—A little east of Sussex is an elevated sand and gravel plain, similar in many respects to the North Church plain. Its greatest length, one mile, is from northwest to southeast, and its shortest, a quarter of a mile, from northeast to southwest. Its elevation, about 535 feet, is nearly 100 feet lower than that of the North Church delta, and about equal to that of the kame terraces southeast of Woodbourne. From the south, it rises by a steep slope eighty to 100 feet above the low land at its border. Its southern margin is lobate, and the lobes resemble delta fronts. The characteristic features of stagnant ice topography are wanting, but in two places the projecting lobes of the plain were built out to previously formed kames, which they partly buried. On the top, the delta form is less distinct. Instead of being flat or gently sloping, it is pitted by sinks, twenty-five to forty feet deep, and one knoll rises ten feet above the general level. The inequalities are less strongly developed near the front of the plain than back from the edge. The northern and northeastern or inner slope of the plain is kame-like. In this respect, as in its steep and lobate front, it is like the North Church delta. While no exposures reveal the structure, the form of the southwestern slope indicates that this part of the plain was built into a temporary lake. The immediate presence of the ice is probably responsible for the form of the surface of the delta, and its slight extent indicates that the lake into which it was built had but a very brief existence.

The gravel of the plain is generally rather fine, and interstratified with sand. The material was derived largely from the Hudson River formation, but there are some pebbles and cobbles from the Oneida, Medina, limestone and gneiss formations.

In spite of the delta-like front of this plain, there seems to be little chance for a lake to have existed here, unless it was held in at the south, as well as at the north, by ice; for the water would need to rise only to the level of 501 feet to overflow the divide between Papakating creek and Paulinskill. With the present configuration of surface, therefore, no lake could have existed at Sussex above a level of 501 feet, unless held in at the south by ice. The absence of an outlet channel over the divide makes it improbable that a lake discharged in this direction. If the lake was held in at the south by a body of ice left when the main front retreated, the life of the lake would have been short, as the smallness of the delta suggests.

Kame belt northeast of the Sussex plain.—A long, narrow kame belt stands in much the same relationship to the Sussex delta that the Sussex-Hamburg belt does to the North Church delta. The kame belt is separated from the northeastern end of the plain by an alluvial flat, but beyond this flat it extends without interruption three and a half miles northeast of the delta. In width it varies from 300 to 600 yards. It is composed of a succession of massive kames, surrounded and connected with one another by smaller hillocks. It occasionally becomes terraciform, but this is not its usual habit. Its greatest relief is more than fifty feet, but the relief between the crests of hillocks and the bottoms of adjoining kettles is rarely more than thirty feet. Topographically, this kame belt is nearly everywhere clearly separated from the shale knolls on either side, but occasionally the shale knolls cannot be distinguished by their form from the kames.

Here, as in the Sussex-Hamburg kame belt, a suggestion of an aggradation level can be made out, by comparing the elevations of the highest knolls. This level rises gradually northward, though it is everywhere much below the level of the Sussex plain. Near the plain, the highest knoll of gravel is at 460 feet; three-eighths of a mile farther north, the level is unchanged; a quarter of a mile still farther north, the gravel rises to 489 feet; in the next mile and a quarter, several knolls reach above 480 feet, and the tops of the highest, nearly to 500 feet. In the latitude of Quarryville, the height is 501 feet, or 109 feet above the alluvial plain just east of the kame belt. A little farther north the gravel reaches a height of 513 feet. The gradient, therefore, of the aggradation level represented by the tops of these kames is about sixteen feet per mile. Comparing these elevations with that of the plain, which is about 535 feet, it is seen that the latter is much higher than any part of the kame belt. This kame belt, like the Sussex-Hamburg belt, was probably formed a little later than the delta plain with which it is associated, and after the lake in which the delta was built had disappeared. When this body of stratified drift was deposited, ice must still have occupied the bottom of the valley of the Wallkill, and the drainage was to the south. The reversal of drainage took place after the ice had disappeared from the lower course of the Wallkill.

There are no deep exposures in this kame belt. The pebbles of the gravel average one, two or three inches in diameter, and few cobbles exceed six inches. The material is largely from the Hudson River shale and sandstone, with some admixture of limestone, quartzite and gneiss. The surface is generally loose and gravelly, in spite of the large percentage of shale in the gravel.

A short distance west of the above kame belt is an irregular area of stratified drift which may be described in this connection. It commences a quarter of a mile southeast of Quarryville, and a little north of Wantage cemetery, and extends southward interruptedly about a mile and three-quarters. The material is largely of shale, and the surface, as is usual in such cases, is clayey, save on the steep slopes. About the Wantage cemetery the deposit forms a plain, having about the same height as the Sussex delta. South of this plain the surface is low, and along the brook there is considerable alluvium. Beyond this the gravel rises again to an elevation of about 540 feet. In places the surface is slightly kame-like. A mile south of Quarryville, on the east side of the brook, an embankment of gravel juts out from the hillside, after the manner of the Ogdensburg embankment, but on a much smaller scale. It is probably an ice-crevasse filling.

In the southern part of this area, the drift is generally thin, and the underlying rock topography is not entirely concealed.

On the east side of the Wallkill.—East of the Wallkill, north of Hamburg, there are no continuous deposits of stratified drift, though there are isolated kames and kame areas. Some of them lie between one and two miles north of Hamburg at elevations ranging from 400 to 535 feet.

At Independence Corner are small but well marked kame terraces, at elevations between 540 and 560 feet. The gravel does not cover the lower slope of the hill, but is limited below by the

480-foot contour. At lower levels the rock is nearly bare, and was probably covered with ice while the gravel of the terrace above was being deposited. The gravel here is mainly of gneissic origin, and is not well rounded or well assorted.

Half to three-quarters of a mile north of Independence Corner, a huge spur-like embankment of sand and gravel projects from the hillside into the valley of the Wallkill. The main part of the embankment is triangular in outline, the base being against the hill, and the apex extending northwest for half a mile. The average height of its top is about 500 feet, although it rises to about 530 feet where it joins the hill. Seen from a distance, its crest line appears even and nearly horizontal, but at closer range its surface is found to be broken by shallow depressions. The slopes of the southern flank are not distinctly undulatory, but the northern slope retains the peculiar topography given it by the ice, against which the gravel was deposited. This embankment probably marks the position of a huge crevasse in the ice which occupied the bottom of the Wallkill valley, while drainage came down between the ice and Pochuck mountain. From the free end of the embankment a narrow belt of kames extends for nearly half a mile to the southwest, their direction being at right angles to the main mass.

Towards the apex of the embankment, its surface is loose and gravelly, and strewn with cobbles and small bowlders. Towards the gneiss hills, the surface is more or less bowlder strewn, and to some degree resembles till, though exposures show that the underlying material is stratified.

Two miles north of Independence Corner is a low kame area near the Wallkill. It is surrounded by alluvial and humus deposits, above which it rises twenty-five or thirty-five feet. The individual knolls are low, but sharp and distinct, the relief being about fifteen feet.

From one to two miles south of Milton, there are low terrace-like deposits of sand and fine gravel rising a few feet above the alluvial plain. Occasional low mounds of coarser gravel rise ten to fifteen feet above these terraces. Near the State line, also, are low flat gravel areas with clayey surfaces. These deposits present no features of especial interest.

STRATIFIED DRIFT OF THE VERNON VALLEY.

Summary.

In the Vernon valley there are several areas of kames and kame terraces which represent deposition at different stages of the ice retreat. Near Hamburg several massive, bowlder-strewn kames rise to heights of 560 feet and more, and sixty to 100 feet above their surroundings. Near by is a kame terrace at 520 feet, and another at 580 feet. The upper terrace extends with more or less interruption as far north as McAfee. A third kame terrace, at an elevation of from 600 to 620 feet, occurs a mile south of McAfee, in the direction of Rudeville. Immediately south of the McAfee depot is a mass of stratified drift heaped up into very characteristic kame forms.

Northwest of Sand Hills station, and extending as far north as the Sprague schoolhouse, and southward to within half a mile of McAfee, is still another area of kames and kame terraces. In this area the gravel locally attains a thickness of 100 feet or more. Near the Sprague schoolhouse, the topography is typical of this phase of stratified drift.

East of Maple Grange station high massive kame terraces have been built against the hill. Till-strewn rock ledges occur at lower levels, and nearer the center of the valley. At the southern end of the terrace the aggradation level has a height of 540 feet, and rises to 570 feet in a distance of about a mile. Half a mile east of De Kay's station, there is another kame terrace extending northeastward into New York.

On the western side of the valley a narrow kame belt extends, with some interruption, from a point northwest of Vernon, near the Longwell schoolhouse, to the State line and beyond. For the first mile north of the schoolhouse, the belt is sharply set off from the hills on either side by depressions. For this part of the area, the glacial drainage appears to have been between ice walls or through a subglacial channel. Farther north, the gravel is more or less banked against the hills in the form of kame terraces. At the southern end of the terrace it has an elevation of 460 feet, but to the northward its level rises rapidly to 520 feet, which level persists to Glenwood.

The elevations of the kame terraces in the Vernon valley are far from constant, and do not belong to one aggradation level. Each of the terrace areas just mentioned seems to have been formed independently, those to the south having been formed earlier than those to the north.

Constitution.—The gravel deposits in the Vernon valley are composed largely of gneiss and limestone with smaller proportions of material from the Hudson River, the Medina and Oneida formations. The gravels of Maple Grange and the De Kay terraces contain a large amount of shale, due to the proximity of shale just north of the State line. In size the material varies from fine silt to bowlders five or six feet in diameter. In general the bowlders occur only on the kames, particularly on the massive kames near Hamburg. They are generally absent from the kame terraces.

The gravel deposits in the Vernon valley have suffered no considerable erosion in post-glacial time. The creeks draining the valley have been chiefly engaged in filling up the marshes along their courses.

Local Details.

Hamburg to McAfee.—West of Hamburg are the two important kame areas already described in connection with the North Church plain. These areas extend eastward across the Wallkill in the southern part of Hamburg. The massive hills of coarse gravel and sand are well shown in the angle between the two railroads. The new schoolhouse at Hamburg is located on one of them.

In the northern and lower part of the village, the drift is difficult of classification. The surface is clayey and somewhat till-like, and the topography is not decisive. Records of excavations, however, indicate that the drift is stratified. A little farther north, across the brook, the surface is flat or gently undulatory, with a few shallow, saucer-like depressions. Along the easternmost of the two roads which cross it, fine silt and laminated clay are exposed. Several of the low swells of the plain are of clayey gravel. It seems possible that the whole plain is of stratified drift.

Half a mile northeast of the center of Hamburg, south of the road to McAfee, is a massive hill rising to more than 560 feet A. T., and more than 100 feet above its surroundings. Kames fifteen to twenty feet high occur on its lower slopes. Judging from its topography, its surface material, the shallow exposures and its surroundings, the whole hill is probably of gravel and sand. Its surface, however, is strewn with bowlders, some of which are six and even eight feet in diameter. Just northeast of this huge kame are two well-marked dome-like kames, the one nearer the road being bowlder-strewn, while the other is free from bowlders. A few bowlders occur on some of the knolls of that part of the area lying west of Hamburg, but they are not so numerous, nor of such size as those on the two kames mentioned.

Just north of the two bowlder-strewn kames, the gravel forms a pitted terrace at an elevation of about 520 feet, and about a quarter of a mile farther north are well-marked kame terraces at 580 feet. Bowlders are absent, and the gravel is generally fine and the surface comparatively loose and sandy. The topographic effect of deposition against ice which occupied the bottom of the valley, meets one on every side.

A mile and a quarter northeast of Hamburg, near the limekiln, the L. & H. R. railroad cuts through a kame, giving a good exposure of the gravel. The material is largely sand and fine gravel. There are no bowlders, and the cobbles make up but a small part of the whole. An estimate of the pebbles two inches and less in diameter gave the following result:

Gneiss,	55%
Blue non-crystalline limestone,	33%
White crystalline limestone,	2%
Shale, slate and greywacke (Hudson River),	7%
Flints, cherts, etc.,	2%
Oneidas and Medinas,	1%

The lithological constitution of the gravel of this kame is probably a fair average for the whole area, though, as already noted, the size of the material varies widely.

Just east of this cut the gravel forms a high, well-marked terrace, its steep face rising abruptly seventy feet above the railroad. It is 300 yards wide at the top, and its upper margin has an elevation of about 580 feet. More or less disconnected gravel deposits are found against the hillside as far as McAfee, the highest of them having elevations of between 580 and 600 feet. Frequent outcrops of rock show that the gravel is in small bodies only, lodged here and there on the hillside. If the gravel was deposited by streams flowing between the ice in the valley bottom and the rock wall of the valley, as it probably was, the deposition took place at intervals only. This was probably the result of constrictions and expansions of the channel.

As shown by the contour map, a depression extends from a point a little east of Hardystonville, *via* Rudeville, to McAfee. The few isolated gravel deposits along this depression between Hardystonville and Rudeville, have already been noted (p. 417). Midway between Rudeville and McAfee there is a gravel area, which extends northward and joins the deposits in the valley followed by the railroad. About a mile south of McAfee, the gravel forms a broad terrace at an elevation slightly above 600 feet. The surface is flat or gently undulatory, and to the southward passes into a small kame area with an elevation of about 620 feet. To the north, the terrace falls off abruptly, its slope being marked by kettles, sinks and knolls. The gravel of this slope was probably deposited against an ice mass which occupied the depression to the north.

A striking example of the topography resulting from the deposition of stratified drift against ice is seen in the great mass of sand and gravel immediately south of the McAfee depot. Here are kettles twenty to forty feet deep. They are often nearly circular, with unbroken rims. A good view of them can be obtained from the hill opposite the hotel at McAfee, where the gravel attains an elevation of 560 feet. A little east of the depot is a kame sixty to seventy-five feet high, built against a rock ledge, which it almost buries.

Northeast of McAfee.—Deposits of stratified drift occur on the eastern side of the valley most of the way between McAfee and Sand Hills station. In two or three places they form well-defined kame areas or kame terraces; but for much of the distance the topography is not distinctive, and the coating of gravel and sand on the hill side is probably thin. Occasional small exposures along the road show that the gravel is composed chiefly of gneiss and limestone. About a mile northeast of McAfee the gravel forms a sharply marked kame area, which, nearer the road, passes into a kame terrace having an elevation of about 520 feet.

Sand Hills station gets its names from the huge hills of stratified drift in the vicinity. The group of hills just south of the station rise 100 feet above the alluvial plain, and the kame terrace to the north is even higher. Just south of the station the railroad cuts through one end of a kame, giving an exposure of fifty to seventy feet. The material is of all sizes, from fine sand up to bowlders three feet in diameter, but more than two-thirds of it is of sand and small pebbles. Of the materials exceeding an inch in diameter, limestone predominates. The finer gravel, however, and the sand is made up more largely of gneiss, shale and quartz. The quartz grains are decidedly angular, whereas the shale bits of the same size are almost universally rounded. Some parts of the gravel are cemented into a firm conglomerate.

The gravel north of Sand Hills station is part of an irregular shaped area of stratified drift which extends northward beyond the Sprague schoolhouse, and southwestward nearly to McAfee. The southwestern extension of the area is the more irregular in outline, lying as it does between hills of limestone. The gravel is occasionally interrupted for short distances, and small outliers of stratified drift are found beyond the limits of the main area. Over most of the area the gravel attains great thickness, in some cases apparently as much as 100 feet or more; but where it wraps around the limestone hills it thins to zero. The different parts of this area, also, differ greatly in their topography, most of the various forms of the stagnant ice series being represented.

North and northwest of the Sand Hills station are flat-topped terraces with steep slopes marked by hummocks and kettles. Their elevation is about 540 feet A. T. Three-quarters of a mile due west of the station the gravel is disposed in the form of kames around the limestone outcrops. There is here no indication of an aggradation level. A little southwest of this kame area the terrace form is again prominent, although broken by deep kettles. South of the Sprague schoolhouse the topography is marked by deep hollows (twenty to forty feet) enclosed by winding ridges and flat-topped hillocks, all of which have a common elevation of about 560 feet. One of these ridges just north of the schoolhouse resembles a short esker. The surface of this part of the area is strewn with cobbles and occasional bowlders. Exposures along the road leading west from Sand Hills station show gravel, sand and fine, clayey silt.

A comparison of the height of the aggradation levels in various parts of this area shows a southward slope of about twenty feet in two miles. It is believed that the gravel of this area from north of the Sprague schoolhouse southwestward to within half a mile of McAfee, is a unit in time and mode of origin. The gravel deposits southeast of the railroad between Sand Hills and McAfee, even where there are traces of an aggradation level, do not agree in elevation with those mentioned above, and probably represent the deposits of another drainage line, separated from the former by ice.

The 600 to 620-foot plain three-fourths of a mile south of McAfee seems to stand by itself, as its elevation is greater than any of the other deposits. It was probably formed earlier than the terraces farther north. The summit of the great mass of kames (560-feet) at McAfee, also, cannot be connected with the aggradation level of the area to the north, nor does it agree with the well-marked levels (580 feet+) a mile nearer Hamburg. From its position and height it may be supposed to have been formed after the gravels nearer Hamburg, and before those between McAfee and the Sprague schoolhouse.

Between Sand Hills station and Maple Grange station there is little stratified drift on the southeastern side of the valley. The only notable exception is a small area at Vernon, just north of the church, where there are a number of low mounds of sand and gravel. The stratified drift here is thin and rests on a thick bed of till.

East of Maple Grange station there are high kame terraces extending more than a mile along the side of the valley. Till occurs below the base of the terraces, and between them and the alluvial plain. The line between the till and the gravel can, in general, be sharply drawn. The former is strewn with bowlders, and the limestone outcrops frequently, whereas on the gravel areas there is no stony material larger than cobbles.

A short distance southeast of the station is a large kame, sixty to seventy feet above its surroundings, composed of loose, rather fine gravel. This kame is closely connected, both in position and time of origin, with the adjoining kame terrace.

Towards its southern end the kame terrace has an altitude of about 540 feet. Its surface rises and falls in swells and hollows, with a relief of ten to twenty feet. Northeastward the terrace rises above 570 feet. Its top is much interrupted by winding, irregular, more or less connected depressions, some of them forty feet deep. The short ridges and hillocks between them are, therefore, more or less discontinuous. This area is an excellent example of one form of kame terraces.

Three-fourths of a mile northeast of the above kame terrace, and a half mile east of DeKay's station, is another considerable deposit of stratified drift, which extends towards New Milford (N. Y.). At its western end, the gravel forms two high terraces, one at 548 feet, the other at 528 feet. Westward and northward these terraces have steep slopes, which in places look as if they were built into standing water. In general their surfaces are loose, gravelly, and free from bowlders, but towards the southern end of the area the bowlders become numerous. For a little distance their tops are flat, but towards New Milford the terraces pass into a kame area, the hillocks of which are twenty to forty feet high. Occasional traces of the terrace level can, however, be seen, even among the kames.

The gravel of this area, and of that east of Maple Grange station, contains a large amount of shale and sandstone from the Hudson River formation. In this respect it is in marked contrast with the gravel exposed in the cut near Sand Hills station. The reason for the rapid increase of shale in the gravel areas northeast of Vernon is explained by the occurrence of a belt of shale in New York, in the vicinity of New Milford. Its known occurrence in this valley in New Jersey is limited to one very small outcrop.

Stratified drift between Vernon and Glenwood.—A line of kames extends from near the Longwell schoolhouse, northwest of Vernon, on the west side of the Wallkill, to the State line, and for an unknown distance beyond. It is best marked for the first mile and a half north of the Longwell schoolhouse. Farther north it is more or less interrupted by outcropping ledges of rock and areas of till. For most of its extent, it does not lie next the alluvial plain, but is separated from it by rock hills thinly covered with till. Not infrequently these hills are lower than the gravel deposits west of them. During the formation of this belt of kames, ice must have occupied the center of the valley, and covered at least such of these hills as are lower than the stratified drift. Since for a part of its extent the land just west of the stratified drift has an elevation less than that of the gravel, the ice probably covered at least parts of the surface west of the stratified drift. Between these ice masses, and around isolated blocks of ice, the glacial drainage may have deposited the stratified drift of the kames, or the stratified drift may have been deposited beneath the ice by sub-glacial drainage.

The average width of the kame belt is about a quarter of a mile. The length of the uninterrupted part is a mile and a half. For the first mile north of the schoolhouse the kame belt is sharply set off from the hills on either side by depressions. For this part of the area, the glacial drainage may have been between ice walls, but farther north, where the gravel is banked against the rock ledges, sometimes veneering them but thinly and sometimes forming terraces, the drainage seems to have been between ice in the valley and rock north of it. In its topography this kame belt is similar to those in the valley of the Wallkill. It is marked by a number of massive kames, on the flanks of which are smaller knolls. At its southern end, the belt begins with a sharply marked group of kames, whose elevation exceeds 460 feet. Several small pits have been opened in them, and there are good exposures along the road leading southeast from the schoolhouse. The gravel is fine and composed chiefly of crystalline and non-crystalline limestone, shale and gneiss. Half a mile to the northeast there are several large kames whose crests have an elevation of a little more than 525 feet. There are good exposures along the road to Maple Grange station.

For three-quarters of a mile or more north from this road, the stratified drift is more or less discontinuous, but half a mile south of the Glenwood cemetery there are several large kames, composed, so far as exposures show, of sand or silt and fine gravel, a large proportion of which is of shale. Cobbles as large as five inches in diameter are rare. Both horizontal and cross stratification is shown. The kame topography is well developed in the Glenwood cemetery, where the knolls are fifteen to twenty feet high.

At Glenwood stratified drift rises to an elevation of about 520 feet against the hills on both sides of the brook. The terrace form is best shown back of the church and back of the creamery. The surface of most of the stratified drift is clayey, and where exposures are wanting, and the topography is not distinctive, it is difficult to differentiate the stratified drift from the till. Where the stratified drift crosses the State line, its elevation is not more than 440 feet.

AREAS OF STRATIFIED DRIFT NOT ALONG MAIN DRAINAGE LINES.

Summary.

The main deposits of stratified drift in the Kittatinny valley have been described in the preceding pages, but there are still to be mentioned a number of small areas, not along the main drainage lines.

In addition to the stratified deposits already summarized, there are (a) kame areas, (b) kame terraces, (c) overwash plains, and (d) esker-like ridges at a number of points.

Well-defined *kame areas* in which the kame topography is distinctly shown, occur (a) in Culver's gap, (b) at a number of points northeast of Sucker pond, Stillwater township, (c) west and southwest of Unionville, (d) near Andover, (e) and near Sussex Mills (near Mulford station on the L. & H. R. railway).

Young's island in the Pequest meadows is made up of two kames, and two more occur on Pochuck mountain, two and one-fourth miles east of north of Hamburg.

Kame terraces of various degrees of complexity are common. The more important occur (a) half a mile southwest of White pond (Marksboro); (b) half a mile northwest of Hardwick Center; (c) near Mud and Catfish ponds, southwest of Stillwater; (d) on Blair's creek near Hardwick; (e) one mile northeast of Sucker pond (Stillwater township); (f) along Trout brook, three-fourths of a mile northwest of Middleville; (g) near Wykertown; (h) one mile southeast of Libertyville; (i) half a mile west of Fredon, where the terraces have been eroded to a depth of 30-70 feet; (j) north of the Fountain house at Fredon; (k) along the inner margin of the moraine northeast of Washingtonville; (l) near the Beaver Run post-office; and (m) west and southwest of Unionville. Of the above those lettered e, f, i, j, k, l and m are the best marked and the most extensive.

Overwash plains of small extent occur in front of the recessional moraine (a) northwest of Balesville, where the plain has a length of a mile and a width of three-eighths of a mile, and (b) near Washingtonville, where the plain is less extensive. West of Branchville Junction, the moraine is bordered for a short distance by a subaqueous overwash plain fronting the Paulinskill meadows, northeast of Newton.

The only well developed esker, and this somewhat discontinuous, is in Sussex county near the State line, southwest of Unionville, N. Y. Two poor examples of the esker type are found in Warren county, three-fourths of a mile northeast of Walnut Valley, and north of Southtown, respectively.

Local Details.

Half to three-fourths of a mile *west of Hainesburg* are two small gravel areas. The one nearer the road forms a low flat clayey terrace at one end of a small marsh. The other has rather the form of a ridge banked against a side hill. A mile northwest of Hainesburg, the road cuts through a low mound of earthy compact shale gravel on the top of a slate ridge. There is a second low mound a little west of the first.

Half a mile or more *southwest of White pond,* near Marksboro, are two patches of gravel between limestone hills. Kettles and irregular shaped depressions are well marked in the larger area. The gravel varies much in thickness. Limestone outcrops in the midst of the area, while near by the gravel is known to attain a thickness of more than thirty-eight feet.

Half a mile *northwest of Hardwick Center* is a small kame terrace area of sand and gravel surrounding a small swamp. Towards its southern end the surface is plane, but northward it becomes undulating, depressions being separated by even crested ridges and knolls, whose tops mark a common aggradation level. *A mile and a half farther north* is another small kame area with well-marked knolls of gravel and sand. The area is surrounded by a surface of morainic topography, where the material is till. *A mile northwest of the last area,* and directly at the foot of the mountain, are two low knolls of sand and fine gravel. The largest is but ten or twelve feet high. These mounds are surrounded by knolls of shale of slightly different contour, practically free of drift, and of about the same size.

Deposits of clayey gravel form low mounds or small kame terraces in the *vicinity of Mud* and *Catfish ponds,* and *southwest and west of Stillwater.* Three areas of gravel in the form of kames or kame terraces also occur about a mile northwest of Stillwater. In some places the gravel is hardly more than a coating over the limestone knobs, while in others it attains a considerable thickness.

East of Newbaker's Corners are three small areas of gravel which will be passed with mention.

The deposits along the lower part of Blair's creek have been already described (p. 369), but near *Hardwick* there are deposits of some little extent. At the corners northwest of the mill pond are a number of closely associated knolls of loose, coarse gravel. Ill-formed terraces and small knolls of gravel are found along the eastern side of the creek for a mile below Hardwick. Just across the northern end of the swamp is a narrow kame area in which the knolls are sharply marked, and the gravel is loose and somewhat sandy. Kame terraces, strewn with cobbles, and marked by undrained depressions five to ten feet deep, extend along the creek for three-quarters of a mile above Hardwick.

At the southwestern end of Sucker pond there is a small flat-topped area of coarse gravel, well set off topographically, from the surrounding till areas. At the northeast end of the pond also there are considerable accumulations of coarse gravel. Within this area, kames and terraces are sharply marked, though not on a large scale. The relief is not infrequently fifteen to twenty-five feet. Traces of the same aggradation level are found in low knolls and kame terrace patches along the swamp to the north, and in a small, gently undulating clayey plain to the north-east. About a mile farther northeast, on the western side of the swamp the same aggradation level is again shown. Within this area two sharply contrasting types of kame terrace topography are shown. In one part of the area are sharp, steep-sided knolls and winding ridges, enclosing undrained hollows, but a common summit level prevails. Closely adjoining, the terrace form pre-dominates, and the even surface of the gravel is marked by slight depressions only. Although the ridges and knolls are sharply marked, the relief is not great, as they do not rise high above the swamp. Across the swamp, to the southeast and to the east, are small gravel areas showing much the same topography.

A mile farther northeast, and a little beyond the road leading to Swartswood, are large accumulations of gravel, which show the same aggradation level as those just mentioned. Massive kames, kame areas and kame terraces are all represented. In general the surface material is loose. Cobbles are very abundant on some parts of the area, and bowlders are not rare. Some knolls are made of fine materials and some of coarse.

Closely associated with these areas, which are unmistakably of stratified drift, are others in which the evidence is not so unequivocal. These doubtful areas occur at levels both higher and lower than those of the well-marked gravel areas. Their surfaces are generally more bowldery, more clayey, and, on the whole, more till-like. Their topography, on the contrary, suggests stratified drift. In the absence of exposures it is impossible to classify them definitely.

A little more than *a mile southeast of Sucker* pond, high terraces of stratified drift border Trout brook for a short distance. The stream has cut deeply into the original deposit, so that the terraces, rising high above the stream, are conspicuous. Their extent is small and no other gravel deposits are found along the valley of Trout brook as far as Middleville, save a small area of low mounds high up on the valley side, three-fourths of a mile northwest of Middleville.

At the north end of Swartswood lake, there are gravel deposits of some little extent. They have been eroded by the stream flowing into the lake, and a secondary and lower terrace developed. The deposits are generally coarse and rather clayey, cobbles and small bowlders being common. The gravel is finer towards Little pond, and in places sand predominates. North and east of Little pond are low, narrow terraces of shaley gravel.

Northwest of Balesville, the moraine is bordered for nearly a mile by an overwash plain averaging three-eighths of a mile in width. Its surface is, in general, plane, sloping gently away from the moraine, but towards its western end, it becomes somewhat undulatory. Part of the way the overwash plain is separated from the moraine by a depression twenty to thirty feet deep. Another small and unimportant area of gravel lies just south of the moraine at the north end of Bear swamp, but otherwise the moraine from Balesville to Culver's gap is not bordered by stratified drift.

In the vicinity of Wykertown are two gravel areas. One of these is a small kame terrace along the brook just southeast of the village; the other is in the midst of the swamp a mile north. The latter rises a little more than twenty feet above the humus and alluvial deposits. Its surface is flat or but gently undulating, and its slopes often show the effect of the ice, against which its materials were probably deposited.

Three-fourths of a mile *southwest of Coleville,* there is a low hill of sand and gravel. A mile to the southeast are two small, unimportant patches of stratified drift.

A mile south of east of Libertyville, and a short distance southwest of Clove, there is an area of stratified drift of considerable size, and of some interest topographically. It is a strongly marked kame terrace, having an aggradation level of 650 to 660 feet. This level is more than 100 feet higher than that of the kame terrace along Clove river near by. Indications of an aggradation level are of frequent occurrence, but in general the surface is characterized by a rolling, tumbled topography of knolls and kettles, having a vertical relief of twenty to thirty feet. Some of the depressions contain ponds or swamps.

Narrow kame terraces border a small brook a mile and a half *north of Sussex.* The surface of the terraces is usually plane, but sometimes slightly undulatory. The gravel is rather clayey, and composed chiefly of shale.

West and southwest of Unionville, are several large areas of stratified drift, forming kame terraces around the shale hills and along the margin of the large swamp. In the northern part of the area, the terraces are clearly marked. In the eastern part, there is a broad, flat, clayey plain, the elevation of which is slightly less than that of the terraces just mentioned. Its surface is clayey, but well-borings show that there is loose sand and gravel beneath.

On the south side of the swamp there are two slightly separated areas of gravel. That on the west is composed of several massive kames, which are, in a measure, distinct from one another, though connected at their bases by low mounds of gravel. These kames rise from twenty-five to sixty-five feet above their surroundings. In the eastern area the individual kames are less marked, the knolls are smaller and approach a common level. On the northern side of the marsh is another row of kames, the height of which agrees quite closely with the aggradation level farther north, but is less than the elevation of the kames at the south.

In the midst of this area of stratified drift there is a well-defined esker, the best example in this part of the State. This will be described below.

Between the Paulinskill and Pequest river there are some patches of stratified drift, of which mention is here made.

Half a mile west of *Swayze's Mills*, Hope township, is a small kame area, and near Mount Herman are several small patches of gravel, one of which is cut through by the road. A little farther northeast, and west of Feebletown, narrow, slightly hummocky terraces border the alluvial plain. In spite of the till-like nature of their surfaces, the material is stratified.

At the south end of *Green's pond* there is an area of stratified drift, the surface of which is generally flat, though broken by shallow depressions. At the northern end of the pond also are small, ill-defined patches of gravel.

Young's island, near the upper end of the Pequest meadows, is composed of two kames, rising twenty-five feet above their surroundings. At a number of places between Young's island and Allamuchy, there are areas of gravel on the left side of the Pequest. They take the form of single kames, kame areas and kame terraces. Their elevation is greater than the height of the Quaker Settlement level, with which they are not to be correlated. They belong rather with the half-buried kames which rise above the Settlement plain.

Between Southtown and Glover's pond, Frelinghuysen township, are small kame-like deposits of gravel, which have no great thickness, as shown by the frequent outcrops of limestone. Associated with them is an esker-like ridge, which will be referred to later.

Several small mounds of gravel and cobbles occur along the brook and alluvial plain *a mile west of Kerr's Corners, near Paulina.*

Two miles *due east of Stillwater* there is an irregular area of stratified drift. Near the three road corners, the gravel forms small flat-topped terraces separated from each other, and in some cases from the higher land, by a swampy alluvial plain, above which they rise twenty-five to thirty feet. They seem to have been formed in separate cavities or re-entrants in the ice, rather than to have been separated by subsequent erosion. This gravel area extends southwest along the road for nearly a mile.

Half a mile due west of Fredon is a large gravel area. Its topography is that of an interrupted, flat-topped terrace bordering the shale hills, and surrounding depressions of more or less regular outline. The area is divided by the brook, which has lowered its channel thirty to seventy feet since the ice time. One kettle thirty-five to forty feet deep was noted. The finer gravel is chiefly of shale, but it contains a small amount of limestone. A large per cent. of the cobbles are Oneida. Although the lower part of the gravel is loose and sandy, the surface is, in many places, firm, clayey and till-like. The general level of the terrace is about 660 to 670 feet. Half a mile to the southeast, near the Fredon schoolhouse, are three or four knolls of loose shale gravel of the kame, rather than the terrace type.

North of the *Fountain house at Fredon,* are distinct terraces of gravel having an elevation of 690 feet. They border the shale hills and more or less completely enclose irregular hollows. The terrace rises ninety feet above the road leading to Emmons station, and has a width of between 100 and 200 yards. Traces only of gravel are found on the west side of the brook, and it is not certain whether the terrace formerly extended across the valley, or whether it was built on the side only. In the former case, the stream on the average, has lowered its channel eighty feet. The topography of the stratified drift in parts of this area suggests that it was deposited in the presence of ice, and if so, the terrace may have been restricted to one side of the valley. Near the mill-pond at Fredon there is a good exposure of the gravel. Layers of very fine yellow sand, four or five inches thick, are interbedded with coarser sand and fine gravel. The bedding is regular, but steeply inclined towards the ends of the lobes of the terrace. As a whole the gravel is not at all clayey, though its surface is. Most of the pebbles are of shale, and have the iridescent, bluish-bronze color, so often noted in the shale gravel.

A mile and a quarter *northeast of Newton* is a small patch of gravel forming a narrow and ill-defined terrace on the hillside.

Just south of the *moraine* at *Washingtonville* is a small but clearly marked overwash plain, the surface of which slopes from the moraine. While the soil is clayey, shallow excavations show loose shale gravel beneath, the depth of which exceeds fourteen feet. Three-fourths of a mile farther east another small flat, probably of stratified drift, borders the moraine.

For a mile *west of Branchville Junction,* the moraine is bordered by a gravel plain having an average width of a fourth of a mile. Its surface slopes gently from the moraine, and is rarely interrupted by shallow depressions. Cobbles and small bowlders are abundant on some parts of the plain. South of the gravel deposit is a large swamp, where the plain ends in a steep escarpment forty to fifty feet high. The front is slightly lobate and resembles a delta front, but the form is not sufficiently well defined to make this interpretation certain. The situation, however, is one in which a temporary lake might well have been formed. The swamp to the south is now drained to the north, *via* Lafayette. When the ice front stood just south of Lafayette a small lake probably covered the meadow which extends southward to Newton. If the depressions in the stratified drift south of Newton were still filled with ice blocks when the edge of the main ice sheet lay at the line of the moraine, the lake might have had an elevation of 600 feet or more. In such a lake the above plain may have been built. The gravel of the plain, composed largely of Hudson River shale, is well shown at a number of cuts along the railroad. Not far from the overwash plain, on the western side of the swamp, are a number of gravel mounds banked against limestone ledges.

Immediately about Branchville Junction is a nearly level tract, at an elevation of from 590 to 600 feet, which is probably of stratified drift. Half a mile *southeast of this area,* and across the swamp, there is a low elliptical hill of loose sand and gravel, the surface of which is marked by undulations five to eight feet in height. Half a mile farther to the southeast, along the railroad, are two small gravel patches, one of which is utilized by the railroad as a source of ballast.

A mile northeast of Washingtonville, the inner margin of the moraine is bordered by great accumulations of sand and gravel. These have the characteristic topography of stratified drift deposited about ice. The pitted plain topography is sometimes present, but over the greater part of the area the hollows are so numerous and so large that the general level is marked only by the ridges and mounds between the depressions. Towards the northern part of the area, the gravel deposits form several large, flat-topped and nearly isolated kames. Judging by exposures along the road in the side of one of them, the gravel is very uniform in size, the pebbles varying from one-half to one inch in diameter. It is free from sand, and composed almost entirely of shale pebbles. Half a mile northwest is a fine example of a single massive kame. It rises sixty to eighty feet above its surroundings. A few minor hillocks partly destroy the symmetry of its slopes. Much of the hill is composed of fine sand, but Oneida and Medina cobbles are abundant.

A mile and a half *northeast of Lafayette,* a deposit of shale gravel forms broad, flat-topped mounds, rising a few feet above its surroundings.

A mile and a half due *west of North Church* is an extensive low-lying plain, sloping gently southward. The higher part, which is in places slightly pitted by shallow kettles, is certainly of stratified drift, although the surface is rather clayey. It is difficult, however, to separate this part from the lower slightly swampy portion of the plain, which is covered with alluvium. At its northern margin, this plain has an elevation of a little above 580 feet. At its northeast corner it passes into a well-marked kame area, the knolls of which do not rise above the level of the plain to the south. At the northwest, also, there is a kame area, where the gravel attains an elevation of about 600 feet.

A number of small kame terraces are found along the creek northward from *Harmony Vale.* Their elevation (580+) is about the same as that of the plain just mentioned. The gravel is made up largely of shale.

In the vicinity of *Beaver Run* post-office are considerable deposits of gravel, which in places form broad terraces at about the same elevation as the small terraces at Harmony Vale, and the larger plain a mile and three-fourths to the south. Their elevation is from 580 to 600 feet. Back of the post-office, the gravel forms well-marked knolls on the hillside, rather than a distinct terrace, but a little to the west, and north of the road leading to Papakating, the terrace is finely developed. It is built against a limestone ledge on the east, but to the west and south it falls off steeply twenty to thirty feet. Its margin is lobed, and the lobes resemble delta lobes more than slopes built against ice-masses. They may have been formed in a temporary lakelet. South of the road the gravel forms two or three massive kames, the largest of which is sixty feet high.

From a number of exposures along the roads which cross this area the gravel is seen to be largely of limestone and shale, though Oneida and Medina cobbles are by no means rare. Gneiss pebbles occur but sparingly.

Kames on Pochuck mountain.—Two sharply marked kames occur on Pochuck mountain. They lie in a sort of amphitheater two and one-fourth miles east of north of Hamburg, and one and one-fourth miles south of Independence Corners. Their slopes are as steep as loose material will lie. The larger of the two is forty feet high. The gravel is chiefly of gneissic origin, and contains a large amount of sand. From this kame a splendid view of the even crest of the Kittatinny mountain and the broad rolling Kittatinny valley can be obtained.

Andover kame area.—A kame area extends northward from Whitehall a little beyond the cemetery at Andover. Over most of the area there is no trace of an aggradation level, and the topography is that of a kame area rather than that of a terrace. In and about Andover, however, there is an approach to kame terrace topography, and there are traces of an aggradation level at about 650 feet. This is much less than the height attained by several of the kames south of Andover. It is quite probable that the southern part of the area was formed a little earlier than the northern, and under somewhat different conditions.

Much of the material of the southern half of the area is fine gravel and sand. The surfaces of the kames are loose and sandy. Occasional bowlders are present, but they are not abundant. The largest kames of the area, and one of the largest individual kames in Sussex county, lies half a mile north of Whitehall, and a little east of the road. It rises eighty-seven feet above its surroundings. East of the large mill-pond at Andover the surfaces of the kames are thickly covered with bowlders, whereas nearer the village, on the 650-foot level, they are rare.

The best exposure of the material of this area is found in the large pit just east of the cemetery. The material is of all sizes up to bowlders six or seven feet in diameter. Seventeen bowlders between three and seven feet in diameter were seen either in the pit or still imbedded in the gravel. All but two of them were of gneiss. The gravel is sandy, loose, and contains little or no earthy matter. Oxidation has affected only the upper two or three feet. Of the pebbles between one and a half and three inches, limestone constitutes about fifty per cent., gneiss about forty per cent., and shale and slate most of the remainder. A few Oneidas and Medinas were noted.

That part of the gravel area near the cemetery presents the undulatory topography of a much pitted kame terrace. It rises thirty to forty feet above the alluvial plain. The irregular outline, varying width and marshy character of the alluvial plain indicate that it was originally outlined by ice-blocks, not by post-glacial erosion. The aggradation level of the wide terraces near Andover Junction (p. 406) is fifty feet lower than the level at the cemetery. They were evidently of later origin.

About *two miles south of Pinkneyville* is a small terrace of gravel rising ten or twelve feet above the neighboring swamp. Its surface is flat save for an occasional shallow kettle. Cobbles are quite abundant. Ledges of limestone outcrop through the gravel at a number of places.

At Sussex Mills is a good example of a kame area in which the individual kames attain considerable size. The topography is strongly undulatory, the relief reaching forty feet. Bowlders are by no means rare on the surface, which is often till-like. The gravel is chiefly of gneiss, but it contains a little lime carbonate and considerable shale. Low mounds and ill-defined terraces occur for a little distance along the stream. A quarter of a mile to the south are two large typical kames, one of which is sixty feet high. They are made up, so far as the surface shows, of fine gravel, containing a large amount of gneissic sand. Across the road farther south are narrow gravel terraces surrounding deep swampy depressions. The southeastern limit of this area is very indefinite.

A short distance east of this area, on the south side of a swamp, is a small, ill-marked kame terrace, the material of which is loose and chiefly gneissic.

ESKERS.

Well developed eskers are not abundant in the northwestern part of the State. Indeed, they may almost be said to be absent, for the few examples are hardly typical of this rather remarkable phase of stratified drift. In Warren county there are but two eskerine ridges, both of which are small and ill-defined. One is on the northern slope of a limestone hill, about three-fourths of a mile northeast of Walnut Valley. Its length is not more than 250 yards, and its width is fifty to sixty yards. At its upper end it thins out gradually, but to the north it ends abruptly. Its crest is undulatory, and nowhere does it rise to a great height above its surroundings. It is, perhaps, an eskerine or "serpentine" kame, rather than an esker. The other is north of Southtown and southwest of Glover's pond. Its length is 350 to 400 yards, its width forty to fifty yards, and its height five to fifteen feet. To the north it ends sharply at the swamp; southward it fades away on the hillside. Its surface is cobble strewn.

In Sussex county there are but two well defined eskers, one east of the mountain and one west of it.

The former, in the midst of the kame area southwest of Unionville, N. Y., is the best developed esker in this part of the State. It begins a little south of the road which leads southwest from Unionville to Clove river, and about a mile south of west of Unionville. At its northern end it is not distinctly separable from the kame deposits with which it is associated, but southward it speedily assumes the form of a ridge, and is bordered on either side by a swamp, above which it rises abruptly about twenty feet. It is slightly sinuous, narrow on top and steep-sided. After a course of 450 yards it ends abruptly, but after a break of fifty yards is continued as a low winding ridge, at first not more than five feet high, but soon rising to twenty feet. It suffers another interruption of 300 yards, or more, but re-appears in the kame area on the south. Here it is a sharply marked, slightly sinuous ridge, with steep sides, narrow top and undulating crest. At its southern end it merges into the kame terrace not far from the road. Even where lowest, it is clearly separated from its surroundings. In its narrowest portions it is barely twenty feet wide at top, but the width is usually nearer fifty feet. The length of the last section is about 600 yards. Its length, including the two gaps of fifty and 300 or more yards is nearly a mile. The material is, in general, coarse gravel. Cobbles are numerous on the surface, and are often twelve or fifteen inches in diameter. Its southern end is a few feet higher than the northern.

Midway between Glenwood and DeKay's station is a narrow belt of gravel which extends from the alluvial plain of the Wallkill northeast into New York. Its length in New Jersey is about three-quarters of a mile. Its width varies from seventy-five to 130 yards. This belt of gravel is not marked by a single winding ridge. On the contrary, it is composed of a succession of elongated knolls, somewhat isolated from each other, but connected by smaller hillocks. These knolls rise fifteen to thirty feet above their surroundings. Sometimes a single hillock occupies the whole width of the belt, but in the widest part of the belt there are several knolls side by side. Nearly everywhere the gravel is sharply set off by depressions from its surroundings. Under a strict classification this belt of knolls might better be regarded as a narrow, somewhat sinuous kame belt than as an esker. Its classification would be determined largely by its form and relationship north of the State line.

The material is well exposed in several pits. The gravel is loose and generally fine. Bowlders are rare. Three-fourths of the material is limestone, mostly the white crystalline variety. Shale and slate form most of the remainder. Gneiss, Oneida quartzites and Medina sandstone are also present, the last two sparingly.

CHAPTER XI.

THE DRIFT OF THE HIGHLANDS.[1]

BY ROLLIN D. SALISBURY, HENRY B. KÜMMEL AND
CHARLES E. PEET.

CONTENTS.

TOPOGRAPHY AND SUBDIVISIONS.

The Highlands of New Jersey is the area between the Triassic plain on the south and east, and the Kittatinny valley on the northwest (See Plate VII, p. 6). It is, for the most part, underlain by crystalline schists and gneisses of pre-Paleozoic age.

[1] The detailed study of the drift of the Central and Eastern Highlands was chiefly by Mr. Charles E. Peet, and many of the facts and relations brought out in this chapter are based on his work. The drift of the Western Highlands was studied by Mr. Henry B. Kümmel, upon whose report this part of the chapter is based.

There is, however, not a little quartzite and even sandstone in the Highlands, and the Green Pond mountain belt is of Paleozoic age.

As the name implies, the Highlands is an area of high land notably above its surroundings on all sides. Generally speaking, it is highest to the northwest and lowest to the southeast; but instead of being a plateau, as its name might suggest, it is an area of strong relief. The valleys of the Pequannock, the Wanaque, the Rockaway, the Musconetcong and the South Branch of the Raritan, as well as the valleys of many lesser streams, are notably below the summit level of the region in which they occur. So numerous are the valleys, large and small, and so far do they separate different portions of the Highlands from one another that the various parts have received distinct names.[1] Most of the mountains of the Highland area, unlike the Kittatinny range and the Wallpack ridge, are not narrow, even-crested ridges, but mountain masses instead, often with horizontal dimensions approximately equal in all directions. It follows that the northeast-southwest trend, so pronounced in the topography of the region farther west, is much less conspicuous in the Highlands. There are various local features, however, some of them obtrusive, which show the recurrence of this trend. This is especially true of the Green Pond and associated mountains, and of the valleys and ridges in Warren county.

The crests of adjacent mountains in the Highlands so closely approximate one another in elevation, that were the intervening valleys filled, the Highlands would be converted into a plateau, declining gently to the south and east. The great valleys which dissect the plateau are the work of the streams which cross it.

While the Highlands is in some sense a unit, it is, nevertheless, so diversified that it is convenient to speak of it as composed of three parts, the Western, the Central and the Eastern. The Western Highlands lies west of the Vernon-Sparta and Musconetcong valleys; the Central Highlands between this valley and the Greenwood Lake-High Bridge valley; the Eastern Highlands between the last named valley and the Triassic plain.

---

[1]See Physical Geography of New Jersey, Vol. IV, Final Report of the Survey, 1895.

The western division, so far as it lies north of the moraine, includes the Pochuck mountain, the Pimple hills, and their southward continuation west of Sparta mountain, Allamuchy and Jenny Jump mountains, and the north end of Upper Pohatcong. The topography of this division is broken, Pochuck and Jenny Jump mountains being completely isolated from the main Highlands area, and the others nearly so. West of the south end of Sparta mountain is the only topographic bridge connecting the western division with the central.

The topography of the central division is much less broken, more plateau-like, and the area is somewhat higher. North of the moraine it includes Wawayanda, Hamburg, Sparta and Bowling Green mountains, as well as other parts which have no separate names.

The eastern division is more broken and lower than the central. Ramapo mountain, somewhat isolated topographically by the valley of the Wanaque, forms its northeastern part.

THE TILL OF THE WESTERN HIGHLANDS.

General statement.—The till of the Western Highlands is composed largely of gneissic and granitic material derived from the underlying formations; but since the movement of the ice was a little less to the west than the face of the Highlands, some material was carried up from the Kittatinny valley on to the Highlands to the east. Material from the Kittatinny valley, as would be expected under these conditions, is most abundant along the slope of the Highlands facing the valley. The ice which came on to the Highlands from the north had been passing over gneisses and schists for but a few miles, when it entered New Jersey. Farther back in its course, it had traversed broad areas of Hudson River shale and sandstone, and materials derived from this formation in New York are more abundant in the drift of the Highlands than those carried up from the Kittatinny valley in New Jersey. To the north, also, the ice had crossed the Oneida ledges of the Shawangunk mountain, and had brought bowlders from this formation with it to the Highlands.

Over the Western Highlands, therefore, and over the Highlands farther east as well, material derived from somewhat distant sources is mingled with that of local origin. In general, bowlders of distant origin are more plentiful where the drift is thick than where it is thin.

The till of the Western Highlands is often clayey and compact, and is sometimes foliated, though none of these characters is universal. Sometimes it is loose, and much like the unconsolidated products of gneiss decay. It is generally stony, and many of the bowlders are large, frequently exceeding ten feet in diameter. Not infrequently they are so abundant at the surface as to render the task of clearing and cultivating the land an almost hopeless one. This is particularly the case where the till is thin, and where numerous outcrops of the underlying ledges add to the general rocky character of the surface.

Nearly everywhere the larger part of the bowlders are of the local rock, and others are abundant only near the western edge of the Highlands. Many of the bowlders show little sign of wear, while others are distinctly glaciated, though rarely striated. The proportion of bowlders showing signs of wear varies greatly in different localities, and the proportions of bowlders of different varieties showing glaciation is also variable. The Hudson River sandstones are usually distinctly glaciated, very often on all sides. This is partly because of the readiness with which they received striæ, and partly because they weather less readily than some of the others. The limestone bowlders on the surface have been so deeply weathered that the marks of glaciation are generally obliterated. In many cases their surfaces are so rough that it is difficult to believe that they were ever glaciated.

The color of the till at the surface is uniformly that of gneiss residuary, a yellowish brown. This color commonly changes beneath the surface to greyish brown, but in many places exposures are too few to make this evident on cursory inspection. The brown color sometimes extends to a depth of six feet, but this is exceptional. Even where limestone bowlders of considerable size are occasionally found at the surface, the till exposed in shallow cuts (six feet and less) is rarely calcareous, but where limestone is a considerable constituent of the till, the latter is sometimes so calcareous as to respond to the acid test within one or two feet of the surface.

Owing to the forested character and the scanty population of much of this region, exposures of the till are not abundant. The shallow and often old and weathered cuts along the roads afford nearly all the available data, aside from those furnished by the surface, from which to judge of the constitution, physical character, color, amount of oxidation and thickness of the till.

The till is almost uniformly very thin on the steep slopes, many of which have barely enough to afford a foot-hold for timber. On the gentler slopes, the broader summits, and in the cols, till is more plentiful. While outcrops of the rock are more or less common over all the Western Highlands, there are, in the aggregate, considerable areas where the rock is well concealed.

In the absence of frequent exposures and borings, any estimate of the thickness of the till may be far from the truth. Where its thickness exceeds the depth of the shallow exposures, there is usually no way of determining whether it is ten or fifty feet deep, though between these extremes, surroundings may give some clue. One case is known near Ogdensburg where the depth of the till is about 100 feet. There may be many others, but it is certain that the general average for the whole of the Western Highlands is very much less than this. The average thickness is, perhaps, between ten and twenty feet.

Local Details.

Jenny Jump mountain.—The till of Jenny Jump mountain is largely of local origin, even though the mountain is isolated and almost completely surrounded by formations of other sorts of rock. On the broad summits and gentle slopes, the till is clayey, often compact, and beneath the surface often foliated. This structure is always absent down to the depth to which the disintegrating effects of weathering have penetrated. Where the till is present in best development, it contains a good admixture of limestone, Oneida, Hudson River and Medina bowlders and cobbles. All of these materials were carried up by the ice, some of them several hundred feet. Some of them, like the Oneida bowlders, were probably carried down from the Kittatinny mountain (or its northward extension) to the valley before being carried up to the Highlands.

Locally, the till is decidedly arkose, the matrix being largely of disintegrated gneiss. This type of till is often firm and compact, and sometimes so largely of local material that careful search is necessary to discover any foreign material whatsoever. Several exposures of this type of till are found along the road leading from Hope up the mountain.

In many places rock ledges, large and small, project through the till. These are most abundant along the steep escarpment southwest of the Davis mines, east of Shiloh. They are less numerous along the northwestern slope of the mountain. The largest bare ledge is at the southwest end of the mountain, north of Bridgeville.

From the minimum of zero, the depth of the till increases to a known thickness of forty feet, a thickness observed in a ravine on the slope of the mountain east of Shiloh. It is probable that still greater thicknesses exist, but not probable that they are common.

That the till in many localities rests on the eroded and polished bed rock is a fair inference from the many firm *roches moutonnées* which project through the drift. Numerous observations, however, show that this is not always the case. In some instances a thin layer of till rests on loose and disintegrated gneiss which was not disturbed by the ice, as is evident from the distinct gneissic banding still visible in the decayed product. The line of contact between the till and this product of decay is often sharply marked. In one case the decayed gneiss was exposed to a depth of nearly three feet, and was as completely disintegrated at that depth as at the point of contact with the till. In view of the general fresh appearance of the gneiss ledges where not protected even by a thin layer of till, it is rational to conclude that this disintegration took place before the till was deposited, rather than afterward, and that locally, for one reason or another, the ice failed to completely remove the products of decay.

One example of "crag and tail" occurs near the northeastern end of the Jenny Jump mountain. The 1,130-foot hill just east of the Davis and the Old Silver mines is but thinly drift covered, and ledges of all sizes are common. On the southwestward prolongation of this hill, at an elevation of about 800 feet, the till is thick, although there are a few outcrops on the steep slope towards the Pequest meadows. This is the only example observed on the mountain where the drift is notably massed on the lee side of a hill.

Good illustrations of post-glacial disintegration were noted on the surface of this hill. Many of the small bowlderets and cobbles of some varieties of gneiss have been completely disintegrated, their former position being marked by patches of arkose. Occasionally a small, firm core of a large cobble is present in these patches. Around the larger bowlders also the surface is sometimes covered by this disintegrated material.

Post-glacial weathering has been sufficient, in nearly all cases, to destroy all striæ on rock surfaces which have been exposed. Although *roches moutonnées* are common, their surfaces are so weathered that striæ rarely remain; but from the few scratches which were found, and from the general shape of the *roches moutonnées*, the movement of the ice over the Jenny Jump mountain is known to have been about S. 12° W. Local deflections, even to the extent of 27° to the east of this (S. 15° E.), occurred under the influence of local topographic conditions. The general movement of the ice was therefore somewhat more southerly than the trend of the mountain, so that the ice crossed it obliquely.

Bowlders ten or fifteen feet in diameter are not rare on the mountain, and even larger ones occur. The large bowlders are usually of gneiss, and were probably transported but a short distance. The largest bowlder of the region, however, near the schoolhouse northeast of the Kishpaugh mine, is of blue limestone. It is rough and angular, and measures approximately 50 x 25 x 15 feet. Prof. Cook[1] estimated its weight at 2,000

[1]Annual Report of the State Geologist for 1880, p. 53.

tons. This bowlder must have come from a point at least two miles northwest of the mountain, and must have been carried up over a ridge some 200 to 400 feet above its source and down again on the other side, before being carried up the mountain where it now lies. This is one of the largest bowlders in the State.

Allamuchy mountain.—The till on Allamuchy mountain is so similar to that on the Jenny Jump mountain, that the description of the one is applicable in most of its details to the other. In general, the till on this mountain is thicker than that on the Jenny Jump, but it is thinner on the spur of the mountain extending southwest towards Danville than near Warrenville and Allamuchy. The ledges are large and numerous on the steep slopes north and northwest of Petersburg, a mile northwest of Warrenville, and just west of Allamuchy pond. Just north of the pond the till is thick, and forms a dam across the valley confining the pond. On the westward face of the mountain northeast from Allamuchy the till is so thick that outcrops are rare, even though the slope is steep. The average thickness on the mountain may approach twenty feet.

Over most of the area large bowlders are common. By far the greater part of them are of gneiss, but bowlders of other sorts are common, if not abundant, and in a few localities they predominate. At one spot on the broad, till-covered crest of a low ridge a mile and a half due west of Warrenville, limestone bowlders are the most abundant (thirty-three per cent.), with gneiss next (twenty-eight per cent.), and Oneida third (twenty per cent.), whereas a quarter of a mile to the south the gneiss bowlders are five times as abundant as those of limestone.

So far as could be judged from surface indications, the till on the mountain between Allamuchy and the moraine north of Hackettstown contains a considerably smaller percentage of limestone than the moraine itself. Where the till is thin, it seems to be largely of local material with but a slight admixture of foreign material; but where it is thick more of it was brought in from north of the mountain.

At a number of places on the northern slope of the mountain there are small areas of till in which the morainic topography is slightly developed. The largest and most pronounced of these areas is near the corners about two miles west of Warrenville. Here the knolls are steep and sharply marked. In places the relief is twenty to forty feet. Judging by the surface indications, the bulk of the material is till, though some of the knolls are of gravel.

Gneiss hills northeast of Andover, the Pimple hills, and the western slope of Sparta mountain.—The till of this region is largely of gneissic origin, and often resembles the products of gneiss decay. So far as is shown by the shallow road-side exposures, it is often loose and sandy, so much so that its surface sometimes resembles the surface of stratified drift. In other cases it is more clayey, and therefore more compact. Occasionally slight traces of foliation are to be observed, but fresh exposures sufficiently deep to show this structure are rare.

Its color, so far as seen in the exposures, is nearly always yellowish brown, the color produced by varying degrees of oxidation and weathering of gneissic rocks. The till over all this area is stony, the bowlders sometimes reaching a large size, in more than one instance exceeding fifteen feet in diameter. Eight per cent. or more of the surface bowlders are of gneiss, and others are frequently very rare. Those foreign to the Highlands are Hudson River, Oneida and Medina sandstones.

The thickness of the drift is very variable. Outcrops of gneiss are somewhat abundant, and yet in places the till probably attains considerable thickness. On the steep slopes it is usually very thin, and the steeper faces, like the escarpment facing the swamp a mile north of Sparta, are practically free from drift. Till is not present in any quantity on the upper slopes of the two sharp hills just north of Sparta, although banked thickly against the lower slopes 100 feet below the crest. Bare ledges are common, also, among the Pimple hills wherever the slopes are steep. On the gentler slopes, on the other hand, on the broad summits of the plateaus, and in the cols, the till is often relatively thick.

Exposures in the till are found only along the railways and highways. They rarely exceed eight feet in depth, and often do not reach its bottom. On the other hand, over many acres, the rock outcrops every few yards, and the till covering is therefore very thin. Ten feet probably represents a high average for the thickness of the till of this area.

Good exposures of till are found along the railway just south of the South Ogdensburg station and at the Ogdensburg zinc mine. At the latter point the drift is from ten to thirty feet thick. The underlying rock is crystalline limestone, but gneiss ledges are not far distant. Blue and crystalline limestone are very abundant in the till, and striated stones are common. The till is compact, clayey, and but little oxidized on the surface. There is here no indication of an upper till.

At a number of places about the mine, the till is covered by several feet of sand made up of grains of partially disintegrated crystalline limestone. This material is found only on the steep slope and in the vicinity of a projecting ledge of much-weathered limestone. It affords some clue to the amount of post-glacial weathering and wash.

Good examples of glacial grooving occur at the eastern apex of the triangle of roads about two miles south of Pinkneyville. One of the best examples of a perched bowlder in the State occurs on the property of Mr. Earl, between two and three miles southwest of Sparta, in plain sight from the road. Here a bowlder of gniess measuring approximately 8 x 8 x 10 feet, appears to be so delicately balanced on a gneiss ledge that a push would topple it over. It rests, however, on two or three points of its under surface, and although the greater part of its bottom does not touch the ledge, it cannot be moved.

Pochuck mountain.—In general the till on Pochuck mountain is very similar to that on the other areas of crystalline schist already described. It is largely of local origin, and has the color characteristic of disintegrated gneissic rock. Judging by the bowlders on the surface—there are very few exposures—there is a larger percentage of foreign material than on the Highlands farther east. The gneiss bowlders make up about three-fourths of the whole, the others being of Hudson River sandstone and Oneida and Medina quartzites and sandstones. There are occasional bowlders of limestone, but they are rare. Where the till is relatively thick, the matrix is generally clayey and compact, though stones abound. No good examples of foliated till were seen, but this is doubtless because there are no deep, fresh exposures, rather than because the till is not foliated. Where the till is thin it is less compact, less clayey, and apparently of more local origin than where thick. On the western slope of the mountain, from about a mile south of Milton to Independence Corner, the till is thick enough to effectually conceal the underlying rock over considerable areas. The same is true of the lower slopes east of Milton. Within this general area, however, there are places where the till is very thin. Thus in the vicinity of the corners, one and and three-fourths miles north of Independence Corner, the rock outcrops with great frequency. From wells depths of twelve and twenty feet of till are known in this vicinity.

Till conceals the rock most of the way along the road leading east of the high, almost bare ledges which guard Decker's pond on the southeast, and along the road leading northward from the Sprague schoolhouse, three-quarters of a mile north by west of Sand Hills station; but on the steep slopes east and west of this road ledges are abundant. The till is also accumulated to considerable depths on the flat summits and cols west of Glenwood. On the steep slopes of the higher hills and main ridges it is usually very thin, and ledges are abundant. Thus on the hills back of Milton there is little drift, save in the cols and on the lower slopes, and rock outcrops are exceedingly abundant along the hillside a mile south of Milton, where *roche moutonnées* are finely developed along the road. Faint striæ bear S. 32° W. The high ridge east of Decker's pond, and its continuance southwestward to Hamburg, has, on the whole, little till, save in the cols. Just east of the pond the escarpment is almost free from drift. Ledges are very abundant on the upper slope of the eastern face of the mountain northeastward from the Fisher schoolhouse. The average thickness for the mountain is probably not far from eight or ten feet.

In spite of the fact that the majority of the gneiss outcrops have something of the *roche moutonnée* surface, and in many cases afford typical examples of this form of glaciated surface, striæ are rare. Sharply marked scratches are never found on the exposed surfaces, which have been etched by post-glacial weathering. This is the case even where the surface is still firm. The absence of striæ is further accounted for by the texture of the rock itself. As a class, the gneissic and other crystalline rocks found in the Highlands are too coarse grained and uneven in texture to be finely polished and striated. They are harder, also, than much of the rock carried by the ice, and so not readily scratched. The general paucity of striæ on exposed rock surfaces over all the Highland region—for what has been said applies not only to Pochuck mountain but equally well to all the Highlands—is due rather to the post-glacial weathering than to failure of development. Striæ are doubtless not rare beneath the till.

TILL OF THE CENTRAL HIGHLANDS.

General Statement.

The till of the Central Highlands is composed chiefly of material derived from the underlying gneiss and schist. Being somewhat farther removed from the Kittatinny valley, out of which the ice had a disposition to crowd on to the Highlands, the gneissic type of till is better developed here than in the Western Highlands; yet even this region is so little removed from the shale, sandstone and limestone to the north (see Plate VII), that some material from these formations was brought in. On the whole, however, its amount is so small as to illustrate clearly the general fact that but a small proportion of the drift (till) of any locality comes from a great distance. Though most of the ice which invaded the Central Highlands had, at the northern boundary of the State, come over shale, limestone and sandstone no more than five miles away, yet, except at the extreme border of the Highlands, the drift contains probably less than five per cent. of material derived from these formations. Some of that five per cent., however, came from the northern extension of the Kittatinny range, some forty miles away, by the route which the ice followed. The topography and the character of the rock of this range fitted it for this contribution. Being high, narrow, and abrupt, the range yielded abundant material to the ice well above its base, and in this position it was carried forward without lodgment and without notable wear, while its hardness helped it to preserve its integrity. For these reasons the amount of material derived from the Oneida and Medina outcrops, especially the former, is disproportionately large when compared with the amount from the Hudson River formation nearer at hand, and outcropping over a much larger area.

While gneiss is the major constituent of the till of the Central Highlands, there are a few localities where other sorts of rock predominate in the drift, or where their contributions to it are conspicuous. These are 1) on the slope to the Wallkill, where limestone locally makes up a third to a half of the stony material; 2) on the shale formation between Milton and the Clinton reservoir, and particularly north of the Oak Ridge station for a mile or more; 3) along the Rockaway valley, slaty material sometimes predominates in the till of the lower slopes, where the underlying rock is shale or slate. Two of these localities, it will be noted, are really off the Highlands proper, and the other is on its border. There are other localities where constituents other than gneiss are important without being dominant. For example, on Bowling Green mountain, the slate, sandstone, and quartzites from the local rock, and from the formations just to the north, form a considerable percentage of the stony matter of the till, though they are not the major constituents.

Till along the western border of the Central Highlands, Hamburg and Wawayanda mountain.—These mountains lie at or near the western border of the Highlands, and therefore in a position to receive more drift from the Kittatinny valley than any other part of the Central Highlands. Yet here, as elsewhere in the Highland region, gneiss is the most abundant constituent of the till, except for a short distance, generally a fraction of a mile, east of the line of contact of limestone and gneiss. On the lower western slopes of both Hamburg and Wawayanda mountains, the till contains much limestone, bowlders of which are abundant both on the surface and beneath it. This distribution of the limestone shows that the ice, though moving nearly parallel to the trend of the west face of the Highlands, as shown by striæ, ascended the slope obliquely from the limestone belts below. South of Vernon, the face of Hamburg mountain curves westward in such a way that the ice from the valley ascended it less obliquely and carried up more debris. Associated with the limestone on these mountains is much red sandstone, resembling the Medina formation in color, but which is derived from shaley red sandstone at the base of the limestone a little south of the village of Vernon. Bowlders from this ledge were noted along the road several miles south of the outcrop. The large amount of limestone in the drift along the road leading south from Vernon indicates that the ice movement was up the valley followed by this road.

On the crest of Hamburg mountain, and farther east on Wawayanda mountain, limestone in the till is far less abundant than on the slopes below, though bowlders and cobbles from the Hudson River formation, and well-worn quartzites from the northward extension of the Kittatinny mountain are not rare. The till on the face of Wawayanda mountain south of New Milford (N. Y.), carries a large proportion of bowlders from the Hudson River formation, which lies but a short distance to the north.

Except along the western faces of Hamburg, Wawayanda and Sparta mountains, and in certain places where there are local sources of quartzite, sandstone and shale in the Highlands, the till of the Central Highlands approaches the pure gneissic type. In its unmixed form this type of till consists of a gritty matrix, composed of the comminuted products of the gneiss and schist, in which are imbedded fragments and masses of gneiss varying in size from that of sand grains to bowlders several feet in diameter. The stony constituents are generally abundant, constituting a considerable part of the mass of the till. Bowlders commonly abound on the surface where it has been left in its natural state, and bowlder walls (fences) abound elsewhere. Till of the gneissic type is rarely gravelly, and never so clayey as much of the till which overlies the shale formations.

The till of the Central Highlands, while approaching the type described above, has yet an admixture of material derived from other formations. The source of the fine material is not always readily recognized, except where it has a distinctive color; but the sources of the stony material are more readily determined. While nine-tenths or more of the stones of the drift of the Central Highlands, counting large and small, came from the underlying formations, the small remainder contains a goodly variety of material. There are sandstone and slate bowlders from the Hudson River formation to the north, quartzites and conglomerates from the Oneida and Medina, and perhaps other formations, limestones, occasional masses of Cambrian sandstone, black flints and, locally, bowlders of zinc ore. Bowlders of magnetite should perhaps be mentioned, though their source is in the Highlands.

Many of the quartzites are purple in color, while others are greyish-blue, white or pink. The source of some of them has never been determined, but may be in the Highlands. The conglomerates are often light colored, with white quartz pebbles. Portions of the Oneida formation of the Green Pond range are so like portions of the same formation in the Kittatinny mountain that bowlders from the two sources are not always readily distinguished; but most of the bowlders which on lithological grounds might be referred to either range, are probably from the latter, or from its northern extension.

Some of the sandstone bowlders are grey; others, more quartzitic, are reddish or yellowish-brown outside, and lighter within. Their distribution is very unequal. Thus along the road leading from Vernon toward Stockholm, bowlders of this sort constitute so considerable a proportion of the bowlders on the surface, that they are thought to have a local, though undiscovered, source. Locally, also, there are purplish sandstones which occur in blocks of such size and shape as to lead to the belief that, like those last mentioned, they have a local source in the Highlands, though the ledges from which they could have come have not been located. Such sandstone masses are common two miles northwest of Stockholm, where one angular mass fifteen feet in diameter was seen.

The limestone bowlders are partly white and crystalline, and partly blue and compact, corresponding to the two varieties of limestone west of the Highlands. Bowlders foreign to the Highlands are more abundant where the till is thick than where it is thin. Apart from the western slopes of Wawayanda, Hamburg, and Sparta mountains, the till of the Highlands is made up largely of material other than schist and gneiss only at points where the underlying rock is not schist or gneiss. The conspicuous illustrations are the shale and slate areas at the eastern edge of the Central Highlands, areas which really belong with the Green Pond mountain belt, rather than with the Highlands.

The bowlders and stony constituents of the till of the Central Highlands commonly show glacial wear, though they are not generally striated. One per cent. would probably represent the full proportion of distinctly striated gneiss and quartzite bowlders to be seen in the till of the region. The limestones, sandstones and shales, all minor constituents, are frequently striated, but the quartzites and gneisses seldom. The general absence of striated gneiss bowlders at the surface is largely the result of post-glacial weathering, which has obliterated any striæ the exposed bowlders may have had; but even the gneiss bowlders seen in cuts where weathering has been slight are not usually striated. The inference is that this rock did not take striæ readily.

Distribution of Bowlders.

Limestone.—Limestone is common in the drift only in the western part of the area. It is a minor constituent west of a line drawn from a point a mile east of Mt. Arlington station (Rustic), northwestward to Byram Cove (Lake Hopatcong), and thence northeastward to South Ogdensburg and Vernon. In railroad cuts in the moraine three-fourths of a mile east of Mt. Arlington station, it constitutes as much as two per cent. of the stony matter. In cuts east of Stanhope it is even more abundant. Some of the limestone of these localities may have come from within the Highlands. There is, for example, a little limestone in the Green Pond mountain belt. The limestone makes up a large proportion of the drift only where the underlying rock, or the rock in the immediate vicinity, is of this sort. Thus, north of Hackettstown, limestone is locally more abundant than all other stony constituents, and it is also abundant on the west slope of Sparta and Hamburg mountains, as already noted. East of the line indicated above, there are occasional cobbles and bowlders of limestone, but they are rare and irregular in their distribution.

The limestone bowlders in the Central Highlands are of two kinds, a white crystalline variety and a blue, compact dolomite. The latter is the more widely distributed, and its bowlders are well worn and striated where protected from weathering. The crystalline variety is the less widely distributed. The most easterly point where it was observed was south of Morris pond, and the most southerly about three miles north by west of Woodport. The distribution of white limestone is essentially the same as that of zinc ore in the drift, and the two probably came from the same place, the vicinity of Franklin Furnace. The blue dolomitic limestone is common in the moraine as far east as Rustic. That south of Ogdensburg was probably derived from the Wallkill valley. Rustic, the easternmost point where it is abundant, lies about S. 20° W. of the easternmost outcrop of limestone in that valley, and ice movement with a westing of not more than 20° would have carried the limestone as far east as that point. The striæ show that the westing of the ice movement was somewhat less than the above figure. This direction of movement would have sufficed to distribute the white crystalline limestone and zinc ore bowlders from Franklin Furnace over the same area. Their more restricted distribution, so far as observed, is probably the result of the non-resistant character of the crystalline limestone, which allowed it to be disrupted in transit.

Limestone appears also in small amount in the drift of the northern part of the Central Highlands, at points not distant from limestone outcrops in New York.

Hudson River and Devonian sandstone and slate.—Bowlders from the Hudson River formation have a wide but unequal distribution over the Central Highlands. As will be seen from Plate VII, the ice had been coming over considerable areas of this formation before reaching the Highlands. The slate material from this formation is not always distinguishable from that derived from the Devonian shales about Milton. Material from one or the other of these sources is more than usually abundant 1) east of Wawayanda lake; 2) south of Milton, on Bowling Green mountain, where the material is from the Devonian shales to the north; 3) on the west side of Lake Hopatcong where sandstone and shale sometimes make four or five per cent. of the stony material; and 4) at the head of Cranberry reservoir, where the sandstone and slate make up ten per cent. of the stony material.

North of Lake Hopatcong, and west of line drawn from Russia through Uttertown to Wawayanda lake, the slate and sandstone are less abundant than east and south of that line. The greater abundance to the east probably points to the Devonian shales and sandstones of the Green Pond belt as a source of some of the material. The area east of this line, too, is a little less distant from the Hudson River formation to the north, along the line of ice movement, than the area to the west. This is shown by the map, Plate VII.

Quartzites, sandstones (other than Hudson River) and conglomerates.—Many of the bowlders included in this group are so like beds of rock found in both the Green Pond mountain belt, and in the Kittatinny mountain and its northeastward extension, that their origin would be uncertain, but for the fact that the direction of ice movement points to the latter as their principal source. The fact that these constituents do not increase noticeably as the western edge of the Highlands is approached, shows that their source for most of the area was from the north, not from the west, a conclusion which the striæ confirm. Next to the gneiss and Hudson River sandstone and slate they have the widest distribution of any of the constituents of the drift, but west of a line drawn from Buckabear pond to the west side of Bowling Green mountain, they rarely make any considerable proportion of the drift, though they are locally sufficiently numerous to attract attention.

East of the above line bowlders belonging to this general class are more abundant, but they were probably derived from the underlying or adjacent formations of the Highlands. Bearfort and Bowling Green mountains were sources whence they could have come.

Bowlders from the Green Pond-Bearfort mountain belt.—The westernmost point where certainly identified conglomerate from these mountains was found is a little east of Mt. Arlington station, a position in harmony with the direction of striæ in the region. Bowlders of Green Pond or Bearfort conglomerate occur in abundance east of the Green Pond mountain, making up one-third to more than one-half of the stony material of the till near the east base of the mountain. In the moraine at Port Oram and Rockaway, bowlders of this formation make up nearly half of the stony material, and they are abundant to the eastern edge of the Highlands. If the movement of the ice at any stage of glaciation was more westerly than the trend of the mountain, bowlders should also have been carried over Bowling Green mountain, in the direction of Lake Hopatcong. The absence of these distinctive conglomerates from the Central Highlands is further evidence that the quartzites, sandstones, etc., of this region, many of which might on lithological grounds be referred to the Green Pond-Bearfort belt, really had another origin. Quartzites and sandstones which might easily be confused with those coming from the Green Pond-Bearfort belt, but probably came from Bowling Green mountain, occur as far west as Port Morris, and at other points east of a line drawn from Port Morris to the south end of Bearfort mountain. Quartzite bowlders are found rather commonly between Lake Hopatcong and Green Pond mountain. Some of them are from Bowling Green mountain, which is partly of quartzite, but some of them are perhaps from the Bearfort mountain. The quartzite bowlders west of a line drawn from Lake Hopatcong to the west base of Bearfort mountain, which on lithological grounds might be referred to the Green Pond-Bearfort belt, probably came from the extension of Kittatinny range in New York.

Distribution and thickness of the till.

The till of the Central Highlands is a discontinuous mantle. Where the rock is bare, as it frequently is on steep slopes and less commonly in other situations, it is not because the ice failed to cover such points, but because it failed to leave deposits, or (rarely) because erosion has since removed them. Even adjacent to the moraine, where the ice was thinner than farther north, the bowlders of distant origin on the tops of the highest elevation show that the ice covered them.

On the whole, the till is thicker on the more level tracts, in capacious valleys, and on gentle slopes, than on narrower summits, in constricted valleys, and on steep slopes.

Data are insufficient for a close estimate of the average thickness of the till, but the thousands of outcrops, not only on steep slopes and narrower crests, but on the planer tracts as well, and the numerous exposures of rock afforded by shallow road cuts, make it clear that the drift is thin. The maximum depth of till found in this region was reported in the moraine at the Mount Arlington depot, where a well was driven 260 feet without reaching rock. The deeper wells at most points show that the depth of drift rarely exceeds forty feet, and lesser depths are much more common. Such data as are at hand indicate that the average depth for the region may be fifteen to twenty feet. On Hamburg and Wawayanda mountains, it perhaps does not exceed the half of these figures.

Good exposures of till are not abundant. Such as occur are found chiefly along the railways and wagon roads, and the latter are rarely so well graded as to afford deep cuts. Among the deeper exposures are those on the railway at Hopatcong Junction, where the till is stony and composed chiefly of gneiss; near Shippenport, on the D. L. & W. railway, south of Mountain pond; at Port Morris, where a railway cut shows the till to be very stony; at the Lake Hopatcong station of the D. L. & W. railway, where large bowlders occur; a short distance east of Stanhope, where a railway cut shows fifty feet of sandy till; half a mile west of Stanhope, where the till is sandy; on the Sussex branch of the D. L. & W. railway, near the inclined plane on the Morris canal; three-fourths of a mile east of Nolan's point, at the crossing of railway and wagon road; shallow exposures along the railway north of Hurdtown, where till of the gneissic type is seen; on the N. Y. S. & W. railway, northwest of Morris lake, where the till is rather stony and the stones little worn; at the Ogden mine at Edison, where the material of the till is mainly of local origin; at the southwest corner of the Oak Ridge reservoir, a deep exposure which shows a considerable variety of stones and bowlders; a mile northwest of Oak Ridge station, on the N. Y. S. & W. railway; near the Two Bridges station of the same road; one-fourth mile west of Stockholm, a railway cut twenty feet deep, showing till of the bowldery gneissic type; at the southwest corner of the Clinton reservoir, where extensive shallow cuts show a greater variety of stony material, most of which is of rather local origin; and between Rudeville and Sand pond, where the till is more than usually calcareous. Exposures are also found about Vernon, at the west base of the Highlands.

In keeping with the thinness of the till, rock exposures abound. Mention has already been made of those on the west slope of the Highlands. East of this slope and west of the Paleozoic Bearfort-Green Pond mountain belt, rock outcrops are so numerous that their enumeration would be unprofitable. They abound on the steeper slopes, but they are by no means confined to such positions. There is scarcely a road which does not show them in abundance, and scarcely a high point which affords a wide view, where ledges of rock do not obtrude themselves.

The rock surface.—In spite of the thousands of *roche moutonnéed* surfaces, striæ are rare. The reasons for their paucity have already been given (p. 455). The few readings recorded are from freshly exposed rock surfaces, and range from S. 25° W. to S. 55° W. West of Canistear reservoir striæ on an east slope have the anomalous (for this region) direction of S. 15° E. This course is doubtless the result of local topography, and does not represent the general direction of ice movement. Good examples of glacially smoothed and polished rock surfaces occur at numerous points—as between Rudeville and Sand pond, and between Clinton reservoir and Uttertown.

The till probably rests for the most part on fresh, glaciated rock surfaces, with sharply marked lines of contact between till and rock. But locally, and perhaps in not a few places, it rests on disintegrated rock. In all observed cases of this sort the relations indicate that the disintegration of the rock was pre-glacial, the ice failing to remove the weathered product.

Foliation.—This structure, which amounts to little more than a crude sort of cleavage in nearly horizontal planes, is probably the result of the pressure to which the till was subjected by the overlying and over-riding ice.[1] Foliation is common in the till of the Highlands, though because of the few good exposures it is rarely well shown. It never appears in the shallow cuts which do not reach below the zone of weathering, nor on the talus slopes of deeper cuts; but deep fresh cuts show it frequently—perhaps generally. Good examples of this structure were noted about a mile north of Bear pond on the Roseville-Sparta road, at the head of Big Cove east of Nolan's point, and at numerous points between Stockholm and Hamburg.

Post-glacial weathering.—The amount of weathering which the till has suffered is inconsiderable. It is shown by the change from the greyish-colored matrix which characterizes the fresh gneissic till, to a buff or brownish-buff color which characterizes the uppermost two to three (rarely four or five) feet.

TILL OF GREEN POND, COPPERAS, BEARFORT, AND KANOUSE MOUNTAINS,[2] AND THE ASSOCIATED VALLEYS.

This mountain belt divides the Eastern from the Central Highlands. These mountains are composed chiefly of quartzite, sandstone and conglomerate. The valleys and lowlands associated with the mountains are underlain chiefly by slate and shale, all the formations being of Paleozoic age. The till of the region consists largely of material derived from the local rock, but to the drift between Oak Ridge and Petersburg, and to a less extent to that on the west slope of Bearfort and Green Pond mountains, especially the latter, the gneiss and schist to the west have made a generous contribution.

[1]Report of the State Geologist for 1892, p. 51.

[2]The rocks of this belt are now classified as follows: The quartzite and limestone north of Macopin lake and east of Kanouse mountain, Cambrian; Green Pond, Kanouse, Copperas, and part of Bowling Green mountains, Oneida and Medina; the limestone near Newfoundland, Niagara; the grits at Newfoundland, Oriskany-Corniferous; the shale about Milton, Devonian (Hamilton?), and the Bearfort mountain, later Devonian, probably Chemung or Catskill. Ann. Rept. State Geologist, 1901.

The till of this belt usually has a compact, gritty matrix, set with many stones and bowlders. The bowlders are generally abundant, and rather angular if near the ledges from which they were derived, as is often the case; but at other points they are often well worn and sometimes striated. Striated bowlders are rather more common at the surface than on the Highlands, either to the east or west. This is doubtless because the gneiss bowlders weather more readily than those of quartzite, and have therefore lost their striæ to a greater extent.

With the material from the underlying formations are associated materials from the gneisses and crystalline schists, shale, slate and sandstone, probably from the Hudson River formation. Material of the last-named variety is more abundant to the north than to the south, as the former tract is nearer the outcrop of the formation which yielded it.

Slaty material is particularly abundant in the drift at the south end of the Clinton reservoir, south of Newfoundland on the west slope of Copperas mountain, and just west of the north end of Green Pond mountain. For the slaty material of this locality there was a local source, shale and slate being the underlying formations over an area between the south end of Bearfort mountain and Milton. In the valley between Kanouse and Bearfort mountains, too, where the underlying rock is shale or slate, the slate is often the major constituent of the till, as may be seen in the vicinity of Postville, where both the till and the topography resemble those of some parts of the Kittatinny valley.

Bearfort mountain.—The drift of this mountain is thin, particularly in its northern part. Outcrops occur by the hundred from the State line nearly to the Clinton reservoir, where the aggregate area of the outcrops may nearly equal the aggregate area covered by drift. From the Greenwood lake-Wawayanda road south to a point opposite Uttertown, the bare rock surface probably exceeds the surface covered by drift. The surface of the mountain is so rugged, the rock ledges so precipitous, and their height so great, that it is difficult to cross the mountain except along the two or three wagon roads. From the State line south, the west slope has more drift, and therefore fewer outcrops than the summit and east slope. In the vicinity of Uttertown and south along the road to the Clinton reservoir the drift is, for this region, thick. From the reservoir south to the railroad, also, the till has considerable depth.

So far as exposures show, the till of Bearfort mountain is made up almost wholly of local rock, the foreign material noted consisting chiefly of occasional gneiss bowlders. The paucity of material of distant origin is accounted for by the fact that the movement of the ice was essentially parallel to the trend of the mountain, so that there was little tendency to bring drift to the range from either side. The contrast between this till and that of the Highlands on the west is marked, and the transition at the west base of the mountain from till made chiefly of gneiss, to till derived chiefly from the rock of the mountains is abrupt.

The stony material is rather angular, bowlders occasionally show striation, but the bed rock rarely.

Depth.—If there is any considerable thickness of till at any point on Bearfort mountain the fact is not known, though for one-half mile directly south of Uttertown drift is thick enough to conceal the rock effectually. Data concerning the depth of drift are few, except as furnished by the multitude of rock outcrops. It is difficult to estimate the average depth for the entire mountain, but it probably does not exceed five feet. On the 929-foot hill northeast of Newfoundland a little east of the axis of Bearfort mountain the till is thirty-two feet deep.

Between Bearfort and Kanouse and Green Pond mountains.—The till in the valley between Bearfort and Kanouse mountains is made up largely of the local slaty rock. It often consists of unworn slate fragments, with little earthy material associated. Less often it has a generous clayey matrix. Associated with the shale are some bowlders from the adjacent conglomerate and quartzite. Many of the bowlders may have been in the valley before the advent of the ice. Slate outcrops are frequent, and the depth of the drift is not great.

Till of the same general character occupies the area west of the north end of Green Pond mountain, and the gap between that mountain and Bearfort. Here, however, the bowlders are almost wholly of schist and gneiss. The abundance of material of this sort, even up to the base of Green Pond mountain, shows that the movement of the ice was slightly less westerly than the trend of the mountain, and that when topography did not prevent, the ice moved very obliquely up the mountain from the Central Highlands to the west.

Weathering is not so well shown in the till of this and adjacent mountains as in the till of the crystalline schists. This is partly due to the character of the material from which the drift is made, and partly to the scarcity of exposures.

Green Pond mountain.—The till of this mountain is in a general way similar to that on Bearfort mountain.

The west slope of the mountain is less precipitous than that of Bearfort, and is generally covered with till, but to what depth is not known. Exposures are few and shallow, the best being along the roads which cross the mountain. A stone quarry at the east foot of the mountain near the powder magazine also exposes the till to a slight extent. The matrix of the till, so far as seen, was largely derived from the Highlands to the west, a further evidence that the movement of the ice was obliquely over the mountains from the west.

North of Woodstock, rock outcrops are rare on the west slope, but at Woodstock, and between Upper and Lower Longwood, outcrops are rather common, and from the latter place to Berkshire valley they are frequent. On the crest, outcrops are frequent. The east face of the mountain at its northeast end near Newfoundland is a nearly perpendicular rock ledge with a talus slope at its base. It rises steeply from an elevation of about 800 feet, to about 1,200 feet at the crest. This steep face extends down the brook leading southwest from Newfoundland, becoming less precipitous to the southwest, and finally gives way to a gentler till-covered slope two miles southwest of Newfoundland. East of the brook above mentioned, and south of Newfoundland, there is another precipitous ledge facing east between Newfoundland and Green pond. Farther south another steep rock face, almost a continuation of the last, borders the west side of Green pond.

Kanouse mountain.—Kanouse mountain has a thicker covering of drift than Bearfort. The island which lies in Greenwood lake, between Cooper and Lakeside, may be considered as the northern extremity of Kanouse mountain. It has numerous outcrops of conglomerate and quartzite at its south end, but a goodly coating of drift at the north end. From this island south to a point a mile or two southwest of New Milford, the drift is so thick as to generally conceal the rock. Farther south the drift thins, but as far south as the south end of Macopin lake there is enough drift so that the rock does not outcrop frequently, though bare spots are not wanting. Southwest of the lake, also, the drift covers the west slope, and is well exposed along the road through the gap east of Newfoundland. The east face is a precipitous ledge nearly free from drift, but the east *foot* of the mountain is well covered with till.

The till of this mountain at the north, near West Milford, has a more clayey character than that of Bearfort mountain. Farther south its character changes somewhat, and it resembles that on Bearfort mountain.

Copperas Mountain.—Most of what has been said of the drift of Green Pond mountain applies to that of Copperas mountain. The eastern face of the mountain is less precipitous, but the rock outcrops frequently, and there is little drift. The west side of the mountain, especially north of Green pond, has sufficient drift to conceal the rock.

Till is thick in the valley between Green Pond and Copperas mountains. The deep trench of the stream flowing northeast through this depression, does not reach rock.

TILL OF THE EASTERN HIGHLANDS.

The till of this region is composed chiefly of debris from the gneiss (see p. 462). Like all such till it has a grey, sandy, or clayey matrix, containing numerous stones and bowlders, more or less worn and striated. The stony part of the gneissic till, as compared with that of the Triassic areas, is coarse, and often includes bowlders of large size. Where the surface remains in its natural condition, bowlders are sometimes so abundant that fields may be crossed, almost without stepping off them. The bowlder walls which abound in the region are evidence of the great quantities of stony material which originally lay at the surface. The decrease in the bowlder walls on the Triassic plain east of the Highlands, is a mark of the transition from the gneissic type of till to the till of the Triassic sandstone and shale type.

Constituents.—Material derived from the gneiss predominates over that derived from all other sources, both in the finer and coarser parts of the till. The second most abundant constituent is that derived from the Green Pond mountain belt. At the east base of the mountains, bowlders from this belt are often as abundant as those of gneiss, though this is never true far from the mountain ledges. Bowlders from these mountains are distributed eastward to the limit of the Highlands, and even beyond, and are more abundant in the southern part of the Highlands than in the northern.

The greater percentage of the conglomerates and quartzites in the southern portion of the region may be due to the more easterly movement of the ice in the lower latitude, as shown by the striæ on Green Pond mountain, though the striæ on the crystalline rocks east of the mountain add little to the force of this suggestion. Striæ are, however, too rarely recorded in this region to show the exact course of the ice, and the eastward distribution of bowlders from the Green Pond and associated ranges is perhaps the best evidence of its course.

Sandstone and slate are also sometimes important constituents of the drift of the Eastern Highlands.

At the south end of Greenwood lake, the slaty material was carried somewhat to the eastward, and up on to the area of crystalline rock. Here the till is clayey, with slate and sandstone the major stony constituents. East of Ringwood, also, similar material is a considerable constituent of the drift, or at least of its superficial parts. Pieces of sandstone and slate either from the sandstones and slates of the Green Pond belt, or from the Hudson River formation in New York, are found in meager quantity over the entire area of the Eastern Highlands.

Of the stony constituents in the region under consideration, the sandstone, slate and shale show striation most commonly. The conglomerates and quartzites show greater wear far from their source than near it, but they are rarely striated. The gneiss bowlders, though often worn and rounded, are rarely striated.

The stony material of gneissic origin varies from pebbles a fraction of an inch in diameter to huge bowlders. The Green Pond or Bearfort conglomerate bowlders are sometimes six to eight feet in diameter near their source, but their average size is much less and decreases to the southeast. The shale and slate are generally in small bits, but sandstone bowlders are not rare.

Exposures.—The best exposures of till are along the lines of the railways.

1.) *On the New York and Greenwood Lake railway* they occur at Cooper, where shallow exposures show clayey till, with an unusually large proportion of shaly and slaty material; two-thirds of a mile west of Monks station, where a deep cut shows bowldery till of gneissic type; at Monks station, where the till is also of gneissic type; a mile southeast of Monks station, where the till is disposed to be gravelly; at the Ringwood mines, and on the wagon road at Ringwood on the east side of the creek, where there is an unusually large amount of shale and sandstone, considering the distance of the place from the outcrops of the formations furnishing these materials.

2.) *Along the New York, Susquehanna and Western railway* exposures occur west of the Charlottesburg station, where there is a long and deep cut of till similar to that of Kanouse mountain, but with a large proportion of shale; just north of the crossing of the Charlottesburg-Newfoundland wagon road and the Macopin Lake branch of the railroad, where stony material makes about one-tenth of the drift, conglomerate and quartzite predominating; on the railway at the end of Macopin lake, where the till is clayey and contains slate; east of Charlottesburg station where the road to Butler crosses the railroad, where the clayey matrix has a reddish color due to the material from the Green Pond mountain rocks; between Charlottesburg and Butler, where railroad cuts and other excavations afford several fine exposures twenty to fifty feet in depth, all of which show till of the gneissic type, the stony material being chiefly from the gneiss and Green Pond formations. Bowlders from the latter become less numerous to the eastward. Occasional limestone bowlders, which may have come from the Green Pond belt occur in these cuts; north of the Bloomingdale station, where compact, bowldery till, with a clayey matrix, is seen; a third of a mile farther east on the east side of the river, and in the east part of Bloomingdale, where sandy till of gneissic type, with large bowlders, is exposed to a depth of thirty to forty feet.

3.) *On and near the Delaware, Lackawanna & Western railway,* in the northwestern part of Boonton, on the road to Powerville, where twenty-five feet of till overlies five feet of stratified drift, and railroad cuts twenty to thirty feet deep, one-fourth and three-fourths of a mile east of the Montville station. These cuts are just off the Highlands, on the Triassic formation, but the till exposed is of material derived from the Highlands. The till is compact, with a clayey matrix in which are set bowlders and cobbles of worn stony material. The more easterly cut shows foliation when the section is fresh.

Foliation.—Foliation is not often shown, though it is doubtless much commoner than the weathered and talus-covered slopes of the cuts show. It is to be seen in a large proportion of the fresh cuts, sometimes in good development.

Thickness of till.—The maximum depth of till known in the Eastern Highlands is at Bloomingdale, where a well penetrated sixty feet of drift before striking rock. In general, greater depths are found in the Pequannock valley than either north or south of it. Frequent exposures in the valley show depths of twenty to fifty feet. South of this valley, the greater thicknesses obtained from well data were thirty to thirty-five feet, while north of it there are frequent records of twenty-five to thirty-five feet. These figures are, however, well above the average. If the drift were spread out evenly over the entire region, it is probable that its thickness would fall short of twenty feet, and might not exceed the half of that figure.

Rock outcrops are of frequent occurrence over the entire region, being most numerous on the steep sides and sharp summits of the mountains. Outcrops are, however, not rare on low-lying surfaces. They are notably less frequent than in the Green Pond mountain belt, and somewhat less frequent than in the Central Highlands. They are so frequent, however, that there are few areas a square mile in extent where the rock does not appear.

Post-glacial weathering.—Weathering has affected the till to about the same depth as in the other parts of the Highlands, namely, two to four feet. The till is rarely weathered or oxidized so as to make the change evident to the eye to a depth greatly more than two and a half feet. Beneath that depth, the color is commonly grey, the color of freshly-ground gneiss.

STRATIFIED DRIFT IN THE HIGHLANDS.

The amount of stratified drift in the Highlands is small. It is found chiefly in the valleys, but as these are mostly narrow, the stratified drift occupies an area proportionately much smaller than in the Appalachian province, or in the Triassic plain.

In the valley of the Musconetcong.—The deposits of stratified drift above the moraine in this valley are not extensive. West of Stanhope they have the form of prominent kames, which reach down to the present flood plain. About two miles northwest of Stanhope, the surface of the valley gravel approaches a plain. Above Waterloo the stratified drift is mainly on the north side of the stream, but from Waterloo to Saxton Falls it is mainly on the south side. In general, the gravel has an undulatory surface, and the undulations occur down nearly to the water level, showing little post-glacial erosion in the valley.

In the valley of Lubber's run.—Gravel occurs at intervals in the valley of Lubber's run from a point about three miles above Roseville, to its junction with the Musconetcong. Above Roseville it has an irregular topography with but little relief. For one and one-half miles south of Roseville it is present, now on one side of the stream and now on the other, in the form of a gravel plain with a somewhat uneven surface. At Lockwood there is a kame area of coarse gravel. South of the Cascade mine west of Lockwood, there is another similar area, with a relief of twenty to twenty-five feet, with rather abrupt depressions. It is composed of loose, angular gravel, with a few bowlders.

There is a considerable amount of gravel in the valley tributary to Lubber's run at Roseville. It begins about a mile northeast of Wright's pond as a plain of fine gravel, with a width of less than a fourth of a mile. It widens out in the vicinity of the pond, and narrows again to the south, continuing to Roseville. A fourth of a mile south of Wright's pond an ill-defined kame rises up to ten or fifteen feet above the plain.

Three-fourths of a mile west of Wright's pond there is a small kame area crossed by the road. It has a knob and basin topography with a relief of about twenty feet. It is composed chiefly of rather angular gneiss gravel. A large limestone bowlder 8 x 10 feet, practically unworn, occurs in the area.

In the northwestern part of the Central Highlands.—There are a few small areas of stratified drift on Wawayanda mountain. Two miles due north of Canistear, at the head of a small swamp, are low cobble-strewn terraces, and one or two small kames occur at the southern end of the swamp. Several small knolls of gravel occur near the northern end of the large alluvial plain a mile west and northwest of Cherry Ridge. Small, flat-topped terraces of gravel are also found at the northern end of Wawayanda lake, where the gravel has a large shale content.

The creek which joins the Pequannock from the south, just east of Stockholm, has its source in a small tract of gravel about a mile above the main stream. There are here kames and some associated gravels. The northernmost kame near the north end of the gravel area is thirty feet or so above the swamp bordering the brook, and is composed of loose gravel. Southwest of it, and separated from it by a considerable stretch of gravel, is a small kame area. From the north it rises forty to fifty feet above the brook. Its topography is notably undulatory, especially at the north. The gravel is chiefly of gneiss, with a little sandstone (Hudson River?), and some blue flints. A third small kame is a little farther southwest in the fork between two swamp-bordered tributaries.

In the valley of the tributary from the south joining the Pequannock next east of the above, there is a small amount of gravel. At its junction with the Pequannock, the gravel takes the form of a small kame, which rises up from the swamp at the river's edge. It is composed of angular loose gravel up to six inches and less in diameter. Up the valley there are two or three small areas of loose gravel without distinctive topographic form on the hillside.

There are several small and unimportant patches of gravel at the following points: Half a mile to a mile west of the Carey mine; four miles to the north near the Green mine, where the gravel contains much slate; a mile southeast of the above in the valley; a half mile or more west of the Centennial mine, west of the road, where there is a kame thirty feet high, composed of fine slate gravel. Gneiss outcrops at its east end. A small gravel area is associated with it on the west.

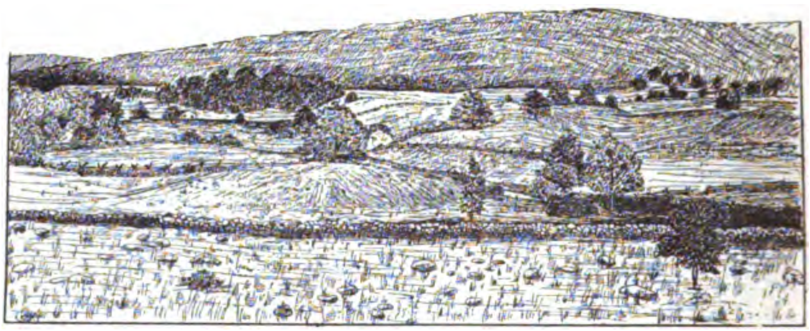


Fig. 71.

Shows in the foreground the topography of stratified drift deposited in the presence of ice, half a mile east of Oak Ridge. The mountain in the background is the north end of Green Pond mountain. Drawn from a photograph.

Stratified drift in the Pequannock valley above Newfoundland.—Between the south end of the Oak Ridge reservoir and Newfoundland the valley of the Pequannock contains a considerable amount of gravel, having the topographic form characteristic of deposits made in contact with ice. It is sometimes in the form of kame terraces (see Figs. 71 and 72), but the terrace form is sometimes nearly lost in that of kames. Including the narrow flood plain of the river, the width of the belt of stratified drift along this part of the stream varies from a fourth to three-eighths of a mile. It has a maximum elevation at the north of 880 feet, or about 100 feet above the present level of the river.

The surface of the gravel declines southward to 820 feet near south end of reservoir, where it is continuous with the gravel of the Rockaway valley.

A few hundred yards east of the schoolhouse at Newfoundland, on the road leading to Postville, there is a kame thirty feet high, nearly circular in form, and composed of fine gravel, so far as exposures show.

East, north and west of the Newfoundland schoolhouse the stratified drift has a kame topography, which continues west for nearly three-fourths of a mile, with a relief of ten to twenty feet. The hillocks and hollows are more crowded to the westward. At the west margin of this kame-like area, a high gravel ridge appears, and runs southwestward along the river parallel to the

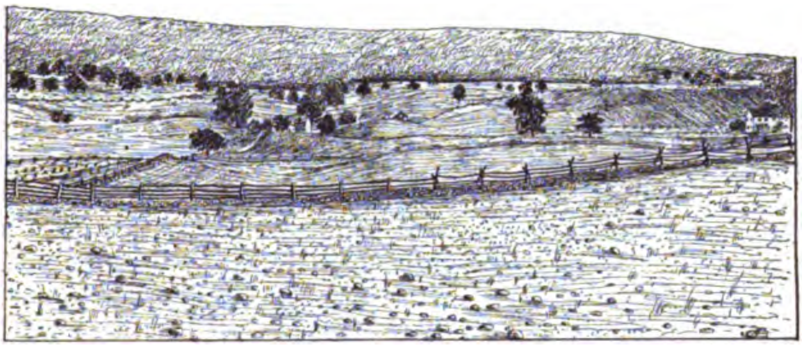


Fig. 72.

Topography of stratified drift deposited in the presence of ice. The kame-terrace type. One mile east of Oak Ridge. Drawn from photograph.

road leading to Oak Ridge. It terminates abruptly where the north and south road crosses the river a mile and a half west of Newfoundland. It has a height of about sixty feet above the river road and a width of 100 to 120 feet. Its surface is composed of cobbles and bowlders of slate, sandstone of the Hudson River and Green Pond mountain series, and gneiss, all well rounded.

Westward toward Oak Ridge the stratified drift has the form of winding ridges, with steep sides, narrow tops and a common level. The depressions between them are sometimes swampy.

Near the river the ridges unite to form a wide, flat-topped plain about sixty feet above the stream. An exposure in the flat-topped area shows gravel above silt and sand. The laminæ at the bottom of the exposure are nearly horizontal, while those at the top dip about twenty feet to the west.

On the right bank of the river, opposite the Newfoundland schoolhouse, the gravel has an elevation of about 860 to 780 feet. For nearly a mile to the northwest it has the form of a terrace, sometimes descending abruptly to the river, and sometimes breaking into undulations which affect the slopes nearly to the flood plain of the stream. The stream has not sunk its channel more than ten to twenty feet below the terrace.

Farther up the valley, the terrace breaks up into hillocks and hollows. Locally the gravel assumes eskerine forms, but the ridges have little persistence, and usually break up into hillocks which merge into the kame terrace. There is sometimes a depression between the gravel deposits and the mountain slopes above. Some of the depressions between the ridges and knolls of gravel are bowlder covered, and may be underlain by till.

A mile southwest of Oak Ridge depot, the terrace has an elevation of 820 to 840 feet, and a width of about 600 to 700 feet, on the right-hand side of the river. Its terrace form is lost half a mile farther south, though stratified drift continues to the southwest, assuming complex forms about the headwaters of the Rockaway.

Three-fourths of a mile due northeast of Mooseback pond, and at the southernmost point reached by the river south of Oak Ridge, the gravel takes on the form of kames with a relief of about forty feet. The gravel is coarse and bowlders are present. From this point southward, the material becomes progressively finer.

There can be little doubt that at one stage in the retreat of the ice, drainage from the Oak Ridge region flowed southward *via* the Rockaway valley. Indeed, it is not clear what the conditions of drainage would now be if the drift were removed from the region between the Oak Ridge reservoir and Petersburg, as well as from the Pequannock valley below. It is possible that the Pequannock once followed the course of the Rockaway. If so, it was probably changed to its present course in pre-glacial times.

Exposures.—Besides the exposure along the railroad east of Oak Ridge, already referred to, there are other exposures in the stratified drift of this valley. One is half a mile east of the Oak Ridge station, on the road to Newfoundland. The gravel is compact, not showing distinct stratification at all points. The material is well rounded. Sandstone, shale, and quartzite constitute half or more of the gravel, and gneiss the remainder. The shale and sandstone are of local origin. Other exposures occur along the railway on the right bank of the Pequannock, about a mile west of Newfoundland.

The gravel is not compact, and stratification is not always distinct. The material is rather coarse, and is composed of gneiss, slate and sandstone, quartzite, and conglomerate. The slate bits are often striated.

Post-glacial erosion.—The Pequannock has done little eroding between the south end of the reservoir and the kames near the Newfoundland schoolhouse, since the gravel was deposited. Its channel has hardly been lowered more than twenty feet at most points, but locally it has developed an alluvial plain a fourth of a mile wide.

Above the Oak Ridge reservoir, there is little stratified drift in the valley of the Pequannock, and what there is, is in small patches. One of them is at Stockholm, where an undulatory area of gravel about fifty acres in extent lies mainly to the north and west of the station. The material is sub-angular gneissic gravel, with occasional bowlders.

In the valley of Pacock brook.—From a point about a mile above Canistear, to a point more than a mile below, gravel borders Pacock brook on either side. Including the alluvial plain of the brook, the belt of stratified drift varies from one-eighth to three-eighths of a mile. It has an elevation at its north end of about 1,100 feet, and declines southward at the rate of about twenty feet per mile, which is nearly the same as the grade of the stream. At the north, its topography is somewhat morainic, with hummocks and sinks of ten to fifteen feet relief. To the south, the topography is planer, though interrupted by swampy depressions, some of which were probably occupied by masses of ice while the gravel was being deposited. Three-eighths of a mile farther south, and again about the same distance northeast of the Stockholm station, gravel again occurs in the valley of the Pacock. In both places the material is irregularly disposed.

The material is almost wholly gneissic, rather angular, and, on the whole, poorly assorted. It is coarse at the north, consisting of cobbles and small bowlders, but becomes finer to the south.

North and west of Oak Ridge reservoir.—There is a little gravel at the north end of the Oak Ridge reservoir, and more is probably concealed by the water. It is chiefly of gneissic origin. A considerable amount of fine material mixed with the coarse gravel makes it more compact than is the habit of gneiss gravel. North of the head of the Oak Ridge reservoir there are small patches of stratified drift just east of Dunker pond, and again half a mile north of it. Sand predominates in the former place, but not in the latter. Small patches of gravel also occur at some points west of the reservoir.

Gravel occurs at several points in the valleys of the small brooks between Russia and the Oak Ridge reservoir. One of these brooks flows into the Rockaway, but the gravel in its valley is practically continuous with that of the brook flowing into the Pequannock.

On the east side of the brook at Russia, there is a small patch of poorly-assorted gravel with rolling kame-like topography. North and a little west of the above, on the north side of the road, there is a ridge of coarse gravel, twenty feet high and a fifth of a mile long, which may be called an eskerine kame. It lies near the highland on the west side of the marsh. On the east side of the brook, nearly opposite the north end of this ridge, there is a kame, about twenty feet high, composed of loose gravel. About it, especially to the south, there is some gravel with plane surface. Still farther north, on the east side of the brook, there is a small kame area, with associated gravel. The maximum relief in the kame area is forty to fifty feet.

PLATE LX.

Pot holes in Monroe shale near Clinton reservoir.

Traces of stratified drift also occur between this area and the reservoir.

Between Uttertown and Newfoundland.—The upper part of the small valley between these places has little gravel. Two irregular patches occur southwest of Uttertown; one near the Wallace mine, and the other a quarter of a mile east of the Sigle mine, near the brook. Stratified drift occurs at one or two other points north of the Clinton reservoir, but it has little extent and has no distinctive features. South of the reservoir are other small bodies of stratified drift in the valley leading down to the Pequannock at Newfoundland, and a considerable area just above the junction of the creek with the Pequannock.

North of Uttertown.—The gravel in the valley north of Uttertown, at the west foot of Bearfort mountain, is traversed by the north and south road passing near the Carey mine. The larger body of it extends from a point about three-fourths of a mile south of the mine to a point about a mile and a quarter to the northeast. It has a broken topography with a relief of ten to twenty feet, with occasional flat stretches. The gravel is coarse, with more or less sand, and is not well exposed. North of the Wawayanda-Greenwood Lake road, the topography near the highland is nearly level, but the surface breaks up into ridges and isolated hillocks in the swamp west of the wagon road. The gravel is coarse. There is a narrow patch of stratified drift in the valley still farther north.

Stratified Drift in the Valley of the Rockaway.

Above the moraine.—There is a nearly continuous belt of stratified drift in the valley of the Rockaway, from Mooseback pond to the moraine. At the former place, it is continuous with the stratified drift of the Pequannock valley, with which it is one in origin.

In the twelve miles between the pond and the moraine, the surface of the stratified drift declines somewhat more than 120 feet. Within this belt, the stratified drift has sometimes the form of kames, sometimes that of kame terraces, and sometimes that of normal river terraces. Kames are well shown north and east of Mooseback pond, near Upper Longwood, Lower Longwood, and Berkshire Valley. The topography developed by deposition against ice is shown south of Mooseback pond, and at Berkshire Valley. The normal terrace form is best seen between Milton and Woodstock, along the west side of the valley.

In the moraine.—South of Berkshire Valley, the Rockaway crosses the moraine. Where it turns eastward, near the D., L. & W. railway, it is bordered by a plain of coarse gravel at an elevation of 680 to 700 feet, or twenty to forty feet lower than the stratified drift south of Berkshire Valley.

Northeast of Port Oram, the area of stratified drift expands northward beyond the Mt. Pleasant mine, over an area about three-fourths of a square mile in extent. The topography of this area is undulatory at some points, and plane at others. With the gravel are numerous bowlders, as is commonly the case in close proximity to the moraine. On the south side of the valley, the stratified drift extends a short distance up the valleys of Jackson and Spring brooks. There are some things at Dover which indicate that the ice crossed the river at that point. In this event a pond or small lake may have been formed west of Dover, if the Rockaway river was obstructed. Such a lake might have extended up the lower courses of Jackson and Spring brooks. There is not much evidence, however, that the gravel terraces in these valleys originated in a lake. The material of the terraces is coarse, containing bowlders, though the surface has a coating of loam. Any lake which existed here must have had its outlet eastward along the edge of the ice blocking the valley.

At Dover, the stratified drift has the form of a plain, with an elevation of about 580 feet. Farther east its surface declines, and it spreads out in the valley of Mill brook at an altitude of 560 feet. A kame rises up from the edge of the plain, about half a mile west of Mill Brook, notable because it lies outside of the moraine at the edge of the Dover-Rockaway overwash plain. The kame has a length, in a north-south direction, of about one-fourth of a mile, and a width a little more than one-half as great. Its top is about sixty feet above the plain on its north.

It is composed of gravel and sand, dipping at various angles, and showing faulting to an unusual degree.

East of Rockaway the stratified drift of the Beaver Brook valley becomes continuous with that along the north side of the Rockaway. A mile east of Rockaway, and north of Denville, the gravel is disposed as a pitted plain on either side of the river. Stratified drift continuous with that of the Rockaway extends for a distance up the valley of Den brook. It has a slight slope from south to north.

Northeast of Denville the river has a wide gravel plain on its right bank. The plain is occasionally interrupted by sinks, which perhaps represent the position of ice blocks during the deposition of the gravel. Two kames also rise above it, one about a mile northeast of Denville, and the other about a mile southwest of Powerville.

A mile and a half northeast of Denville, just below the point where the Morris canal crosses the Rockaway, there is a considerable area of stratified drift a little outside the main valley of the Rockaway, along the lower course of a tributary. Its topography is undulatory in some places, and level in others.

Between Powerville and Boonton (above the Falls) a small amount of gravel with level surface, borders the river, at about 500 to 520 feet elevation. At Boonton the Rockaway leaves the highlands.

In the valley of Beaver brook.—The stratified drift in the valley of Beaver brook commences at Meriden, about four miles northeast of Rockaway, where it is banked up against the south side of a rock hill at an elevation of about 600 feet. A little farther south it assumes a terrace form, at an elevation of 580 feet, and declines to 540 feet at Beach Glen, and to 520 feet where it joins the Rockaway river. The gravel is generally disposed in the form of a terrace, the topography of which at Beach Glen is slightly undulatory. The gravel is rather fine, with much sand and an occasional bowlder.

Above the plain at Beach Glen, and south of the hill on which the Beach Glen mines are located, is some stratified drift in the form of kames and kame areas. The isolated kames are just south of the point of the hill, and the kame areas a little to the northeast. The materials are coarse gravel and sand, overlying fine stratified sand. Bowlders are present on the surface. These kames probably mark the position of the ice edge during one of its temporary halts, and are essentially contemporaneous with the formation of the gravel plain farther south.

Apart from the areas about Beach Glen, the stratified drift of the valley possesses no noteworthy features. There is a little stratified drift in the valley between Hibernia and Beach Glen. It is generally terraciform in disposition, but near Beach Glen it has something of the undulations which characterize deposits made about ice.

In the valley of Stony brook.—The gravel at Brook Valley, in the valley of Stony brook (five miles northeast of Boonton), is irregularly disposed, and consists of hillocks of coarse gravel with more or less sand and some bowlders. The hillocks are fifteen to twenty feet in height, some having smooth slopes and irregular forms, while others are irregular. The stratified drift in the same valley farther north has the form of a plain, with occasional irregular hillocks.

Stratified Drift in the Green Pond Mountain Belt.

The stratified drift associated with the Bearfort-Kanouse-Green Pond-Copperas mountain belt is chiefly confined to the valleys between Kanouse and Bearfort mountains, and between Green Pond and Copperas. Within these limits there are four principal areas of the stratified drift—1) at the south end of Greenwood lake; 2) north of Postville; 3) east and south of Newfoundland, and 4) at the ends of Green pond.

At the southwest end of Greenwood lake.—The stratified drift at the southwest end of Greenwood lake occurs at two distinct levels. At the higher level there are ridges of gravel jutting out from the high land, and a terrace with an upper limit at an elevation of between 720 and 740 feet. The gravel of the upper terrace falls away to the east in undulations until it reaches the plain of the lower gravel. Two ridges which might have been made in crevasses in the ice run out from the high land at the higher level. This is especially true of a ridge north of the 707-foot hill (see topographic map) a mile or more southwest of the south end of the lake.

The lower gravel plain has an elevation of about 680 feet on the west side of the lake and in the valley west of the hematite mine, and declines southward to 640 feet. Its topography is generally plane, though sometimes broken by sinks and by depressions now occupied by streams, but which are apparently not due entirely to erosion.

The gravel is composed of shale, quartzite, and sandstone from the adjacent formations, and of gneiss. It is more or less waterworn and rather coarse.

North of Postville.—A little north of Postville, and thence northeast for a mile and a half, stratified drift occupies the valley. The most conspicuous part of the stratified drift of this area is a small group of kames near its northern limit. The kames have a rough topography with notable relief, and are composed of coarse gravel with some bowlders. South of the kames, a gravel plain, the surface of which is somewhat pitted, extends down the valley. The plain begins with an elevation of about 837 feet, and declines to about 800 feet in a mile and a quarter. The coarseness of the gravel decreases to the southward. The ice edge is believed to have stood at the kame area, while drainage from it developed the plain to the south.

North of the kames there is gravel with less typical kame topography, above the general level of which rise two small kames. In this area the slate sometimes outcrops. Still farther north there are two gravel ridges, which probably were formed by deposition between bodies of ice. One has something of an eskerine form.

The kames half a mile east of Newfoundland have been mentioned in connection with the stratified drift of the Pequannock valley.

At Green pond.—The stratified drift at the north end of Green pond is much more extensive than that at the south. It has the form of a gently-undulatory plain, sloping south, the material becoming finer as the surface declines. Well data show that the depth of the drift at the north end of the lake is more than fifty-five feet. Data are at hand to show that if the drift were removed from the valley, it would be deeper north of the pond than south of it, and that the valley, the damming of which has given origin to the lake, was doubtless a tributary to the Pequannock in pre-glacial times.

In the Valley of the Wanaque and its Tributaries.

Summary.—Stratified drift occurs in the valley of the Wanaque most of the way from the State line to its junction with the Pequannock at Pompton, and is abundant most of the way below Boardville, where it has an elevation of 320 feet A. T. North of this point, there is more stratified drift in the valley of Ringwood creek than in that of the Wanaque river.

As in all valleys similarly situated, the stratified drift along the Wanaque and its tributaries declines to the southward, but declines at an unequal rate.

Similarly the gravel decreases in coarseness from north to south, but not with regularity. It is relatively coarse at Ringwood, near Boardville, and again a mile north of Midvale, and from these places its coarseness diminishes southward. Its surface slope is greatest below the points where the material is coarse. This is notably true below Ringwood, where its surface declines thirty to forty feet in the first mile below the kames. This variation in coarseness and this unequal decline of the surface, and especially the association of these two characteristics, are interpreted to mean that the gravel of the valley was deposited in sections. The heads of the steep gradients of the terraces are taken to be the places where the ice edge halted while the section of the valley just below was being filled. Except locally, the topography of the stratified drift of the Wanaque valley is not notably irregular. Topography which is thought to be characteristic of deposits made against stagnant ice occurs 1) near Boardville; 2) a mile south of that place; 3) in the Wanaque valley west of Midvale, and for some distance south.

In the valley of Ringwood creek.—The important part of the stratified drift of this valley commences about a mile north of

Ringwood, where it is disposed in kame-like hills with a maximum relief of about twenty-five feet. To the south this kame tract grades into a plain which at Ringwood has an elevation of about 380 feet, but declines to 320 feet a mile above Boardville, at the point where the valley is constricted. Locally the surface of the plain is somewhat undulatory, and kame-like embankments of gravel against the sides of the valley rise twenty to forty feet above its surface. From this point south to Boardville, the gravel forms a narrow terrace on either side of the creek. At Boardville it expands into an undulatory tract east of the river, and becomes continuous with the gravel at the lower end of the tributary joining the Wanaque below Boardville.

In the kames north of Ringwood the gravel is rather coarse, even bowlders being present, but it grows finer to the southward, to the limit of the plain, but becomes coarser again where the valley is constricted and wherever the kame topography reappears.

Between Hewitt and Boardville.—The stratified drift of the Wanaque valley begins at Hewitt, and is disposed in the form of narrow terraces, down to the junction of the tributary coming in from the north, a half mile below. The terrace on the right is the wider. Stratified drift also forms a terrace south of the tributary, up which it extends about half a mile.

Between the junction of this tributary and Monks station, stratified drift has little development in the valley of the Wanaque. From Monks to Boardville there is a narrow strip of gravel, with slightly undulatory topography, on the right bank of the stream. At the latter place it broadens out into a terrace a fourth of a mile wide and forty to sixty feet above the river. On the left bank of the river the gravel has little development, except at the mouth of the tributary a mile above Boardville, where there is a flat-topped terrace of coarse gravel forty to sixty feet above the river.

Between Boardville and Wanaque.—Stratified drift has a more considerable development at Boardville than at any point farther up stream. For a mile below Boardville it covers an area about half a mile wide on the east side of the river, and its topography is notably undulatory. A mile from Boardville, on the road to Conklintown, the gravel is disposed in abrupt hillocks and ridges, having a relief of as much as thirty feet. The irregularities of topography are less pronounced near the river than near the bluff. Something of this topography, though less marked, continues north to Boardville. Near Boardville two bosses of gneiss rise above the plain.

Stratified drift is found up the tributary east of Boardville for about one and one-half miles. It has a broken topography, taking on something of a kame character in its northern part, where the material consists of coarse gravel with many bowlders, and has a relief of fifteen to twenty feet. In general, it may be said that the gravel is coarser where its surface is undulatory, and finer where it is plane.

The surface of the stratified drift in the tributary declines from 380 feet at its northern limit to 320 feet at Boardville, its slope being steeper than that of the stratified drift in the valley of Ringwood creek. As the surface declines the material becomes finer.

The surface of the stratified drift is about twenty feet higher on the east side of the stream than on the west. This disposition, as well as the topography of much of it, indicates its deposition when the valley was partly clogged by ice.

The gravel was derived mainly (seventy-five to ninety-five per cent.) from the gneiss, but quartzite of various colors, conglomerate, and sandstone are locally notable constituents. Its materials are generally well rounded, and rarely show striation. The stratification is generally evident where well exposed.

From a point a mile and a half below Boardville, where the gravel on the left bank of the river has an elevation of 320 feet, it declines to about 240 feet at Wanaque. On the right bank, the decline is from an elevation of about 280 feet to 240 at Wanaque. Throughout this stretch the disposition of the gravel is irregular. It often takes the form of a well defined terrace, and shows a disposition to follow up side valleys and ravines, in which its level rises somewhat above that in the main valley. Its surface, especially to the northward, is often undulatory.

A mile and a half above Midvale, the stratified drift divides into two parts, the one following down the main valley, while the other and larger part spreads out in the valley leading south *via* Midvale to Wanaque. The two belts of stratified drift are separated by the till-covered gneiss ridge west of Midvale. The Midvale belt of stratified drift forms a plain a half to three-fourths of a mile wide, at an elevation of about 280 feet, interrupted by bosses of gneiss. The gravel along the main stream forms a flat-topped terrace a few hundred feet wide, and about sixty feet above the river. Its surface is somewhat lower than that of the Midvale belt. The gravel of the Midvale valley was probably deposited before the ice had retreated north of the point where the belts separate. At that time some of the glacial drainage was through the Midvale valley.

Just below the point where the two belts of stratified drift separate, a kame of coarse gravel twenty to thirty feet high interrupts the level of the terrace on the east side of the Wanaque. A little below the kame, the terrace form is resumed, and continues interruptedly nearly to the point of union with the Midvale belt just above Wanaque.

On the west side of the Wanaque, between Boardville and Wanaque, the stratified drift is sometimes disposed as a terrace, and sometimes more irregularly. The terrace form continues from Boardville to a point due east of Stonetown, where the gravel is disposed in steep-sided gravel ridges, probably deposited amidst ice. This topography continues southward for some distance, being often less broken and more terraciform than at Stonetown. Due west of Midvale, on the west side of the river and near the west border of the valley, the irregular disposition and topography of the gravel re-appears. From this latitude to the western tributary above Wanaque, the gravel constitutes a plain half a mile wide, the bluff margins of which are markedly undulatory. This is especially the case near the southwestern part of the plain, where its surface breaks up into a network of steep-sided winding ridges and knolls, with intervening depressions, the whole having a relief of ten to twenty feet. Like all similar topography in like situations, this is ascribed to deposition around and perhaps over ice blocks which had been left behind when the ice front retreated, or, in some cases, to deposition along the irregular front of the main body of ice. The surface material is of loose, subangular gravel, and has the same composition as all the gravel of the valley.

The gravel of the Wanaque belt, like that of the Midvale belt, becomes progressively finer to the south. As farther north, the materials are largely gneissic, with quartzite and conglomerate from the Green Pond mountain belt (in New York), a little sandstone, probably from the Hudson River formation, and a few bits of trap. The trap indicates that the ice from the Triassic area to the northeast had, in this latitude, crowded over into the drainage basin of the Wanaque. The best exposures of the gravel occur along the railroad, a mile and a half north of Midvale.

Wanaque to Pompton.—Between Wanaque and Pompton, the peculiar topography ascribed to the influence of standing ice is nowhere well developed. The stratified drift here has the form of a low terrace plain, interrupted by a till-covered ridge of gneiss. The surface of the stratified drift declines from 240 feet at Wanaque, to 220 feet at Pompton, two and one-half miles below. The stratified drift becomes progressively finer from Wanaque to Pompton.

At Pompton the gravel plain of the Wanaque river joins that of the Pequannock and Ramapo rivers.

Minor Areas of Stratified Drift in the Eastern Highlands.

About two miles west of Smith Mills, on the left bank of the valley of the Pequannock, there is a level-topped accumulation of coarse gravel banked against the rock. On the east and south, the body of gravel has steep slopes about twenty feet in height. The west part of the area is somewhat kame-like. Half a mile south-southeast of the above, on the road to Smith Mills, there is a small area of gravel, mainly on the north side of the road, at the north edge of which there is a kame thirty to forty feet high. Three-fourths of a mile east of Smith Mills, on the south side of the railroad, there is a pronounced kame about fifty feet high. An exposure along the railroad shows the kame to be composed of sand and gravel, with some bowlders, and to rest on till. Other gravel patches occur north of the above kame on the north side of the river; half a mile north of Smith Mills, on the road to Echo lake; two and one-half miles north of Smith Mills, in the valley of Post's brook, and at several points about one and one-half miles southeast of Upper Macopin, where the gravel is in the form of knolls and ridges.

There are several small areas of stratified drift between the Pequannock and Brook Valley. Just north of Brook Valley, in the valley of Stony brook, and connecting with the stratified drift of the valley of Stone House brook, there is gravel and sand disposed now in the form of plains, and now irregularly. The gravel is practically continuous southward with that along Stony brook, near Brook Valley, where it has the form of more or less irregular kames. The gravel is sometimes coarse, but sand is abundant.

About three-fourths of a mile south of Lake Kinnelon (Stickle pond) there are two kames. The northern one is composed of sand and fine gravel, and the southern of coarser material.

Gravel occurs at a number of points south-southwest of Milford, east of the north end of Kanouse mountain. One of these points is on the west slope of a hill about one and one-fourth miles south-southwest of the village. At the south end of the area, the gravel has the form of a ridge which somewhat resembles an esker. It is about twenty feet high, with a rather steeper slope to the west, but not to the east. The surface rises and falls as the width of the ridge expands and contracts. West of this ridge there is a gravel terrace about fifty feet above the level of the brook. The ridge is composed of sand and gravel, though a few bowlders appear on the surface. The gravel in the north part of this area is more or less ridge-like in places, with associated knolls of irregular shapes.

A short distance to the east there is a small kame about fifteen feet high and of circular outline, composed of coarse gravel. Four other small gravel patches were noted in the vicinity north and northeast of the gravel area just mentioned.

About a mile north of Upper Macopin a small area of gravel about half a mile long and an eighth of a mile wide is banked around a rock knob and rises about twenty feet above its surroundings. Small patches of stratified drift occur north and northeast of Echo Lake post office. The gravel is largely of gneissic origin, with some quartzite conglomerate and sandstone from Kanouse mountain.

Between the Wanaque and the Ramapo.—But three gravel areas have been noted on the Highlands between the Ramapo and Wanaque valleys. Two of these are in valleys or ravines opening northward. One of them is a little more than a mile northeast of Midvale, where a small kame area, about one-sixteenth of a square mile in extent, may be seen south of the road, across an intervening marsh, above which it rises forty to sixty feet. Its topography is undulatory, and the gravel is banked about a knob of gneiss. The gravel is coarse and angular, and is associated with bowlders. Another kame composed of fine gravel occurs on the northwest slope of the hill at Conklintown. Another kame, twenty to thirty feet high and of irregular contours, lies between the road and Tices pond, a half mile from the last. The material of its surface is rather coarse.

West of the Wanaque.—Stratified drift has little development between the Green Pond mountain belt and the Wanaque valley, except along the larger streams. There are a few areas, however, which deserve mention.

In the valley of West brook, about three-fourths of a mile above its junction with the Wanaque, there is a gravel and sand area of kame habit south of the brook, occupying an area of less than half a square mile. It is bounded on the east and west by high land. The kame topography is better shown in the southern part of the area than in the northern. About one and one-half miles west of Wanaque is another small area of stratified drift of undulating topography of feeble kame type. Stratified drift also occurs in the valleys of the tributaries to the Wanaque east of Mud pond.

Isolated kames occur about three-fourths of a mile southeast of the south end of Greenwood lake on the north side of the creek, a mile above Wanaque mine and an eighth of a mile east of Mud pond.

CHAPTER XII.

DRIFT OF THE TRIASSIC PLAIN.

BY ROLLIN D. SALISBURY AND CHARLES E. PEET.

CONTENTS.

GENERAL GEOGRAPHY.

The area of the Piedmont or Triassic plain is shown on the accompanying map, Plate XLVI, p. 264. Only that part which was covered by the last ice sheet which invaded the State, that is, the area north of the terminal moraine, is here brought into consideration. The topography of this area is somewhat unlike that of the Appalachian province and the Highlands. It is, on the whole, much lower than those provinces, though its relief is not notably less.

The Piedmont plain is divisible into two parts or sets of parts. The one is underlaid by trap, the other by sandstone and shale. This subdivision is geographic as well as geologic, for the areas of trap are for the most part conspicuous ridges, often hundreds of feet above their surroundings of shale and sandstone. South of the Passaic, the crests of the trap ridges have an elevation of 500 to 600 feet, and rarely a little more. North of the Passaic the continuation of Second mountain is still higher, reaching a maximum elevation of 879 feet. When it is remembered that the trap ridges rise to these heights somewhat abruptly from a plain which is often no more than 200 feet high, it will be appreciated that they are very conspicuous relief features. At its northern end, the Palisade ridge has a height of between 500 and 600 feet, but declines southward, so that, but for its abrupt slopes, the ridge would not be very conspicuous south of the latitude of Guttenburg.

The trap ridges are separated and surrounded by sedimentary rocks, the surface of which is, in general, much below that of the crests of the trap ridges. About half of that part of the glaciated area underlaid by the shales and sandstones of the Newark series has an elevation of less than 200 feet, and the only considerable area which rises above 300 feet lies in the northwestern part of Bergen county. Here a maximum elevation of a little over 600 feet is attained. In the vicinity of the trap ridges, the sandstone runs up to higher levels than in most other situations.

The trend of the trap ridges is, in general, north-northeast to south-southwest, with considerable departures from this direction north of the Passaic river. The trend of the principal relief features of the sedimentary beds is much the same. This is the result of the structure of the rock, the principal ridges being parallel to the strike of the beds.

The greater relief features of the Triassic plain antedate the glacial period, or at least the last glacial period. The principal process in fashioning its topography was rain and river erosion. Under the influence of running water, the softer sedimentary beds were worn to lower levels, while the more resistant trap rock remained as conspicuous ridges. As a result of pre-glacial erosion, the region between the moraine on the south, First mountain on the west, and the Palisade ridge on the east, had been largely reduced to a lowland before the advent of the ice. The surface of this region was, however, by no means flat. The valleys were even lower than now, and the ridges probably higher, for the former were partly filled by glacial drift, and the latter were somewhat reduced by the erosion of the ice.

Similarly a great area west of Second mountain, the area now occupied by Great swamp, and extending thence northeastward to the Passaic river and to Pompton, had been reduced to a low level by pre-glacial erosion. This lowland was shut in on the east, the north, and the south by the trap ridges, and on the west by the Highlands. Its generally flat surface was interrupted by the trap ridges known as Long hill, Rikers hill, etc. Except for these ridges, this area had even less relief than the area between First mountain and the Palisade ridge. While this basin was nearly enclosed, it was not absolutely so. Its only outlets were those which had been made by the streams which had cut the surface of the area down from its former higher level. These streams had made for themselves passes through the trap ridges. Of such passes there were two, across both First and Second mountains. One was by way of Little Falls and Paterson, along the present course of the Passaic river; the other was across the mountains near Summit, Short Hills, and Millburn. Though the former pass is now the lower, and the one by which all the drainage of the basin is now discharged, the latter was formerly the deeper (see Plate XXXVII, p. 154), and was the pass by which most of the drainage escaped from the basin. This lowland, shut in between the Highlands on the one side and the trap ridges on the other, made Lake Passaic possible, when the ice blocked the narrow outlets.[1]

The two-fold division of the plain, based on the character of the underlying rock, occasioned notable variations in the character of the drift.

Since the trap ridges are several in number, and their positions are such that they divide the area of the sandstone and shale into several sub-provinces, it will be convenient to take advantage of these subdivisions in the following account of the drift.

The relation of that part of the Triassic area here under consideration to the course of ice movement is shown on Plate VIII, from which it will be seen that the axis of the ice lobe which

[1] For fuller account of the origin of the pre-glacial topography of the Triassic Plain, see Volume IV, Geological Survey of New Jersey.

reached its southernmost point at Perth Amboy, lay somewhat west of the base of the Palisade ridge, and that from this axis the movement of the ice diverged both to the east and west, the divergence to the east being the more considerable. The exact position of the axis is not determinable by recorded striæ, but it was not far from the present course of the Hackensack river. At the south, it was a little west of Snake Hill.

It was probably the lowness of this province, as compared with the higher lands on either side, which determined the lobation of the ice, and which allowed the ice to advance farther south on the Triassic plain than elsewhere.

GENERAL SUMMARY OF DRIFT OF TRIASSIC PLAIN.

TOPOGRAPHIC RELATIONS OF STRATIFIED AND UNSTRATIFIED DRIFT.

Ignoring for the moment numerous minor exceptions, it may be said that till prevails in the higher parts of the Triassic plain, east and north of the Passaic river. South and west of that river, till predominates on both the higher and lower lands (see Plate XXVIII, in pocket). The stratified drift, on the other hand, commonly occupies the surface in the valleys and on the low lands north and east of the Passaic, and is present at numerous points south and west of that stream, where its position was not always determined by topography.

THE TILL.

Distribution and Thickness.—Within the area where till occurs, it is, on the whole, thicker on the lower lands and thinner on the higher. Generally speaking, its thickness diminishes with the height of the ridges, and especially with the steepness of their slopes and the narrowness of their crests. Thus the crests of the trap ridges are frequently almost free from drift, and, where the ridges are high, are never deeply covered. On the lower sandstone ridges, the till is, on the whole, thicker by so much as they are lower and less abrupt; but even on the sandstone ridges, it is, in general, thinner than in the depressed areas between them. The numerous quarries, especially about Newark, Passaic and Paterson, show how shallow the drift is at some points within the sandstone area. The frequent outcrops of rock about Passaic, west of Hackensack, north of Maywood, west of Cresskill, north of Ridgewood, and over a considerable area east of the Saddle river above Paramus, as well as at some other points, is further evidence of the thinness of the till in many parts of the area.

It is not to be understood that the distribution of the heavy bodies of till is determined solely by altitude. Its distribution sometimes appears to be quite independent of topography. One general feature of its distribution, other than topographic, should be mentioned. Relatively thick till, often with a good deal of stratified drift associated, is found in certain belts more or less independent of the altitude of the underlying rock. These belts probably represent positions where the edge of the ice halted, either during its advance and retreat, and where, for this reason, the accumulation of drift was thick. The fact that there are places outside these belts where the till equals the average and exceeds the minimum thickness along them, does not interfere with the truth of the general statement.

The average thickness of the till on those parts of the Triassic plain, where it is not covered by stratified drift, is probably not far from twenty-five to thirty feet. The range is from zero to more than 100 feet. The depth of drift where stratified drift instead of till lies at the surface, is, on the whole, considerably greater.

Types of Till.

The till of the Triassic plain is of three principal types, depending on its constitution; 1) The *gneissic* till, made up chiefly of material derived from the Highlands; 2) *the trappean* till, made up chiefly of material derived from the trap; and 3) *red sandstone and shale* till, made up chiefly of materials derived from the Triassic shale and sandstone. Between these several types there are all gradations, yet most of the till is referable to the one type or the other. A minor type of till found only at Stevens Point, contains a large proportion of serpentine.

The gneissic type.—This type of till is made up chiefly of materials derived from the Highlands. In its type development, it consists of a gritty matrix composed of the comminuted products of gneiss and schist, in which are imbedded fragments and masses of gneiss, varying in size from that of sand grains to bowlders several or even many feet in diameter. The stony constituents are generally abundant, often constituting a considerable proportion of the body of the till. Till of this type is rarely gravelly, and never so clayey as much of the till derived primarily from the shale. It is often disposed to be sandy, the sand being of a coarse, angular variety.

The gneissic till of the Triassic area lies in the northwestern part of the Triassic plain, southeast of the junction of the Highlands with the plain. North of the Pequannock, the movement of the ice on the Highlands was about S. 10° W., while the trend of the junction of the Highlands with the Triassic terrane is about S. 40° W. The movement here, therefore, brought material from the Highland to the plain. Farther south the movement of the ice was more westerly, and here the gneissic till has little development on the plain. North of the State line, the Highlands in New York extend northeastward to the Hudson river a few miles above Haverstraw, and some of the gneissic material in New Jersey came from the New York extension of the Highlands.

The gneissic type of till is not sharply limited at the south. The axis of the zone where it grades into till of the red sandstone type, may be said to be along a line drawn from the Hackensack river at the State line, through Hillsdale, Wortendyke and Crystal Lake to Oakland. There are places south of this line where the gneissic constituents are so abundant as to give character to the till, and places north of it where the till is notably red.

At several points in the region outlined above as the region of the gneissic till, sections have been seen which seem to indicate that the till is really less generally gneissic than it seems. It is probably more nearly accurate to say that within the above area the gneissic type of till prevails at the surface. Beneath the surface the till is often distinctly red, even where the surface part shows little or no material derived from the Newark series. Such sections have been seen at numerous points about Hohokus, Midland Park and Wortendyke, and, perhaps, represent a general fact. That material from the Highlands to the north should predominate in the upper part of the till, rather than the lower, is what should be expected; for in coming over the rough Highlands some material was carried by the ice somewhat above its bottom. When the ice descended to the lower Triassic terrane, with its lesser relief, the material which it gathered there remained relatively near its bottom. When the ice melted, such material as was above the bottom was left on the surface of that which was lower in the ice (see Fig. 19, p. 77). There is, however, nothing in the area to warrant the inference that the gneissic material in the upper part of the till became superglacial before deposition.

In the gneissic type of till, materials from the Hudson River sandstone, or from sandstone indistinguishable from it, are always found, and are sometimes very abundant. Other minor constituents foreign to the Triassic formation, and having their source north of the Highlands of New York, are also present. Among these are occasional bowlders of limestone, and bowlders of quartzite which probably came from the Skunnemunk mountain region. There are also occasional bowlders of trap. Near the trap ridges, the presence of trap bowlders is readily understood; elsewhere they probably came from the outcrops of trap north of the State.

The region where the gneissic type of till predominates has, on the whole, a rather heavy body of drift, although its elevation is considerable. It, therefore, constitutes a partial exception to the general rule that the thicker drift is on the lower lands. It is, however, not usually thick on steep slopes or narrow ridges.

Trappean till.—This type of till is practically confined to the trap ridges and their immediate surroundings on the lee side, with reference to the direction of ice movement. In the case of the Palisade ridge, the lee side was to the east, and, therefore, not in New Jersey. In the case of the other trap ridges, the lee side was to the west. The area of the trap ridges is not great, and, in addition, the trap rock yielded debris to the ice less readily than the other formations of the region. The trap, therefore, made a relatively small contribution to the drift. As a result, trappean drift is not prevalent for any considerable distance, even on the lee sides of the trap ridges.

This type of till is generally stony, for the trap yielded bowlders more readily than fine material. The matrix is meagre, and has the brown color characteristic of the soils arising from the decay of the rock, though it is often less ferruginous or ochery than the residuary earths. The minor constituents of the trappean type of till are the same as those of the gneissic type, except the gneiss is here a minor constituent.

The red sandstone and shale (Triassic) type of till.—This is the dominant type of till on the Piedmont plain, and occupies all the till-covered areas not covered by the gneissic and trappean types. Its most conspicuous characteristic is its redness. It is sometimes clayey, where shale furnished most of the material; and sometimes sandy, where sandstone was the chief contributing formation. The more clayey portions are to the south and west, and the more sandy to the north and east. It is often poor in bowlders, especially where derived principally from shale. If it contains abundant bowlders, as it sometimes does when derived principally from the sandstone, they are often little worn.

To the till derived chiefly from the Newark series, other terranes, such as the gneiss of the Highlands, and the quartzite and sandstone of the Green Pond mountain belt, or its northern continuation (Skunnemunk mountain), made minor contributions. They are more generally represented among the bowlders than in the finer material of the till. Even in the southern part of the area of drift, the surface bowlders are often of rock foreign to the region. So far as sections afford a basis for generalization, the bowlders of gneiss, quartzite, Hudson River sandstone, etc., are much more common at and near the surface than is the body of the till below.

At numerous points up to altitudes of more than 200 feet, pebbles and cobbles of quartz believed to have been derived from the former northern extension of one of the extra-glacial gravel formations (Beacon Hill or Bridgeton), are found in the till.

Where the red type of till prevails, the drift is, on the average, much thicker than where the trappean type occurs.

Drumlins.—The till is locally and rarely aggregated into drumlins (p. 91). The best examples of drumlins are in the vicinity of the Oranges, but one hill which is perhaps a drumlin occurs south of Avondale, and two others near Franklin west of Caldwell. There is some difficulty in determining whether some of these are drumlins, or only ridges of rock heavily coated with till, but the data at hand seem to warrant the former interpretation for most of them.

THE STRATIFIED DRIFT.

General Distribution.—East of the Passaic river, and east of a line drawn from Paterson to the head of the Saddle River valley, stratified drift occupies something more than half the surface of the area underlain by the sandstone and shale of the Newark series. In general, it covers the lower lands rather than the higher, but it is not confined to any particular level. In general, it lies at lower levels along the lower courses of the streams and at higher levels along the upper, yet to this general rule there are so many exceptions, and the disposition of the drift is so irregular, as to make it evident that conditions other than those of normal drainage controlled the distribution of the sand and gravel. In the northwestern part (Appalachian province) of the State, the stratified drift of any given valley seems to have a somewhat definite upper limit. This upper limit, with certain regular variations, changes from point to point, but the interruptions and discordances follow certain rules which are readily understood. In the area of the Triassic plain, on the other hand, the variations seem less amenable to rules, or, at least, to rules which are understood.

Not only does the stratified drift seem to fail to conform to the laws which usually govern the distribution of the stratified drift so far as its altitude is concerned, but it has, at various points, peculiarities of disposition. At many places there are rather striking groups and belts of kames. In other places there are plains of stratified drift, the surfaces of which have the slope and configuration of plains which might have been developed by the deposition of sand and gravel by running water, but they terminate in such a way as to show that free drainage did not exist when they were developed. Thus the plain of gravel and sand south of Paramus declines to the southward as might be expected if the material was deposited by running water, but the slopes of the plain to the east and west are often abrupt, and the topography of the slopes at many points is such as to show that they still remain much as they were when the sand and gravel were deposited. They are not slopes which could have been developed by the deposition of gravel and sand by running water if the flow was unimpeded, and they are not slopes developed by subsequent erosion. In some cases these steep slopes would seem to find an explanation if the materials of the plains were deposited by running water in the presence of bodies of stagnant ice which still lingered in the valleys after the main ice front had retreated. Impeded by these masses of ice, the drainage from the north might have made its deposits about them. When they melted, the slopes of the gravel and sand might have been irregular (see p. 121).

At many points, as on the Paramus plain, the surface of the plains of stratified drift are affected by extraordinary sinks. This feature of topography is not unusual or unexpected at the head of a plain of gravel, developed just outside the ice, but is hardly to be expected at any considerable distance from the head. In the case of the stratified drift of this area, these features are almost as prevalent at a distance from the heads of the plains as near them.

Stagnant ice, left behind as the ice front retreated, may well be one of the causes of the irregularities in the disposition of the stratified drift, though a region of greater relief would seem to have been more favorable to the existence of stagnant ice in quantity after the recession of the main body. But even assigning to isolated masses of ice the fullest influence which it seems reasonable to ascribe to them, they still fail to explain some of the peculiarities of the disposition of the stratified drift of this geographic province.

Deltas.—Again, at many points within this area there are bodies of gravel which simulate deltas. In few cases is the delta form unequivocally developed, and in no case so well as in some of the deltas in the basin of Lake Passaic. The evidence is not so conclusive but that there may be serious question concerning the delta origin of some of the deltoid bodies of gravel, but that some of them are deltas admits of little doubt.

These deltoid bodies of gravel and sand are widely distributed, not only east of the Passaic river, but elsewhere at corresponding levels. Among the deltoid bodies of gravel are some of those on the north side of the West Branch of the Elizazbeth river, east of Union, in Union county, where the elevation of the delta fronts, if such they be, is about 100 feet, and others at Athenia and Clifton in Passaic county, where the elevation of the suspected delta front is about 120 feet. Other deposits of gravel which resemble deltas occur three miles west-northwest of Oradell, at an elevation of about ninety to 100 feet; about a mile east of Hawthorne, at eighty to ninety feet; at several localities in the vicinity of Westwood at seventy to eighty feet, and at Englewood and Hackensack, at forty to fifty feet. It is to be noted that these levels are discordant, though most of them are between eighty and 100 feet.

A certain amount of discordance might be accounted for on the basis of subsequent deformation, but this can hardly account for the differences observed. So far as the history of post-glacial deformation has been worked out, the rise of the land relative to the sea has been greater to the north than to the south, and the heights of the deltoid bodies of gravel do not increase progressively to the north.

If these bodies of gravel and sand are really deltas, as some of them certainly seem to be, it would seem to be necessary to suppose that water stood over a considerable part of the Triassic plain while the ice was melting from it, or since, for some of them, and perhaps most of them, are not so situated that local bodies of standing water can be supposed to have existed at the proper level. It would seem, therefore, that if these deltoid bodies of gravel are really deltas, a general drowning of the region must have taken place on the retreat of the ice or afterward. If water stood over this area as the ice retreated, deltas might have been built at different levels if the level of the water varied. Furthermore, levels which were once harmonious may have since become discordant by deformation.

Laminated clays.—There is another feature of the stratified drift of this region which is not only peculiar in itself, but which has a bearing on the question of existence of standing water over the lowlands after the retreat of the ice. A large area west of the Palisade ridge is underlain by laminated clay similar to that of the Hudson and the Connecticut River valleys. These clays are best shown west of the Hackensack river, south of Hackensack, where they are extensively used for the manufacture of brick; but they are far more widespread than would be indicated by the limited localities where they are utilized. The clays are exposed north of Hackensack on the east side of the river. They have been seen at Riveredge (Peet), New Milford, and as far north as Old Hook, just south of the junction of the Pascack and Hackensack. Clays which are probably one with the Hackensack clays in origin, are known to exist as far north as Neuvy, near the State line (Peet). South of Hackensack, the clays are known to underlie the meadows wherever borings have made known the material beneath them.

Similar clays, probably of the same origin, and probably laterally continuous with those of the Hackensack meadows, have been seen at one point in the valley of the Passaic, and have been reported, though not seen, at others. The one locality where the clay has been seen is three-fourths of a mile below Passaic Bridge, in the bank of the tributary to the Passaic on the west side of the river. The surface of the clay is here ten to fifteen feet above sea level. Clay, which from the description given of it, may be the same, is said to occur east of the Passaic just north of Bellair.

The constitution and structure of these clays show that they were deposited in standing water. They resemble in all essential respects the clays deposited in Lake Passaic. At Hackensack, the clay lies on till of last glacial age. This fixes the time of its origin as later than that of ice occupancy. The clay occasionally contains a stone or a bowlder of sufficient size to suggest that floating ice sometimes found its way into the body of water where the clay was deposited. These stones and bowlders are often striated.

In the vicinity of Hackensack the surface of the clays is now but little above sea level. To the northward it is a little higher, and at the State line its surface may be as much as thirty feet above sea level.

Numerous borings have been made about Hackensack, Newark, and at some other points, which give some indication of the depth of the clay. At Merhof's lower brick yard, south of Hackensack, the depth of the clay is about eighty-five feet. Since several feet of sand overlies it, the surface of the rock at this point is about 100 feet below sea level. Other borings about Little Ferry are of similar import. The borings about Newark which are relevant in this connection, are mostly in the south and east parts of the city, in the meadows, or in regions which were meadow before they were reclaimed. These borings show that the drift, much of which is laminated clay, has a thickness of more than 100 feet in most cases, and in some cases of more than 200 feet. One boring, indeed, reports that rock was not reached at a depth of 250 feet, starting from the level of tide marsh. In many cases it is not known how much of the drift is laminated clay, but thicknesses of clay exceeding those at Hackensack are reported.

These data are sufficient to show that standing water occupied a large tract in northeastern New Jersey after the retreat of the ice, and that in this standing water, up to elevations something above sea level, laminated calcareous clays, such as are characteristic of quiet waters, were deposited. The surface of the water may have been considerably above the surface of the clay, but the clay itself does not indicate how much. The clays do not, in themselves, afford any warrant for supposing that the water stood at the level of the deltoid bodies of gravel already mentioned, but they show that standing water stood considerably higher on the land than now, when the clays were deposited.

Various phenomena farther south are consistent with the hypothesis here suggested. It has been pointed out in earlier reports that the surface of the drift about Rahway and Elizabeth had somewhat the aspect of drift which had been beneath standing water, an inference based partly on the character of the till in the basin of Lake Passaic. No distinct upper limit to the phenomena in question has been found, and its absence has served to throw doubt on the submergence so far as this area is concerned.

Submergence of the lower part of the Triassic plain since the last glacial epoch.—Taken all in all, the phenomena of the lower part of the Triassic plain of New Jersey seem to point to the existence of standing water over the area up to levels of something more than 100 feet after the ice departed.[1] This stand of the waters may have been somewhat temporary, and the water may not have reached up to such heights for any very long period of time. Possibly its level relative to the land had become notably less before the ice had receded to the northern border of the State. If there were such a body of water, and if, in addition, considerable masses of ice were left behind in the shallow water as the body of the ice retreated, the disposition of some of the stratified drift of the lower part of the Piedmont plain would be more readily accounted for than on any other hypothesis.

The clays of the Hackensack region, like the clays of the Hudson and Connecticut River valleys, are essentially without fossils. The only animal remains which have ever come to the knowledge of the Survey is a skeleton found at the lower brick yard of Mr. Mehrhof, south of Hackensack. This skeleton has, unfortunately, not been preserved, but, according to Dr. Conrad, of Hackensack, who seems to have been the only man who examined it with care, it was the skeleton of a carnivore, possibly that of a fox.

The clays are admirably adapted to preserving fossils, and the lack of marine shells in them seems to indicate that the water in which they were laid down was not normal sea water; yet

[1] Mr. Peet does not subscribe to this conclusion.

there is to the south at the present time no obstruction to prevent the entrance of the sea, when standing water existed where the clays now are. If the moraine of the main land at Perth Amboy formerly extended with less interruption than now to Staten Island, it would have helped to exclude the sea from the Hackensack bay. The topography of the west end of Staten Island, and of the main land opposite, are not inconsistent with the hypothesis that the moraine once extended across the Arthur kill at a level something like twenty-five feet above the present sea level. The topography of the west side of Staten Island is not such as to indicate that the dam could have been much higher (Kümmel). If a similar moraine dam existed between Staten and Long Islands, it would have further helped to exclude the sea. Kill van Kull is not so wide or so deep as to make it unreasonable to suppose that it is of post-glacial development, and perhaps the same may be said for the Narrows and East River.

In view of the limitations which seem to be imposed on the height of possible moraine dams, south of the Hackensack meadows, it seems that the water which stood over the Hackensack region in late glacial times was probably not a lake shut off from the sea. Over any dams which may have existed, the water above, constantly fed by the melting ice, must have found an outlet. Such drift dams as may have existed might account for standing water where the clays are, but they could hardly have lasted long enough to allow of the deposition of such thickness of clay as exists. Furthermore, a body of water held in by such dams would not account for the deltas at higher levels. It, therefore, seems that the water over the area was connected with the sea, and that its presence was due primarily to a stand of the land lower than now relative to the sea. If the water which stood over the Hackensack meadows and their surroundings had no more than shallow and narrow connection with the sea, as seems probable, the heavy discharge of water from the melting ice to the north would have probably made the passage-way between this nearly enclosed body of water and the sea an outlet, rather than an inlet, and so the bay may have been kept fresh, or its salinity so much below the normal, that marine life did not flourish in it. It can hardly be supposed that the temperature was so low as to prevent sea animals from entering the bay, for marine life of certain types abounds about the coast of Greenland at the present time.

In advancing the above hypothesis, I am quite aware that the evidence of submergence to the extent here urged is not so convincing as could be wished. The absence of beach lines, and of well-defined shore features in general, would not have been anticipated. It is to be remembered, however, that the body of water was, after all, not very large, and that its waves could never have had the force of ocean waves, both because of its small size and because it was interrupted by islands. It is believed, too, that its waters, essentially fresh, and near the edge of an ice sheet, were frozen much of the time, and that the ice helped to prevent normal wave work.

There is the best of evidence that the southern part of the State has been submerged to the extent of forty or fifty feet at least since the late stages of the last glacial epoch; yet this evidence is almost wholly independent of the common shore marks. Facts might also be cited from other regions, such as the Pacific coast of the United States and Greenland, to show that distinct shore lines do not always remain, as a region recently submerged rises above the sea.

Other phases of stratified drift.—So far as concerns the absence of distinctive deltas about the shores of the supposed bay, it may be said that no streams of consequence entered from the east or south or west. The only waters which entered it came from the north, and if the edge of the ice was constantly shifting, deltas might have failed of development more distinct than that which is now found.

While there is an abundance of stratified drift in the higher parts of the Triassic plain, it occupies a much smaller part of the surface and its disposition is less anomalous. As elsewhere, it is more common on the lower lands than on the higher. In some of the valleys, especially that of the Ramapo and Peckmans brook (between First and Second mountain), it sometimes has the form of kame terraces. In other places it is aggregated into remarkable kames, and less commonly it constitutes eskers. The former are numerous, and the latter few.

About Franklin lake there is a flat of stratified drift which is thought to represent the filling of a temporary lake which existed at the edge of the ice while it was retreating.

West of Second mountain much of the area here under consideration was covered by the waters of Lake Passaic, and about its border considerable bodies of stratified drift were deposited, chiefly in the form of deltas.[1] The most conspicuous are at Preakness and Montvale. North of Little Falls there is a considerable body of laminated clay deposited in Lake Passaic. Locally the clay is covered by till, showing that the ice advanced, at least temporarily, over territory from which it had once retreated, and on which lacustrine clay had been deposited.

Kames.—The kames sometimes occur singly and sometimes in groups. Considerable areas are sometimes affected by kame topography of the less pronounced type, without the development of distinct kames.

The groups of kames belong to two types, which, at their extremes, are distinct.[2] These are 1) the kame moraine type, and 2) what may be called the undulatory plain type.

The kame moraine type of kame group is often associated with till areas showing morainic topography, and the lines of separation are so poorly marked that it is often impossible to sharply differentiate them. In structure there are all gradations from the hillocks made up of distinctly stratified gravel and sand, through those showing imperfect or partial stratification, to hills which have the kame form, but lack the kame structure. The structure intermediate between the type kame structure and the till hills with kame form, but without distinct stratification, seem to be of two kinds: 1) That with till and stratified drift more or less intermingled; and 2) that with varying amounts of drift stratified, but with a large percentage of the fine materials washed out, leaving the coarser material more or less rounded, but often not showing distinct bedding.

Kame groups of this type are often in the form of elongate belts, and are often bordered on the south by plains of gravel

[1] For full account of the history of Lake Passaic and the deltas about its shores, see Ann. Report of the State Geologist for 1893.

[2] This grouping was first suggested by Mr. Peet.

and sand. They have the topography of terminal moraines, and their surfaces are often strewn with bowlders.

Among the better examples of kames of this sort are those two miles north of Cranford; those about Livingston; those at Caldwell; those west of Haledon; those northeast of Bloomfield; those north of Franklin lake; those north of Wyckoff; those two miles west-northwest of Oradell; those at Demarest; and, perhaps best of all, those northeast of Rivervale.

The kame groups of the second type are less well defined. Normally, they are areas of undulatory topography, where the individual hillocks may be looked on as small kames. With the hillocks are depressions, comparable in dimensions to the knolls. In form they are like the preceding type, somewhat flattened out. They do not commonly constitute ridges. They are usually of fine material, or, at least, they are likely to be essentially free from bowlders. They are, on the whole, rather more homogeneous in composition, and more evidently of stratified material. By diminution of reliefs they may grade off toward pitted plains. In pitted plains there are all gradations between the plain with few sinks in it, through the plain that has many sinks with gravel ridges and knolls between, to those where the lowland predominates, with isolated gravel knolls and ridges.

The kame groups of this type may represent deposition of sand and gravel among and about ice blocks. They differ from the pitted plain primarily in the greater proportion of surface covered by depressions, and in the less constant level of the intervening knolls and ridges.

Among the kame areas of this type may be mentioned the following: The kame area in the Rockaway basin, from Troy meadows, to within a mile of the D., L. & W. railway; some parts of the Waverly-Union kame belt, especially west of Waverly; and the area southeast of Ridgewood in the valley of Hohokus creek. Some parts of the Paramus plain approach this type.

Eskers.—Eskers are much less common than kames, and all of them are small, though the number is considerable. The exact number cannot be stated more than arbitrarily, for there is difference of opinion as to whether certain disconnected ridges should be looked on as separate eskers or as parts of one. In other cases it is somewhat arbitrary to say whether a given ridge is an elongate kame or an esker.

All the eskers of the Triassic plain are small, and many of them are not very sharply defined. The largest is in the basin of Lake Passaic between Afton and Hanover. It is nearly four miles in length, but it is not altogether continuous. The next largest is about two miles long, and most of them are less than one mile in length.

In general, the eskers occupy low lands or valleys. A favorite position may be said to be the lower slope of a valley. They sometimes descend from higher levels to lower, lying obliquely on the slope.

In width they vary from a few feet to several rods, and in height from six feet to forty. A common width is 150 feet, and a common height fifteen to twenty-five feet. They are often single ridges with steep sides and narrow tops, but they sometimes broaden out so as to have flat tops. They are neither constant in width nor uniform in height. The width often increases as the height diminishes, but there is no constant rule regulating the changes in height and width. Sometimes an esker divides, and the two parts may diverge and become distinct branches, or they may unite again into a single ridge. Four of the eskers are continuous for more than a quarter of a mile. Where there are interruptions the dissevered parts may not be in a direct line. In structure the eskers are sometimes, though not always, distinctly stratified. The gravels composing them are often loose, not showing distinct stratification. The surface is particularly likely to be composed of loose gravel, but some exposures have been seen in which the materials were thoroughly compact, apparently indicating pressure of the ice.

The materials of the eskers are similar to those in the associated drift of other types. The size of the materials varies from fine sand and silt to coarse gravel. On the surfaces of the eskers there are not infrequently large bowlders. Most of the eskers have a course parallel, or nearly parallel, to the direction of ice movement.

Recessional moraines.—Within the area of the Triassic plain there are several recessional moraines, or moraine patches, but, with one exception, they do not constitute persistent and well-defined belts. Most of them can be looked on as no more than patches, too much dissevered, or too poorly connected with one another, to be correlated with confidence.

The best defined of these recessional moraine belts extends from Waverly on the east, through Lyons Farms and Union, to New Orange. A mile north of New Orange the belt is interrupted, and its further connection is a little uncertain. It is probably to be connected northwestward with the kames about Springfield. A second ill-defined and interrupted moraine belt extends from Harrison, through Woodside Park and Soho, to a point northeast of Bloomfield. At some points within this belt the moraine is well defined. Other morainal accumulations, sufficient to be notable, are found in the vicinity of Paterson, extending from a point a little north of Bellair, west and northwest to a point a little southwest of Haledon; three miles north of Preakness, where there is a well-defined northeast-southwest belt three miles in length; north of Wyckoff; two miles north of Hawthorne; two to three miles west-northwest of Oradell; at Demarest; north of Rivervale; and about Franklin and Crystal lakes. In most cases, the well-defined parts of these areas have their longer axes in a general east-west direction, though this is not true of all. In most cases the morainal accumulations are largely of the nature of kames, but in all cases there is a more or less unstratified drift associated with the stratified.

Yellow loam.—At many points in the Triassic plain, yellow loam covers the till and the stratified drift. It is by no means always present, and when it is present it is by no means always so distinct from the underlying drift as to warrant the inference that it is a separate formation, to be especially taken account of. So far as it affects the Palisade ridge, this loam was somewhat fully described in the Annual Report for 1893,[1] but it occurs at many points between that ridge and First mountain. In latitude, it ranges from Randell and Etna on the north, to

[1] Pages 211–244.

Newark on the south, and on the Palisade ridge it extends to its southern end. South of Newark there is a comparable loam, usually red, occupying a similar position. The loam is less common in the northern part of the region than in the southern, and even where commonest is far from being continuous.

Aside from the southern part of the Palisade ridge, it has its best development south of the latitude of Passaic and west of the Passaic river. It is particularly well developed about Newark, and may be seen in numerous exposures, though by no means in all. It is most conspicuous where the underlying till is red.

Even where it is present, it is often not sharply marked from the till, the two frequently seeming to grade into each other. On the other hand, it is frequently so distinct from the till that it cannot be seen at its numerous points of occurrence throughout the length and breadth of the area, without raising a question, and a very persistent one, whether it is not really, as it often seems to be, thoroughly distinct from the rest of the drift in origin. The loam is not confined to the till, but overlies the stratified drift as well, though over the stratified drift it is often more sandy than where its substratum is till. The loam contains stones here and there, though more commonly it is free from them, especially where its differentiation is sharp.

In general the loam is better defined at low levels than at high ones, but it does not appear to have a distinct upper limit. Its usual thickness is no more than two or three feet, but it occasionally reaches a thickness of as much as eight feet.

Loam somewhat like that here referred to occurs on First mountain and west of it, but its development is less distinctive, and its correlation with that to the east is at best uncertain. Where the sandstone and shale type of till grades into the gneissic till, in the northwest part of the Piedmont plain, the distinctness of the loam is lost.

Within limits, the loam seems to be independent of altitude. East of Great notch, it has an altitude of more than 200 feet (Peet). Surface loam on First mountain, which may not be the equivalent of that at lower levels, is found at still greater heights. In general, it is thicker on gentle slopes than on steep ones, and is very generally absent on narrow summits, though it has a tendency to accumulate in depressions on summits as well as on slopes. It covers indiscriminately till of the ground moraine, or terminal moraine topography, and stratified drift of all sorts. It sometimes covers the rock where till is absent. Striated stones have not been found in it, though both rounded and angular ones have been. Occasionally pockets of it seem to be thrust into the till laterally, where the latter has a steep slope.

In view of the phenomena of a similar nature outside the drift-covered region, the question is certainly pertinent whether the loam here referred to was not deposited by standing water after the recession of the ice. Because of the uncertain nature of the evidence it affords, the loam has not been cited (on preceding pages) as one of the evidences of post-glacial submergence of the lower part of the Triassic plain. If it denotes submergence, its testimony as to the depth of submergence is inharmonious with that of the deltas.

MODIFICATIONS OF TOPOGRAPHY PRODUCED BY GLACIATION.

From what has been said concerning the depth of the stratified drift it is clear that the topography of the rock surface in the Triassic area is very different from the present topography. If the drift were removed, an extensive and somewhat deep bay would extend north from Newark bay nearly or quite to the State line. This bay would occupy the Hackensack valley as far as Old Hook, and would extend thence northeastward. Another arm of the bay would extend north at the west base of the Palisade ridge to Highwood, and would, perhaps, connect northward with the more westerly arm at Neuvy. In this case, the ridge of rock between Haworth and Ridgefield Park would constitute an island. This bay would, at the maximum, be more than 200 feet deep. Still another arm of the bay would extend up the valley of the Passaic as far as Dundee Dam, and probably as far as Paterson. At Delawanna and Dundee Dam, the depth of the water in this arm of the bay would be at least forty to sixty feet. Still another arm of this bay would extend westward from some point south of Newark to Springfield, if the drift were removed, for at some points along this belt the surface of the rock is known to be well below sea level. This is true at Springfield, where the surface of the rock is known to be about twenty feet below sea level at one point, and this may not be its lowest portion.

It is not now possible to say how far these deep, valley-like bays were excavated by pre-glacial (pre-last-glacial) erosion, and how far they were excavated by the ice itself. The amount of glacial drift to the south does not, however, afford warrant for the supposition that the amount of glacial erosion was great enough to account for these deep rock valleys. The presumption is, therefore, in favor of their pre-glacial (pre-last-glacial) excavation by streams. This is the more probable since the pre-glacial valley at Springfield, some ten miles from Newark bay, is below the present sea level, and in a position where glacial erosion is not likely to have deepened it to any considerable extent.

If these deep valleys were pre-glacial, or largely so, the land must have stood much higher than now when they were excavated. In this case, the valleys tributary to these main valleys must have been correspondingly deep, and it is probable that the rock surface in their lower courses was also below sea level. It is, therefore, probable that a very considerable part of the surface (probably not less than one-fourth) of the Triassic plain between the Palisade ridge on the east and First mountain as far north as Paterson on the west, would be submerged, if the drift were removed.

From the foregoing facts, it is clear that the surface has been greatly evened up by the deposition of the drift. Were the drift removed, the relief of the surface would be much greater than now. In many places the filling has gone so far as to completely obliterate even great valleys. Thus the position of the eastward continuation of the deep pre-glacial valley (Plate XXXVII) which passed through Springfield is not definitely known, though it lay somewhere between Elizabeth and Newark.

Apart from the great change in the surface brought about by the filling of the valleys, the deposition of the drift has not greatly modified the larger topographic features of the region.

On the ridges and higher lands, the drift is too thin to affect, in any very important way, the larger topographic features. The most considerable elevations for which the drift is responsible are the moraine ridges between Chatham and Morristown, and between Fords Corner and Scotch Plains. The ridge in the former place, 100 to 200 feet above its surroundings, divides the basin west of Second mountain into two parts. Elsewhere there are minor ridges of drift of consequence, and the kame groups already mentioned are often conspicuous topographic features of local extent.

The minor topographic features of the drift are more numerous. Many of the kames are notable knolls, and some of the belts of recessional moraines (kame belts) are also conspicuous. Many of the notable flats and plains, such as those about Franklin lake, Paramus, Westwood, etc., are due to the disposition of the stratified drift. Many of the striking depressions, such as that half a mile west of Convent station, those on the Delawanna plain, and those between Union and Waverly, are also due to the disposition of the stratified drift.

The ice modified the topography in a second way. It not only deposited drift, but before this was done it had eroded the surface of the rock. The extent of the erosion can best be judged by the amount of drift which resulted from it. The average depth of the drift in that part of the Triassic plain where till lies at the surface is probably not more than thirty feet. The average depth of the drift where the stratified type prevails is perhaps twice, or possibly thrice, as great. These figures warrant the inference that while the modification of the topography by erosion was considerable, it was not such as to profoundly alter it. North of Newark the relations of divides and valleys were not greatly changed. South of that point, and east of First mountain, where the relief was slight, erosion and deposition together, but chiefly deposition, changed the pre-glacial topography materially.

Glacial erosion probably deepened somewhat the valleys which were parallel to ice movement before they were filled. Glacial erosion also smoothed down the roughnesses of surface, both in the sandstone areas and on the trap ridges. Being of resistant rock, the trap ridges were probably not lowered very much. The sandstone ridges, being of less resistant rock, and covered by a greater depth of ice, were probably reduced to a somewhat greater extent. The aggregate effect of ice erosion on topography was probably to smooth down the rugosities of surface, without profoundly altering its relief. In general, the effect of glacial erosion was probably to increase relief, since the valleys were probably deepened more than the hills were lowered.

CHANGES IN DRAINAGE OCCASIONED BY THE DRIFT.

The deposition of the drift modified essentially the drainage of some parts of the Triassic plain. As stated in earlier reports, the drainage of the upper Passaic basin, which now follows a roundabout and rather remarkable course, was formerly discharged across Second and First mountains, near Short Hills and Millburn (Plate XXXVII, p. 154). The depth of this valley where it crossed Second mountain is not definitely known, but it is known to have been lower than the present valley at Little Falls, and it was probably a good deal lower. Its bottom just east of First mountain is below sea level. Considerable portions of the basin west of Second mountain, which this river formerly drained, are now, after having been built up by the drift, less than 200 feet above sea level. At one point half a mile east of Pleasant Plains, and about nine miles from the Short Hills gap in Second mountain, the surface of the rock is reported not to have been reached in a boring which went down to the level of 150-160 feet above sea level. The reduction of the rock surface to a level lower than 160 feet, nine miles from the place where the drainage which did the work, escaped through Second mountain, is clear evidence that the valley across the mountain must have been somewhat lower.

The course of the pre-glacial drainage from the upper Passaic basin, east of Millburn and Springfield, is not definitely known. It was probably to the eastward, reaching Newark bay not very far from the point where the Passaic now reaches it. The surface of the rock is below sea level at various points about Elizabeth, though the rock surface here is not known to be so low, or nearly so low, as in the Hackensack meadows. It is probable that the drainage from the basin of the Rockaway joined the Passaic west of Second mountain. The drainage of the Ramapo, Wanaque and Pequannock basins doubtless united as now, and was discharged along the line now followed by the Passaic. The Passaic appropriated this valley only after its own valley across Second mountain near Short Hills had been blocked with drift.

In the area between the First mountain on the west and Perth Amboy and Newark on the east, the present drainage probably has little likeness to that of pre-glacial times. The Rahway and Elizabeth rivers probably flow across the deep, buried valley of the pre-glacial Passaic.

THE HISTORY OF GLACIATION IN THE TRIASSIC PLAIN.

The history of the advance of the ice into this region is largely conjectural. It is certain that the larger relief features of the region were somewhat as now, though the relief was greater, because the valleys were deeper. It is uncertain whether a bay extended up the west side of the Palisade ridge, though this is not at all impossible. If the land did not stand higher than now, relative to sea level, the bay existed. If the bay existed, it was so shallow as not to stop the progress of the ice.

The history of the retreat of the ice from the region is better known. After standing sufficiently long at the position of the terminal moraine to develop it, the ice retreated to the Waverly-Union-Springfield moraine belt, leaving the area between the terminal moraine and this subordinate recessional moraine very generally covered with till. The relief of this intermediate belt is slight, and the topography of the drift is generally plane. Its thickness varies from zero to more than 100 feet, but its average depth is probably not more than twenty to thirty feet, and considerably less than that of the moraine belts on either side. The till is everywhere of the conspicuously red type, being made up for the most part of materials derived from the Newark series. Of the bowlders, however, other sorts of rock constitute a large part.

It is suspected that as the ice withdrew from this region, standing water occupied the surface from which the ice retreated.

The surface of the till of this area is often, though not always, covered by loam. The loam is sometimes red, and sometimes yellow in color. It sometimes masks the real nature of the underlying drift, so that it is often impossible to say whether it is stratified or whether it is till. This surface loam may be connected with the standing water, which, it is believed, followed up the edge of the ice as it retreated. It should be said, however, that the topography of the drift in this region does not bear evidence of wave cutting, nor does it possess other topographic marks such as might have been anticipated if the area had been submerged.

After retreating to the position of the Waverly-Union-Springfield belt, the ice halted long enough to develop the first recessional moraine. This moraine is largely, but not wholly, made up of kames. It contains some till, and the drift is frequently ill-assorted, being neither distinctly stratified nor distinctly unstratfied. Frequently, too, the stratified and the unstratified drift alternate with each other at short intervals. The most conspicuous part of this moraine belt is in the vicinity of New Orange, where the highest point reaches an elevation of 186 feet, or about 100 feet above its surroundings.

One of the most remarkable features of this moraine belt is the depressions which affect it. To the east, the depressions reach sea level. To the west they are even deeper below their surroundings, though their bases are not so low. The great depression through which the west branch of the Elizabeth river flows southwest of Union is the most notable, but the smaller depression to the south of it, known as the "Ship hole," is, perhaps, more striking.

The thickness of the drift in this belt is not well known. Thicknesses of thirty to forty feet are common, but these are certainly far below the maximum. It is probable that the depth of drift exceeds 100 feet north of New Orange.

It is in connection with this moraine, east of Connecticut Farms, or Union, that there appear to be deltas on the north side of the West Branch of the Elizabeth river. The delta front falls off to the depression through which this stream flows.

After the development of this moraine, the ice retreated northward without notable halts, so far as known, to the vicinity of Woodside and Bloomfield, where morainic patches indicate a temporary halt of the ice. If the several somewhat disconnected moraine patches of this vicinity were contemporaneous, the front of the ice had assumed a northwest-southeast position.

The area between the Waverly-Springfield moraine and the Bloomfield-Woodside belt has notably more relief than the area south of the former. Till is the prevailing form of drift throughout the area, the stratified drift being confined chiefly to the valley of the East Branch of the Rahway, and to the lowland along the Passaic. The drift of the area between these moraine belts is not very thick, probably not averaging more than twenty feet. Rock appears in numerous shallow cuts about Newark and Irvington. As farther south, the bowlders of this area were largely derived from outside the Triassic plain, but the body of the drift was derived mainly from the Newark terrane.

The moraine belt between Bloomfield and Woodside is rather ill-defined, the only conspicuous morainic tracts lying east of Bloomfield; but there are feeble morainic connections southward through Woodside and Riverside. These may be connected with a small area of moraine topography in the southern part of Harrison. The moraine belt cannot be traced farther west than the vicinity of Montclair.

Retreating from the position marked by these morainal accumulations, the ice developed no other distinct moraine belts of considerable length. Local aggregations of morainic nature occur at numerous points, and some of them have already been referred to. Their connections are more or less conjectural, and perhaps do not exist, for it is not necessary to suppose that because morainic accumulations were made at one point, they were made at all points along the ice front at the same time.

Mr. Peet has thought to find evidence of a considerable further number of positions where the ice halted during its retreat. These positions are marked by disconnected and feeble accumulations of moraine material. He thinks that the Waverly-Union moraine is, perhaps, to be correlated with certain morainic patches west of the Watchung mountains, especially with a belt extending from Livingston, north to Preakness. He would make the Harrison-Belleville-Bloomfield belt divide at Bloomfield, one branch connecting over First mountain with the heavy gravel accumulations about Verona and Cedar Grove, the other running east of First mountain to Great notch, west of which it joins the other belt, and is continued north to Totowa. He regards the thick belt of drift along the Passaic from Delawanna, northward to Paterson, as marking another position where the edge of the ice halted. North of the river at Paterson he would make this belt divide, the western branch running northwest through Haledon, *via* Franklin lake, to Crystal Lake, and the other northward through Van Winkle to Midland Park. He would locate another double belt between Arcola and Ridgewood, one branch by way of Fairlawn and Glen Rock, the other along the Saddle valley.

While something may certainly be said for the existence of some of these belts, the suggested connections have too little support to be accepted with confidence. It is to be noted that they would give the ice front, during its retreat, a general north-south or north northwest-south southeast front during its retreat.

The drift of the basin of Lake Passaic west of Second mountain was modified by the waters of the lake. These waters affected both slopes of the moraine from Chatham to Morristown, and modified, to some extent, the drift throughout the basin to the north. In the lowlands, clay and loam deposits were made over the glacial drift.

At the northern end of the lake, in the vicinity of Little Falls, there is evidence of some fluctuation of the edge of the ice during the time of its retreat. This evidence is found in till overlying the stratified clays which were laid down in the quiet waters of the lake, a mile northwest of Little Falls. This relationship does not necessarily signify any great fluctuation in the position of the ice, but it shows that the ice receded far enough north to allow lacustrine clays to accumulate as far north as Totowa, and that it subsequently pushed down essentially to the Passaic river, just west of Little Falls. Since the laminated clays were probably not deposited at the edge of the ice, but at some distance from it, the relations of till and laminated clay, suggest an oscillation of the ice edge amounting to at least two or three miles. It may have been much more. Dr. Kümmel has found evidence that the level of Lake Passaic fluctuated notably.[1] This was interpreted to mean that at some stage the ice retreated enough to allow the formation of a sub-ice outlet *via* the Passaic river. If such an outlet was through Great notch instead, it would call for a lesser retreat of the ice and explain the failure of the lake level to fall more than it did.

The data from which this fluctuation of level of the lake is inferred do not show that still greater fluctuations did not take place.

THE TILL OF THE TRIASSIC PLAIN.

ON THE PALISADE RIDGE.[2]

The Palisade ridge is primarily of trap rock. Sandstone lies along its western base, and at the north extends up its western slope to a height of 200 feet, and locally still higher (see Fig. 73). Sedimentary beds of Triassic age also outcrop at the eastern base of the ridge. Fig. 73 represents diagrammatically its structure.

As already stated, the axis of the ice lobe which covered this region lay just to the west of the Palisade ridge, and from it the ice diverged feebly to the west on the west side, and strongly to the east on the east side. The thickness of the ice was notably greater than the height of the ridge, for ice in considerable volume passed from the axis of the lobe southeastward over the highest parts of the ridge. This relationship of the ridge to the direction of ice movement (see Plate VIII, in pocket) furnishes the explanation of most of the local characteristics of the drift of the ridge.

---

[1] Annual Report for 1893.

[2] The drift of the Palisade ridge is described in greater detail in the Annual Report for 1893.

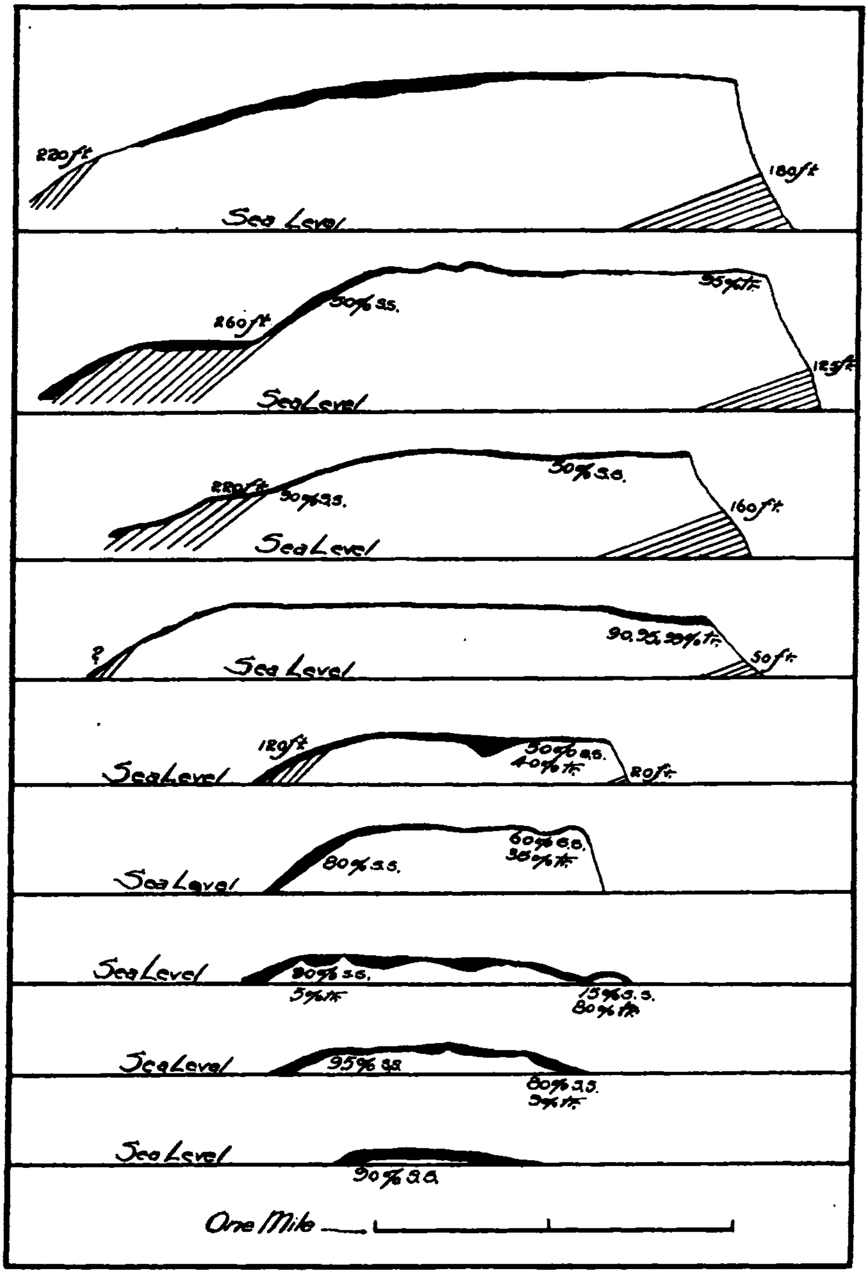


Fig. 73.

A series of sections across the Palisade ridge, the uppermost near the State line, and the lowest near the south end of the ridge. The heavy surface line represents drift, which has a variable thickness. The unshaded part of each section represents trap rock. The lined portions at the sides represent Triassic sandstone.

The drift on the Palisade ridge is mainly till, though stratified drift is plentiful at its western base. Generally speaking, the till is thickest at and near the base of its western slope, thins to the crest, where its amount is small, in case the crest is high, and is absent from the eastern or Palisade face. Thicknesses of thirty to forty feet are common on the lower part of the western side, especially where the slope is gentle, while on the crest of the higher part, thicknesses of as much as ten feet are rare, and in many places the rock is nearly bare. The drift is also thin west of the crest where the slope is steep, as about Granton. Near the south end, where the ridge is low, there is less difference in the thickness of till on slope and crest. These general relations, partially illustrated by Fig. 73, may be expressed as follows: 1) From the State line nearly to Jersey City, the east face of the ridge is essentially free from drift. 2) The drift is thin on the summit, especially to the north, but thickens to the south, in the direction of the declining height of the ridge. 3) North of Marion, the thickness of the drift diminishes with increasing altitude. 4) South of Marion, the ridge is low, and there is little difference in the depth of the drift on the west and east sides.

The abundance of rock outcrops is in keeping with the distribution of the till. There is nearly continuous exposure of rock on the east face of the ridge from the State line to Jersey City. The comparatively flat summit furnishes frequent outcrops from Guttenberg to the State line. From Guttenberg to Jersey City, outcrops are numerous on both the east and west slopes, but rare on the summit. South of Jersey City, a few outcrops occur on the east and west sides, and still fewer on the summit. At Guttenberg there are something like seventy-five outcrops to the square mile, while south of this point there are many square miles without an outcrop.

Like all till, that of the Palisade ridge consists of an unassorted mixture of bowlders and stones of smaller size, sand and earthy or clayey matter. At one point or another on the ridge till may be found in which each of these classes of material predominates.

Lithological Constitution of the Till.

From the position of the ridge with reference to the direction of ice movement (see Plate VIII), and from the relations of movement to the outcrops of sandstone and trap, the general constitution of the till of the ridge may be readily inferred, for till in general contains (1) abundant material from the last considerable formation crossed by the ice before reaching the point of deposition, and (2) lesser amounts from formations crossed at a greater distance from the point of depositon. On *a priori* grounds, therefore, the drift of the ridge should be composed chiefly of 1) trap, and 2) of Newark sandstone, together with 3) lesser constituents of crystalline schist or gneiss, shale, sandstone, limestone, etc., derived from formations farther north. Triassic sandstone, but no trap, at least none carried by the ice from this ridge, should be found in the drift of the western slope, below the contact of sandstone and trap. Along the west edge of the trap, just east of its contact with the sandstone, the drift should be made up principally of material derived from the sedimentary part of the Newark formation, but with increasing distance from the contact the proportion of Triassic material should decrease, while that derived from the trap should increase.

In keeping with these conclusions, which seem evident on the basis of the principles and relation already set forth, the till of the Palisade ridge presents at the extremes two somewhat distinct types; one in which red sandstone debris predominates, and one in which trap debris predominates. The distinctive colors of the two rock formations, the sandstone and the trap, help to emphasize the distinctness of these types of till, but between them there are all gradations.

The local constituents, trap and sandstone.—The till composed chiefly of material derived from the Newark sandstone, is characterized by its redness. Its matrix is sandy where derived chiefly from sandstone, and clayey where derived primarily from shale. This type of till is found on the lower part of the western slope of the ridge up to and somewhat above the junction of the trap and sandstone. Where the ridge is low, as toward the south

Till on Serpentine, Stevens Point.

end, red till often occupies its crest as well as its western slope. Below the level of the trap rock on the west face of the ridge, gneiss is the second most important constituent of the till. Of the red till lying on the trap well above its contact with the sandstone, trap is often the second constituent in importance. In addition to the gneiss and trap, fragments or bowlders of quartzite, limestone and quartz are present, though in small numbers.

In color the trap type of till is in sharp contrast with that derived chiefly from the Triassic sandstone, being yellowish-brown instead of red. Till of this type occupies the crest of the ridge at most points where the ridge is high, and reaches down a variable distance below the crest on the west slope. The till is much more likely to be trappean where it is thin than where it is thick, and the thinner the till the lower on the west slope does the trappean type appear. The minor constituents of the trap till in the order of their importance are Triassic sandstone, gneiss, quartzite, limestone and quartz pebbles. The minor constituents are of more importance where the till is thick than where it is thin.

Between these two types of till there are all degrees and phases of gradation, especially on the western slope above the line of contact of the sandstone and trap. The diagram (Fig 73), representing the disposition of the drift, shows also the percentages of trap and sandstone at different heights. It will be seen that, so far as the stony material is concerned, the sandstone predominates far above the contact of sandstone and trap, and that the red material predominates at some points not only up to the crest, but even beyond it on the east brow. The till at the south end shows, on the whole, a much higher percentage of sandstone than that at the north, though there is as large a percentage of sandstone in the till of the west slope at the north as at the south. This difference is very likely due in part to the greater height of the ridge at the north, and in part to the fact that the ice which deposited the drift on the southern end of the ridge had passed over a greater stretch of country where the Triassic formation constituted its bed.

Serpentine is found in the drift at Stevens Point, Hoboken, where there is an outcrop of this rock, but it does not occur elsewhere. The stony material here is more largely of trap than of any other material, though sandstone from the west side of the ridge is present. The reddish color is due partly to the presence of material derived from the red jasper, which, according to Prof. Cook,[1] lies just west of the serpentine. Certain phases of the serpentine also seem to weather red.

Bowlders foreign to the ridge.—Limestone bowlders, never abundant, decrease in importance southward. Even where they are absent or rare, the matrix of the till often contains enough calcium carbonate to be readily detected, though its percentage is never high. Gneiss, chiefly in the form of bowlders, is distributed with approximate uniformity from the north end of the ridge to the south. Quartzite bowlders are more abundant at the north, and white quartz, especially in the form of pebbles, is more abundant to the south. Pebbles which are believed to have come from former remnants of the Beacon Hill or Bridgeton formations are found at a maximum elevation of 360 feet, as far north as Highwood. They are more abundant at lower altitudes toward the south end of the ridge, but remnants of the formation from which they might have come are nowhere exposed on the ridge. Bowlders of Green Pond mountain (or Skunnemunk mountain) conglomerate have not been observed on the ridge, though they occur but a short distance west of the axis of the ice lobe.

Physical Constitution of the Till.

On the basis of physical constitution, the various types of till are bowldery till, gravelly till, sandy till and clayey till. Between these types there are all gradations on the Palisade ridge.

Till in which clay predominates has its best development at the southern end of the ridge. Till in which sand predominates has little development on the ridge, though some of the till east of Ridgefield contains much sand. The gravelly type of till is represented on the west slope of the ridge much of the way from

[1] Geology of New Jersey, 1868, p. 325.

PLATE LXII.

A perched bowlder of Triassic sandstone on the trap ridge east of Englewood.

the State line to Tenafly, but not above an altitude of 360 feet. It occurs east of the railway south of Tenafly, and between Englewood and Tenafly, east of Nordhoff, southeast of Leonia toward Taylorville, and half a mile northeast of Marion station. In a belt between Union and Marion, the till has more bowlders than is its wont. Other areas of like character occur between Centreville and Constables Point, and at Stevens Point. Bowlders are, however, not the predominant constituent of the drift in all these places.

Notable bowlders.—The bowlders on the ridge which are large enough to be conspicuous are the following: 1) A perched block of Triassic sandstone, 8 x 12 x 12 feet, east of Englewood (see Plate LXII) near the east side of the ridge, at an altitude of 360 feet; 2) a block of the same sandstone, 15 x 10 x 6 feet, a third of a mile northwest of Linwood, at an altitude of 230 feet; 3) a gneiss bowlder, a few hundred yards east of Tyler Park station, 12 x 20 x 6 feet; and 4) a trap bowlder at Stevens Point, 8 x 8 x 3 feet.

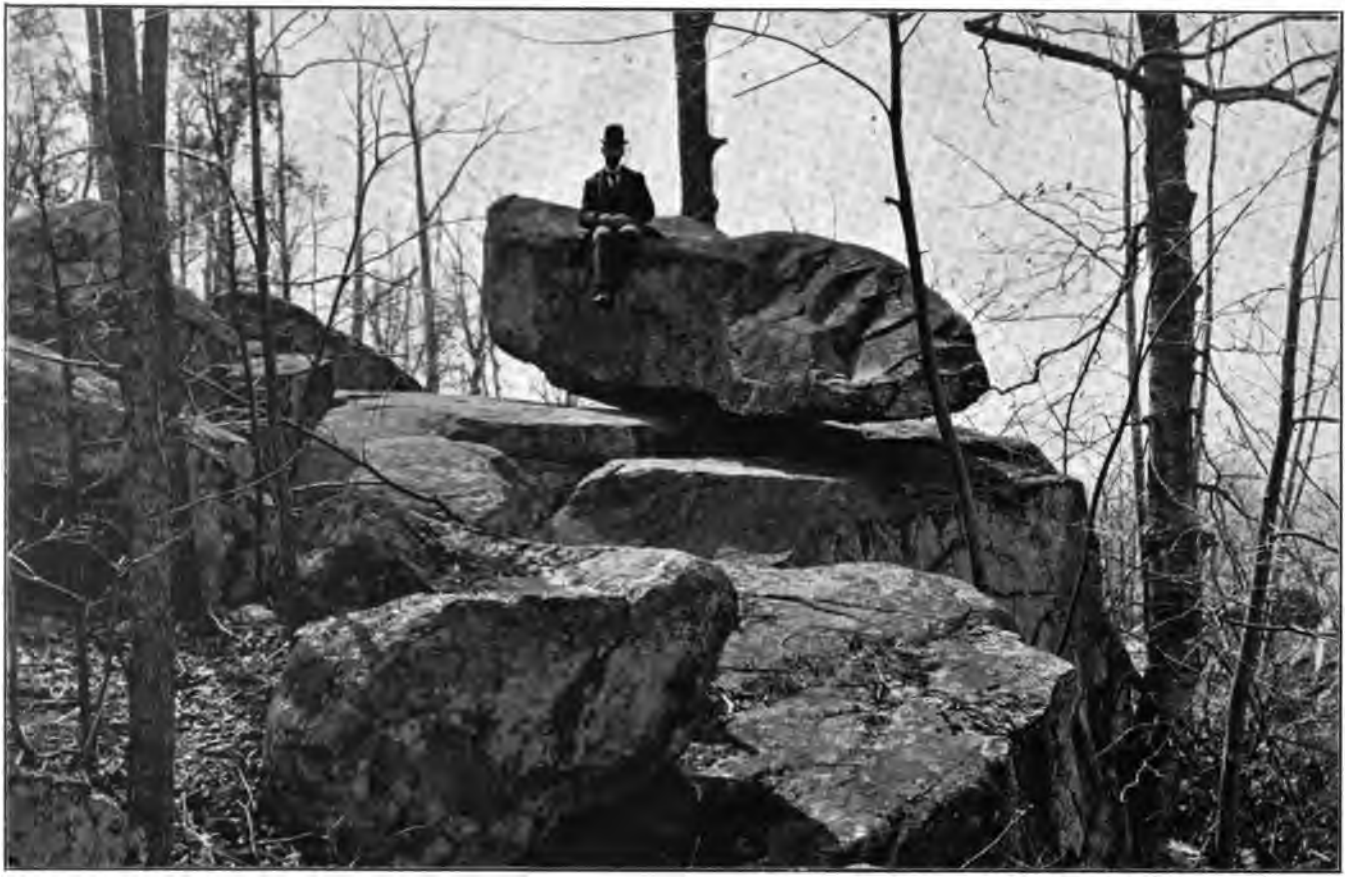
Of these bowlders the first is the most striking, though not the largest. It rests on a clean surface of trap rock. The lower surface of the bowlder is irregular, and the surface of the trap on which it rests is not flat, so that the former touches the latter at a few points only. Because of the slight contact of the two surfaces, the trap surface beneath the bowlder is visible. Nowhere about the bowlder does the trap surface show glacial polishing or striæ, but beneath it the surface is beautifully striated and polished. The bowlder has protected the surface of the rock beneath both from rainfall and from the direct rays of the sun, and so from the solution occasioned by the one, and from the disruptive effects of expansion and contraction occasioned by the other. The position and relations of this perched bowlder, together with its splendid size and its proximity to a great and growing center of population, make it fitting that the bowlder be preserved. It is one of the best examples of a perched block in the State. It is one of the most curious, striking and instructive surface features on the whole Palisade ridge. The bowlder was carried up the west face of the ridge from the sandstone below. Its distance from its parent ledge is not known, but it has apparently been carried up not less than 160 feet, and perhaps twice that amount.

Upward Transfer of Drift.

From the foregoing facts it is evident that the ice carried material from the red sandstone up the west slope of the ridge to its summit, and sometimes in such quantity as to give the till a decidedly red color, even to the east brow of the bluff. Indeed, material from the Triassic formation, some of which was carried up over the lower part of the ridge, forms a notable constituent of the drift in the southern and western part of New York city and in Brooklyn.

The red till on the trap ridge, and the relations of the ridge to the sandstone on the west, and to the direction of ice movement, afford some basis for estimating the amount of upward movement suffered by debris from the Triassic sandstone, though they do not afford a means of measuring the lifting power of the ice. Triassic material was carried to the top of the ridge in all latitudes. The top of the ridge is nowhere more than 300 feet above the upper edge of the sandstone at its west slope, and the maximum may be a little less. It is altogether possible that some of the Triassic material on the top of the ridge came from points below the highest level of the contact of sandstone and trap. In this case it was carried up more than 300 feet, possibly even 500 feet. Some of the Newark material on the trap ridge, on the other hand, may have come from the summits of sandstone ridges west of the base of the Palisade ridge, and higher than the contact. In this case it was lifted less than 300 feet. This alternative is much less likely than the other, since the high sandstone ridges are mostly west of the axis of the ice lobe. Three hundred feet is, therefore, probably a safe minimum estimate of the amount of elevation which debris from the Newark formation underwent.

If the bowlders of gneiss on the ridge were carried to their present position in the bottom of the ice, they must have reached the crest of the ridge after being carried across the depression



Trap bowlders of disintegration on the top of Sourland mountain.

between the Highlands and the ridge. In this case they may have been carried upward an amount equal to the maximum stated above. If they were carried by the ice above its base, a less amount of lifting was necessary to get them to the top of the ridge.

Glacial Modifications of the Palisade Ridge.

There seems to be no way of estimating with accuracy the amount of erosion which the ridge suffered during glaciation, though there are certain considerations which are instructive in this connection. It is certain that such decomposed and half-decomposed materials as lay on its surface were removed, and that the surface of the rock, down to the limit to which any observable amount of oxidation had reached, was worn away. This is shown by the fact that the surface of the trap, wherever seen, is smooth and hard, not decomposed and rough, as are the surfaces of the trap ridges south of the moraine. Some idea of what the surface probably was before glaciation may be gained from Plate LXIII, which shows the surface of the trap on Sourland mountain, Hunterdon county, though the amount of loose material here is exceptional. This Plate should be contrasted with Plate LXIV, p. 537. From the character of the surface of the rock, a few feet of erosion, perhaps not less than five below the loose debris, may be assumed.

There are abundant bowlders of trap east of the Hudson, which came, in considerable part, from below the zone of weathered rock. They are, on the whole, of fresh-looking rock. Their aggregate mass, if stated in tons, would be most impressive; but if all of them were back on the Palisade ridge, its surface would hardly be sensibly higher than now. They afford no warrant for believing that the ridge lost any considerable part of its height during glaciation, or that its surface configuration was greatly modified by the ice. Minor rugosities of surface were doubtless effaced, and, where circumstances favored, the ice probably wrenched large blocks of rock from its bed, and, moving them along in its bottom, ground them into less angular forms.

The rending power of the ice was probably greatest where it passed over a prominence with an abrupt face to leeward. In such situations masses of rock were broken off from the lee side, leaving it rough and angular, while the opposite or stoss face of the same prominence was worn to smoothness. The breaking of blocks of rock from steep lee faces has been termed "plucking." The rock surface at the reservoir at Weehawken shows the result of plucking. Much of the Palisade face of the ridge was so situated as to suffer this phase of ice wear, and while this face possesses the ruggedness which would characterize a ledge face operated on in this fashion, there is no evidence that the plucking proceeded to such an extent as to shift the eastern brow of the ridge any considerable distance to the westward. The steepness of the eastern slope is against such a supposition, for the base of the ridge could hardly have been shifted westward by this process. We must conclude, therefore, that the amount of plucking was limited, and that the great features of the ridge were much as they now are before the advent of the ice of the last glacial epoch.

Glacial Markings.

Grooves and Striæ.—Because of the abundance of exposures of rock on the Palisade ridge, and because the rock was well adapted to receiving striæ and retaining them, they may be seen here in greater abundance and in a greater variety of situations than in any other part of the State. They occur on flat surfaces, on inclined plane surfaces, on vertical surfaces, straight and curved, and on the rounded angles between horizontal and vertical surfaces.

Glacial grooves, with or without the retention of polishing, are to be seen at the following places: 1) a mile east of Englewood, on Palisade avenue (see Plate V); 2) at Linwood, and between that place and Fort Lee; 3) at Alpine, near the schoolhouse; 4) in the eastern part of Edgewater; 5) at Shadyside; 6) at Bull's Ferry; 7) in the western part of Guttenberg; 8) along the east bluff in West Hoboken; 9) at Marion, east of the

Glaciated surface of trap at Weehawken. "Plucking" shown in the foreground.

station; and 10) along the east bluff, a short distance south of the Pennsylvania railroad.

In size the grooves vary greatly. They are sometimes several feet in width and several inches, to a foot, in depth. At Englewood some of them are five feet wide and fully a foot deep. At Marion there are grooves two feet in width and six inches deep.

Considerable areas of plane surface do not exist on the ridge, but limited areas which are nearly flat are found at various points along the crest. In such situations, striæ may be seen almost anywhere where the surface of the rock has been recently uncovered. Where the rock was left bare by the ice, the striæ have generally been destroyed by weathering.

Ascending plane surfaces, considered with reference to the direction of ice movement, are, perhaps, the most favorably situated for receiving glacial striæ. The western side of the Palisade ridge, as a whole, was such a surface. The movement of the ice was oblique to the direction of maximum slope, and the striæ have a corresponding direction. Striæ have not been observed on the Palisade face of the ridge, but the surface of the rock is so uneven that there are vertical surfaces of small extent at many other points, and these vertical surfaces are frequently striated. A good example is found in the cemetery at New Durham, where the striæ are both horizontal and inclined. The inclination from the horizontal is sometimes upward and sometimes downward. The maximum upward inclination observed is 18°, and the maximum downward at another point 74°. Striæ which are horizontal occur within a few feet of others which depart 54° to 74° from horizontality. Other localities where striæ were observed on vertical surfaces are the following: 1) at Marion, a few hundred yards east of the Pennsylvania railway station; 2) along the railway near the east face of the ridge, and 3) at Weehawken, in an excavation for the water-works reservoir. Plate LXIV shows the striæ on a vertical surface, and also illustrates the pliancy of the ice in fitting itself to irregularities of the surface so closely as to polish and striate them. It is frequently to be noticed that while horizontal rock surfaces in a given locality are deeply grooved, vertical faces of the same rock in the same locality are polished and striated only, the grooves being absent.

Striæ may be seen in grooves at most points where grooves are well developed. The best example noted is at Jersey City, along the Pennsylvania railway. Here there is a groove with a maximum depth of nine inches, in a vertical face of trap. It terminates in a blind pocket, three inches deep, into which and out of which the ice passed, so as to polish its entire surface. Outside the pocket the groove is polished on its inner face and on its upper and lower surfaces, affording striking evidence of the pliancy of the ice.

In adapting itself to contiguous horizontal and vertical faces, the ice abraded the angle between them, rounding and smoothing it. Sometimes the striæ on the rounded angles are parallel to the striæ of the horizontal and vertical faces, and sometimes they diverge from them. Striæ on rounded angles are shown at nearly all points where they appear on vertical faces, but nowhere better than at the Weehawken reservoir (Plate LXIV). Now and then the angle between contiguous horizontal and vertical faces remains sharp, with the contiguous horizontal and vertical surfaces both striated.

Small *roches moutonneès* are found at numerous points on the ridge, but they rarely exceed six or eight feet in height. Low as these domes are, rather remarkable divergences of striæ are sometimes seen on their surfaces. Examples may be seen a mile east of Englewood, on Palisade avenue, also at Linwood, Edgewater, Marion, and in the northwestern part of Guttenberg. East of Englewood the striæ on a *roche moutonneè* only five feet high, thirty-three feet long and seventeen feet wide, diverge 32°. It is scarcely credible that such divergence is due to so small a prominence, and it may be that the striæ were made at somewhat different times and when the general direction of movement was not the same. Similar divergences of striæ are to be seen at some points on nearly flat surfaces.

Chatter marks.—The peculiar form of glacial marking known as "chatter marks" is well shown at a number of places on the Palisade ridge. They consist of a succession of short, roughly parallel, curved lines, with their convexities opposed to the direction of ice movement. Their origin has been described as follows: "It is well known to machinists that a vibratory motion is very common whenever a gouging tool is forced over a resistant surface if there is any want of firmness in the fixing of the tool, or any unsteadiness of motion, or any persistent unevenness of the surface or of the texture of the material acted upon. Under any one of several conditions chatter marks are the result."[1]

If a bowlder or pebble be conceived as the tool in the grasp of the ice, and if the motion of the ice furnishes the movement to carry the tool over the surface of the trap, the machinery necessary for the formation of the chatter marks is at hand. In size, the chatter marks vary. The arms of the curve may be one inch or six inches apart at their extremities. Chatter marks have been seen on the Palisade ridge: 1) north of Marion station, west of the D., L. and W. railway tunnel; 2) on the east bluff of the ridge just north of the D., L. and W. railway tunnel; 3) seven blocks north of 2), near the bluff; and 4) on Newark bay, south of the L. V. railway.

Polishing.—By the help of the fine earthy material in its base, the ice sometimes smoothed and polished rock surfaces, without grooving or striating them. Examples of polishing, along with delicate lining, may be seen at various points, but especially well 1) at Bergen Point, on Newark bay, just north of the C. R. of N. J. railway; 2) along the Pennsylvania railway from Marion to Jersey City, and 3) along the east bluff at Guttenberg, where ideal illustrations of glacial polishing, together with delicate striations, are to be seen. Near the schoolhouse at Alpine also, good illustrations of glacial polishing may be seen. Polishing is often seen to good advantage in connection with deep grooving.

In many situations where the rock has not been protected, post-glacial weathering has destroyed the polish of the surface without obliterating grooves and deep striæ. On the north end of the ridge, the bare, or nearly bare rock surface has lost its polish. In the northwestern part of Guttenberg, on the other hand, surfaces which appear to have been exposed since the glacial time still retain the smooth surfaces which the ice devel-

[1] Chamberlin, Seventh Annual Report, U. S. G. S., page 218.

oped, though apparently not with all their original freshness. This difference is probably due to some difference in the texture or composition of the rock in the two localities, a difference which constitutes the rock of the one locality more resistant to weathering than that of the other.

Direction of striæ.—The directions of striæ on the Palisade ridge have already been published,[1] and only a few general statements concerning this topic need be given here. As the map illustrating the direction of ice movement shows, the ice moved obliquely eastward over the ridge, and the easterly diverge is something like 20° greater at the north end of the ridge than at the southern. In the latitude of Closter and Alpine, the maximum easting is 74°; in the latitude of Englewood, 63°; in the latitude of Fort Lee, 52°; at Edgewater, 59°; at Guttenberg, 49°; at Weehawken, 59°; at Hoboken, 43°; at Communipaw, 43°; at Pamrapo, 54°. These figures show that the decrease in easting to the south is not uniform.

On general principles, it would seem that the divergence of the ice movement should have been greatest nearest its margin, that is, to the south. The only suggestion which can be made to account for the existing direction of movement, is that the ridge is higher to the north, and so had a stronger tendency to restrain eastward movement. The striæ recorded are on the trap rock and mainly near the crest of the ridge. It may be that the ice, after attaining the crest, and escaping the restraining effect of the ridge, turned more to the east than would have been the case without this restraint.

TILL BETWEEN FIRST MOUNTAIN AND PALISADE RIDGE.

Summary.

Position of area with reference to ice movement.—The axis of the ice lobe which affected this area lay near its eastern edge. Along the axis, and between it and First mountain, the ice

[1] Annual Report for 1893.

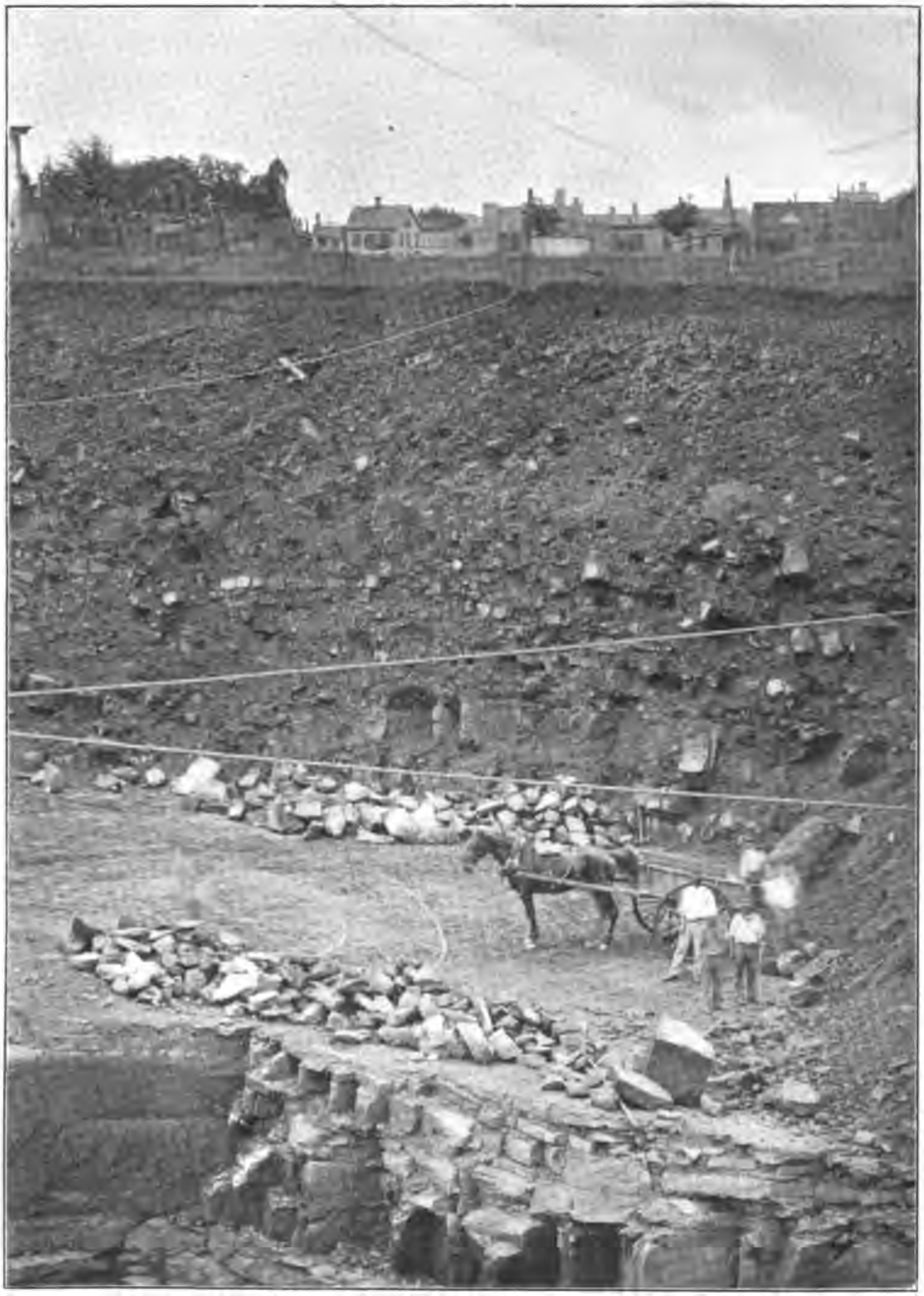
worked on the sedimentary part of the Newark system only, so far as New Jersey is concerned, and whatever material of other origin is found in the drift of this area came from outside the State, except 1) the small amount of trap which was derived from the small bosses and dikes in the area, or which had been brought down into the valleys from the Palisade ridge on the one hand or from First mountain on the other, in pre-glacial time; and 2) the pebbles from such remnants of the Tertiary or early Pleistocene (Beacon Hill, Bridgeton, Pensauken) formations as remained in the region when the ice came in. To the above general statement an exception must be made of the small area between Woodbridge and Perth Amboy, where the ice overrode the Cretaceous beds, and where remnants of the Pensauken formation were considerable.

Constitution.—As a consequence of the uniformity of the rock on which the ice between First mountain and the Palisade ridge worked, the till of most of this area is more constant in character than that where the contributing formations were more diverse. Most of it has the red color determined by the Newark formation, from which it was chiefly derived. This characteristic color is not always obvious at the surface, for the surface material has sometimes been bleached by weathering, and its till is sometimes covered with yellowish loam, which obscures the real color. In general, the proportion of bowlders which came in from outside the Triassic formations is much greater than the proportion of the matrix of the till which had such an origin. In many places, indeed, where the till is made up chiefly of material from the red sandstone, the bowlders are mostly of gneiss, quartzite, Hudson River sandstone, &c. Its composition, therefore, is often not correctly represented by the nature of the bowlders.

The principal exception to the prevalent redness of the till is found in the northwestern part of the plain, within the area already outlined (p. 503) as having till of the gneissic type. For a few miles south and east of this line, the till contains much material from both the gneiss and the Triassic formations, but the zone of gradation from till of the gneissic type to that of the sandstone and shale type is rarely more than four or five miles wide.

The character of the red till has already been described. It is, on the whole, more clayey in the southern part of the area than in the northern. Locally, as at points about South Orange, it is made up almost wholly of sand. It is, on the whole, poor in bowlders, for shale has too little resistance to endure transportation by ice without being crushed. While the sandstone is more resistant than the shale, it is far inferior to quartzite, gneiss, trap, etc., as a source of bowlders. It is often true, however, that the base of the till, where it lies on sandstone, is little more than an aggregation of sandstone blocks of local origin. In such situations the ice appears to have disturbed and disrupted the rock on an extensive scale, but to have moved the broken parts but slightly from their original source, and to have added to them but little foreign matter. In such situations there is sometimes so complete a gradation from the till made up of the local rock, through the slightly disturbed beds, to the rock in place, that it is difficult to say precisely where the till leaves off and the rock begins. There may be also a very complete gradation upward from the till made up of little worn blocks of rock of strictly local origin (Plate LXV) to that made up of materials which have suffered much more wear, and more extensive transportation.

While the matrix or finer part of the red till is derived principally from the underlying red rock, there are not a few bowlders from other sources. Among them are 1) conglomerates and quartzites from the Green Pond mountain belt or its northern extension (Skunnemunk mountain), 2) from the Hudson River formation (or some formation of like physical character), 3) from the gneiss of the Highlands, partly north of the State line, 4) bowlders of trap, some of which may have come from the northern continuation of the Palisade ridge, and 5) occasional pieces of limestone from the Newark conglomerate (as about Suffern) or from some older limestone formations of New York. In the southern part of the area under consideration, and extending as far north as the latitude of Englewood at least, there are also quartz pebbles, probably derived from northern remnants of the Beacon Hill or Bridgeton formation. Quartzite bowlders of unknown origin are also present. On the whole, bowlders of



Till over sandstone. Quarry in Newark. The till is made up largely of local, angular stones.

relatively thick at Rutherford. It is exposed along the railway near tide level east of Lodi, and along the trolley line west of the Saddle river at Lodi and at West Rutherford.

Between Kingsland and Harrison.—The preceding ridge is interrupted at Kingsland, but south of that point it is continued to Harrison. Between these points, the sandstone ridge is covered with till from the river on the west to the meadows on the east. The till is not thick, the rock appearing at intervals on the steep slopes, especially on the east side of the ridge, and in the northern part of Kingsland. At Arlington it is fifteen to twenty-five feet thick. On the crest of the ridge south of Kingsland there is some eolian sand which locally conceals the till, but it does not constitute distinct dunes. In the southern part of Harrison, below an altitude of about twenty or thirty feet, stratified drift covers or replaces the till. In Harrison the till has something of the moraine habit, and stratified drift and till are not distinctly separated. The edge of the ice appears to have stood at this point for a time during its retreat.

Between the Saddle river and the Passaic, south of Ridgewood.—Within this area more than half the surface is covered with sand and gravel deposited by water after the departure of the ice. The stratified drift generally occupies the lower levels, above which rise several till-covered areas, partially or wholly surrounded by the sand and gravel. In a number of places, however, as east of Paterson, till occupies the surface down to low levels. The till-covered areas are 1) the high land between Ridgewood and Fairlawn; 2) an elongate area parallel to the Passaic, east of Dundee lake, rather less than 100 feet in height; 3) an isolated area a mile east of Fairlawn; 4) another a mile and a half northeast of Dundee lake (summit eighty-five feet); 5) another a mile and a half southeast of Dundee lake (summit 124 feet); 6) another north of Garfield; and 7) the high land between Garfield and Rochelle Park. The axes of most of these ridges are sandstone, but this is not known to be true of all.

Between Ridgewood and Fairlawn and west of the latter place, the till is of the usual red sandstone type, but contains rather numerous and rather large bowlders of gneiss.

North of Fairlawn, depths of twelve and fifteen feet of till are recorded. At Fairlawn, wells show the depth of the till to be from twenty-four to fifty-six feet. At some points, however, as east of Glen Rock, the till is much thinner. On the bank of the river west of Fairlawn there is a little eolian sand. North of Bellair, the topography assumes a distinctly morainic habit, and this topography runs down essentially to the level of the flood plain of the Passaic.

The till on the ridge east of Dundee lake is stony, and has considerable depth, thicknesses of thirty to sixty feet being reported. As this ridge is at a maximum only ninety-one feet high, while most of it is below eighty feet, it appears that much of this ridge, if not all of it, may be of drift rather than rock.

The third, fourth and fifth areas mentioned above have a sufficient covering of till to conceal the rock, though the exact thickness is not generally known. In the area north of Passaic Junction, the till is twenty to twenty-four feet thick at some points. The area north of Garfield has not a sufficient body of till to effectually conceal the rock, which appears at frequent intervals over much of the area.

The ridge between Garfield and Rochelle Park shows outcrops of sandstone at its north end, where red till sometimes overlies till of greyish color and of loose, gravelly texture. At the south end of the ridge, there are cuts of till fifteen to twenty feet deep. Fully ninety-five per cent. of the stony material is Triassic sandstone, but Hudson River sandstone, quartzites and conglomerate are also represented. Yellow loam occurs at intervals up to elevations of at least 125 feet. It is sometimes thick enough to obscure the real character of the till below.

Closely associated with the areas of till just mentioned, are isolated areas north of Arcola on the east side of the Saddle river. The larger area extends north from Arcola, and while it has a goodly cover of till at the south end, rock is abundantly exposed at the north. Another small area of till lies west and northwest of the larger.

Between the Hackensack and Pascack north of Hillsdale.—The higher land within this area, including most of that above eighty to ninety feet, is covered by till, composed largely of types foreign to the area decrease in number and in size to the southward, with increasing distance from the formations which yielded them.

Other variations are introduced into the till in another way. Water coöperated with the ice in the deposition of the drift in various ways. Where its work was important it sometimes washed away much of the finer matter of the drift, leaving only the coarser. In other cases, stratified drift is interbedded with unstratified. Through the varying degrees of importance of the work of water, therefore, some variety independent of lithologic composition was introduced into the constitution of the till. The variations introduced by the work of water are more important, on the whole, at low levels than at high. The surface of the till, through the effect of surface water or weathering, has often been made more sandy than the main body below. This is especially true on lower slopes, where wash from the slopes above has accumulated, and in depressions where there has been a slight amount of alluviation.

The till of this region is rarely aggregated into drumlins, though several hills of drumlin type are found in the vicinity of the Oranges. Drumlins are elliptical hills of till, which, when well developed, have a length of twice or thrice their width, their longer axes being essentially parallel to the direction of ice movement. In size they vary greatly, but a quarter to a half mile is a common length. The height of a drumlin, like its horizontal dimensions, is variable, but a height of thirty to fifty feet is common. Drumlins may closely resemble rock ridges coated with till (veneered hills), and in the absence of exposures and of data concerning the depth of the drift the two may be indistinguishable. This is, perhaps, especially true of this region, where the direction of ice movement, and, therefore, of the drumlins, corresponds with the strike of the rock, and, therefore, with the longer axes of the rock knolls.

The average thickness of till for this area, disregarding that which underlies stratified drift, is probably not far from twenty-five feet.

Local Details.

East of the Hackensack and north of Randell.—Below the level of eighty or ninety feet, the surface of this region is very generally covered by stratified drift. In many places the stratified drift probably covers till, and in some places is known to do so. The sand and gravel of the stratified drift were chiefly deposited after the ice withdrew.

The till, or, at least, its surface parts, has a somewhat gravelly character and loose texture, and its color is less red than farther south. The area is not very distant, by the route of the ice, from formations which are less red than the Newark, and the drift contains a good deal of material from them. The till has sufficient depth to conceal the rock very generally. Near the André monument, just across the State line in Tappan, the thickness of the till exceeds forty-five feet, though its depth is not known. Two-thirds of a mile south of Norwood, where the surface has an elevation of ninety feet, the drift is seventy feet deep. Lesser thicknesses (twenty, thirty feet, &c.) occur at other points. Surface bowlders are rather abundant, and are largely of non-Triassic origin.

Randell to Ridgefield Park.—Between Randell and Ridgefield Park there is a long sandstone ridge between the Hackensack on the west and the Palisade ridge on the east. Most of that part of the ridge which has an altitude of more than sixty feet at the north and forty feet at the south, is covered by till. The adjacent lower levels are generally covered by stratified drift.

The till of this area is all of the red sandstone and shale type, and of the sandy rather than the clayey phase. Where thin, it may frequently be seen to contain abundant angular masses of sandstone, and the lower part of the till, where it is thick, probably has a like composition. Surface bowlders are seldom abundant. The surface is frequently sandy, and is locally covered by yellow loam, which often seems to be distinct from the body of the till below.

The till is notably thin on the steep slope west of Cresskill and northwest of Tenafly, and on the ridges between Tea Neck and

Hackensack. At most other points the rock is generally concealed. About Haworth the thickness of the till is often twenty to thirty feet thick, and the stony material is almost wholly of Triassic origin. Farther south, on the top of the ridge, excavations ten feet deep often reach rock, and not infrequently the rock is so close to the surface as to be exposed in the shallow road cuts. The greatest depth of till known on the ridge is about two-thirds of a mile northeast of West Englewood, where a well forty feet deep does not reach its bottom.

Etna (Kinderkamac) to Maywood.—Another ridge, primarily of sandstone, extends south from Etna (Kinderkamac) between the valleys of the Hackensack and the Saddle rivers. At the south it branches, one part extending to Maywood, and one to Cherry Hill. Till covers the surface of most of the higher part of this ridge. It is of the type of all that derived principally from the red sandstone, but, judged by the surface, it is, on the whole, more stony than is the general habit of this type of till. The known data indicate that the drift is thicker to the north than to the south. A well on the ridge near Etna is reported to have penetrated eighty-five feet of drift before reaching rock. At other localities, thicknesses of twenty-eight, thirty, forty and fifty feet are known. North of Maywood the drift but poorly conceals the rock, and on the west slope of the ridge the average thickness of till is probably not more than eight or ten feet. Striæ were observed on this ridge a mile north of Maywood station, and again a mile and a quarter northeast of that point. The directions (corrected) are, in both cases, S. 20° W.

Fairmount to Rutherford.—The preceding ridge is separated but little from another which extends from Fairmount to Rutherford. Most of this ridge, which has an elevation of forty feet or more, and some of the land at lower levels, is covered by till. The till is often gravelly, with a sandy matrix, but sometimes clayey. Sandy loam frequently mantles the surface, and occasional sections show a thin cover of yellow loam at the surface, sometimes rather distinctly separated from the red till below. The till is very thin on the ridge just west of Hackensack, on the crest just north of Woodridge, and at some points on the east slope of the ridge near Corona. Elsewhere it generally conceals the rock, and it is relatively thick at Rutherford. It is exposed along the railway near tide level east of Lodi, and along the trolley line west of the Saddle river at Lodi and at West Rutherford.

Between Kingsland and Harrison.—The preceding ridge is interrupted at Kingsland, but south of that point it is continued to Harrison. Between these points, the sandstone ridge is covered with till from the river on the west to the meadows on the east. The till is not thick, the rock appearing at intervals on the steep slopes, especially on the east side of the ridge, and in the northern part of Kingsland. At Arlington it is fifteen to twenty-five feet thick. On the crest of the ridge south of Kingsland there is some eolian sand which locally conceals the till, but it does not constitute distinct dunes. In the southern part of Harrison, below an altitude of about twenty or thirty feet, stratified drift covers or replaces the till. In Harrison the till has something of the moraine habit, and stratified drift and till are not distinctly separated. The edge of the ice appears to have stood at this point for a time during its retreat.

Between the Saddle river and the Passaic, south of Ridgewood.—Within this area more than half the surface is covered with sand and gravel deposited by water after the departure of the ice. The stratified drift generally occupies the lower levels, above which rise several till-covered areas, partially or wholly surrounded by the sand and gravel. In a number of places, however, as east of Paterson, till occupies the surface down to low levels. The till-covered areas are 1) the high land between Ridgewood and Fairlawn; 2) an elongate area parallel to the Passaic, east of Dundee lake, rather less than 100 feet in height; 3) an isolated area a mile east of Fairlawn; 4) another a mile and a half northeast of Dundee lake (summit eighty-five feet); 5) another a mile and a half southeast of Dundee lake (summit 124 feet); 6) another north of Garfield; and 7) the high land between Garfield and Rochelle Park. The axes of most of these ridges are sandstone, but this is not known to be true of all.

Between Ridgewood and Fairlawn and west of the latter place, the till is of the usual red sandstone type, but contains rather numerous and rather large bowlders of gneiss.

North of Fairlawn, depths of twelve and fifteen feet of till are recorded. At Fairlawn, wells show the depth of the till to be from twenty-four to fifty-six feet. At some points, however, as east of Glen Rock, the till is much thinner. On the bank of the river west of Fairlawn there is a little eolian sand. North of Bellair, the topography assumes a distinctly morainic habit, and this topography runs down essentially to the level of the flood plain of the Passaic.

The till on the ridge east of Dundee lake is stony, and has considerable depth, thicknesses of thirty to sixty feet being reported. As this ridge is at a maximum only ninety-one feet high, while most of it is below eighty feet, it appears that much of this ridge, if not all of it, may be of drift rather than rock.

The third, fourth and fifth areas mentioned above have a sufficient covering of till to conceal the rock, though the exact thickness is not generally known. In the area north of Passaic Junction, the till is twenty to twenty-four feet thick at some points. The area north of Garfield has not a sufficient body of till to effectually conceal the rock, which appears at frequent intervals over much of the area.

The ridge between Garfield and Rochelle Park shows outcrops of sandstone at its north end, where red till sometimes overlies till of greyish color and of loose, gravelly texture. At the south end of the ridge, there are cuts of till fifteen to twenty feet deep. Fully ninety-five per cent. of the stony material is Triassic sandstone, but Hudson River sandstone, quartzites and conglomerate are also represented. Yellow loam occurs at intervals up to elevations of at least 125 feet. It is sometimes thick enough to obscure the real character of the till below.

Closely associated with the areas of till just mentioned, are isolated areas north of Arcola on the east side of the Saddle river. The larger area extends north from Arcola, and while it has a goodly cover of till at the south end, rock is abundantly exposed at the north. Another small area of till lies west and northwest of the larger.

Between the Hackensack and Pascack north of Hillsdale.— The higher land within this area, including most of that above eighty to ninety feet, is covered by till, composed largely of gneissic, or at least of something other than Triassic, debris. The till is, therefore, in contrast with most of that farther east and south. The till is sufficiently thick to conceal the rock at most points. Thicknesses of sixty-two feet half a mile north of Hillsdale, of fifty-one and sixty feet a mile northeast of Hillsdale, and of forty-two feet two miles north-northeast of the village are known. Bowlders are rather common.

Between the Pascack and Saddle Rivers, north of Paramus.—With the exception of narrow belts along the streams, till covers most of the surface between the Pascack and the Saddle, north of Paramus. The till is thin throughout the southern part of the area, sandstone showing frequently in the shallow road cuts and on the steep slopes. At the north and northwest, the body of till is somewhat greater, but even here exposures of sandstone are not rare. Thicknesses of twenty to twenty-five feet are common in the vicinity of Chestnut ridge, but this is, perhaps, near the maximum for area. The average is, probably, not more than half as much.

Within this area, the gneissic material often predominates in the drift, or, at least, in its surface parts, where it is thick; but where it is thin, the till often has the reddish color characteristic of till derived chiefly or largely from the Triassic beds, and since the till is generally thin, its color is often reddish, except in the northern part of the area. Throughout the area, the local sandstone has contributed more largely to the finer material of the till than to the stony matter. Bowlders are more abundant than farther south, and a larger proportion of them came from the Highlands of New York, or from the area north of the Highlands. So distinctly do the numbers of bowlders increase, as the contribution of the gneiss to the till becomes more considerable, that the transition from the till of the Triassic type to that of the gneissic type is distinctly reflected in the size and abundance of the bowlder walls about the fields.

The bowlders of the region are of the same varieties as farther south, though the proportions are different. In the northwestern part of the area, bowlders of Hudson River sandstone (or some sandstone not distinguished from it) predominate, but gneiss bowlders are, on the whole, most numerous. Striæ were recorded in this area at three points, two within half a mile southeast of Paramus, where the directions were S. 20° W. and S. 47° W. respectively, and one and one-fourth miles west of Pascack, where the direction is S. 20° W.

Between the Saddle river on the east and the Ramapo and First mountain on the west.—Within this area there are considerable tracts of stratified drift, even at high levels. The areas where it occurs are, however, generally lower than their surroundings. The aggregate area of stratified drift is distinctly subordinate to that of till. Except at the south, the till of this area is of the gneissic type, and so far does the gneissic material predominate that in many places little or nothing is seen of Triassic material at the surface, or in the exposed parts of the drift. Where the till is thin, however, as along the steep slopes of the Saddle River valley, along Hohokus creek above Hohokus station, at various points about Ridgewood, Midland Park and Wyckoff, the red color appears at the surface.

It is probable that the Triassic sandstone enters much more largely into the composition of the till of this area than the surface indicates. This is occasionally seen in deep cuts and in the materials from wells. That material from the Highlands (to the north) should predominate in the upper part of the till rather than the lower is what should be expected; for in coming over the rough Highlands some material was acquired by the ice somewhat above its bottom. When the ice descended to the lower Triassic terrane, with its lesser relief, the material which it gathered there stayed at or near its bottom. When the ice melted, such material as was above the bottom was left on the surface of that which was lower in the ice. There is, however, nothing in the area to warrant the inference that the gneissic material in the upper part of the till became superglacial before deposition.

Exceptionally, the gneissic type of till is overlain by the red type of till. Mr. Peet noted this relation about a fourth of a mile west of Saddle River village and east of Hohokus station along the road to Waldwick. These localities are near the line where the gneissic type of till grades into the red type. There is some evidence that in its late stages the edge of the ice departed widely from parallelism with its earlier position, and it is possible that the direction of movement shifted so that it was more from the east at these localities in the late stages of glaciation than at the time the main body of drift was deposited.

In keeping with the large proportion of gneissic material in the till of this region, bowlders are very abundant, and those of large size are not rare. They are, however, not distributed with uniformity, and there are considerable areas where they are few or absent at the surface.

The foliated structure (Fig. 10a) is often conspicuous in the till of this region. This structure is, on the whole, more prevalent in till of the gneissic type than elsewhere. The best illustrations noted were in the vicinity of Allendale, but this distinctness of the structure depends so largely on the condition of the section, that localities where it is well shown at one time may show it but poorly at another. It is best seen in cuts which are ***nearly*** fresh, but which have been exposed to a *little* weathering.

Within this area there are a number of bowlders so large as to deserve individual mention. These are as follows: (1) Three-fourths of a mile north of Ramseys, on the surface of an esker, there is a bowlder 8 x 10 x 20 feet; (2) a mile north of Ramseys, near the roadside, at an elevation of about 400 feet, one 20 x 25 x 8 feet; (3) half a mile east of Masonicus, one fifteen feet in diameter; (4) west of Montvale, near road corners, at an elevation of about 200 feet, one 25 x 10 x 10 feet, and (5) the largest bowlder in the Triassic area, and one of the largest in the State, lies west of Glen Rock, just west of the railway (Plate XI, p. 15). Its exposed portion is 42 x 25 x 11 feet (Peet). The bowlder is of gneiss.

The average thickness of the till in this area is probably as much as thirty or forty feet, and reaches a known maximum of ninety feet. The following records give some indication of its depth: West of Mahwah, more than fifteen feet; at Masonicus and east of there, wells twenty-eight, thirty and thirty-two feet deep do not reach rock; west of Saddle River village, more than sixty feet; northeast of Oakland, in the valley, near N. Y. S. & W. railway, more than sixty-eight feet; at Waldwick, eighty to ninety feet.

Some of the larger exposures seen when the work in this region was done, were 1) on the N. Y. S. & W. railway, a fourth of a mile south of Midland Park station, where gneiss, Triassic sandstone, Hudson River sandstone, Green Pond mountain conglomerate and quartzite and trap, are all abundant; and 2) south of the Ridgewood station of the Erie railway, where gneiss, Triassic sandstone and Hudson River sandstone, the latter abundantly striated, are the major stony constituents of the bowldery till. Other good, though not deep, exposures seen in this region are the following: About half a mile west of Mahwah (road cut), where the stony material is almost wholly of gneiss; a third of a mile northwest of Masonicus (road cut), where the till has a reddish tinge from admixture of Triassic material, though four-fifths of the bowlders are of gneiss; rather less than three-fourths of a mile south of Ramseys (railway cut), where the till is compact and clayey, of gneissic type; a mile north of Allendale (road cut), where the till is stony with sandy matrix and abundant surface bowlders; three-fourths of a mile east of Saddle River village (road cut), where a considerable variety (gneiss, Hudson River sandstone, quartzitic conglomerate and quartzite, Triassic sandstone and trap) of stony material occurs; north of Hohokus station (railway cut), where the gneissic till, with a great variety of stony matter, including limestone, shows foliation up to within two feet or less of the surface; other cuts near by, and at the dam, show till of same character; and at various points about Ridgewood, where the red type of till predominates.

East of First mountain and north of Paterson, the till is, for some distance, of the red sandstone type, and contains a considerable percentage of stony material. The matrix ranges from sandy to clayey, the former being the more common. The bowlders are largely of gneiss, sandstone and Hudson River or other northern sandstone.

Striæ at and near Midland Park station have directions S. 33° W. and S. 34° W. (corrected).

Between the Passaic and First mountain, north of Second river.—About Paterson, especially in the eastern part of the city, and in the south part just east of the north end of First mountain, the till has the typical red facies, with the ordinary number, or rather more than the ordinary number, of bowlders. The matrix is rather more clayey than to the north, though this feature is not constant. The well-worn bowlders are largely of gneiss, or of other types foreign to the region, though trap bowlders are also sparingly found. The sandstone blocks are often little worn. Good exposures of till abound in the cuts along the streets in the eastern and extreme southern parts of the city of Paterson. From these cuts a good idea of the nature of till in general, and of the till of this locality in particular, may be obtained.

Farther south, about Passaic and Clifton, the till is disposed to be gravelly or stony, the stony material being chiefly sandstone, and the fragments and masses of the rock are often little worn. About Passaic, and on the ridge a mile north of Clifton, sandstone outcrops are frequent enough to indicate that the till is thin. In these places, the till is hardly more than an interrupted mantle. In general, the till is thinner toward First mountain, and thicker toward the Passaic. Bowlders on the surface are not rare, though less numerous than farther north. They are largely of Triassic sandstone, but Hudson River sandstone, gneiss, quartzite and conglomerate bowlders are associated with the sandstone. Where exposures have been seen in the till of this region its matrix is almost wholly of material derived from the local sandstone. Exposures showing this constitution have been seen at many points, especially about Passaic and Richfield. Some sections show less than one per cent. of other material, and sections showing as much as five per cent. of extraneous material, are rare.

The topography of the drift north of Clifton is somewhat morainic, and stratified drift and till are locally commingled, moraine fashion. Something of the same topography is also to be seen in the eastern part of Paterson, opposite Bellair, and between these points the drift is rather thick. The greatest known thicknesses, however, are in areas of stratified drift. On account of the thick drift along this belt, and also because of the occasional suggestions of moraine topography, Mr. Peet has thought that the ice edge stood for a time along the Passaic, between Delawanna and Paterson. This is perhaps the interpretation of this thick belt of drift, but it seems at least equally probable that the thick drift here is the result of the deep preglacial valley, the bottom of which is below sea level.

On the upland near Athenia and Clifton, there are some remarkable bodies of stratified drift (probably deltas) in positions where till was to have been expected.

The till between Athenia and Passaic on the north, and Third river on the south, has the same general characteristic as that farther north, but the till is notably thicker than about Passaic and Athenia, though thinner than in the area north of these places. Thicknesses of ten and fifteen feet of till are common in this area, though road cuts and other shallow excavations frequently reveal the rock. At Passaic, just west of the Erie depot, a fresh excavation seen in May, 1902, showed a sharper line of demarkation between the yellow loam and its substratum than has been often seen. The section is represented in Fig. 57 (p. 212). The yellow loam was identical where it rested on stratified drift, on till and on red shale. Throughout the section its base was as clearly defined as the base of a formation could well be. The loam varied from three to seven feet in thickness, and in the section, one stone eight inches in diameter, was seen four feet from the surface. The underlying till, like all that of the region, was conspicuously red, while the loam was conspicuously brown-yellow, with no suggestion of redness above the basal inch or two.

The till about Montclair and Glen Ridge is perhaps less gravelly or stony than that about Passaic, but it is more often sandy. Rock comes to the surface rarely, but is occasionally exposed in road cuts and ravines. Thicknesses of fifteen and twenty feet are common about Montclair and Glen Ridge.

Good exposures of till in this vicinity, some of which are no longer open to inspection, have been seen at the following places: North of the Upper Montclair railway station, where Triassic sandstone material predominates, but where gneiss, trap and bowlders of Green Pond Mountain conglomerate occur; north of the Watchung railway station, where the till is red; in a ravine three or four blocks northwest of the D., L. & W. depot at Montclair, where fifteen to eighteen feet of till were seen resting on sandstone; on the N. Y. & G. L. railway a mile southeast of Montclair station, where red till is coated with yellow loam, without sharp line of demarkation; two blocks to the southwest of the last, a shallow exposure showing three feet of loam sharply set off from the till; at the stone quarry east of Glen Ridge; southeast of the Montclair depot of the D., L. & W. railway, along the railway and at a stone quarry, where the till is red and generally rather sandy, with yellow loam locally present over the surface; and at the sandstone quarry in the northeast part of Bloomfield, near the pond on the Yantecaw river, where the relation of the till to the sandstone, the latter cut by a trap dike, is shown.

In an area lying between Bloomfield and Brookfield on the northwest, and Avondale and Woodside on the southeast, the drift is thicker, and stratified and unstratified types are more or

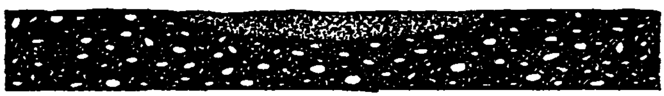


Fig. 74.
A common mode of occurrence of the yellow loam.

less commingled. The topography, too, is often morainic, especially in the northwestern part of Belleville, a mile and a half northeast of Bloomfield, and about Woodside Park and Woodside. The character of the till in this region is often very similar to that of Montclair and vicinity, though rather more clayey; but about Belleville, the till is more stony than is its general habit in this part of the State, the bowlders being largely of sandstone. Depths of fifteen to forty feet are common in this vicinity. This belt probably marks a temporary halting place of the edge of the ice during its retreat (see map), a halt long enough for the tendency to moraine building, under the nearly stationary edge of the ice, to show itself. The halt was probably not very long, for the drift is not notably thick.

About Belleville, Nutley and Avondale yellow loam, which often seems to be very distinct from the till, is of frequent occurrence. It is sometimes gathered in depressions in the surface of the till (Fig. 74). The loam is well seen at the Avondale quarries, though it is here without sharp line of separation from the till below. About Avondale and Nutley, which lie to the north of the moraine tract, the till is not so thick as farther south, as shown at the quarries at Avondale.

Striæ a mile north of Athenia have a direction S. 39° W., and others a mile north of Bloomfield, west of the canal, directions of S. 32° to 41° W.

South of Second river, and north of the Waverly-Union-Springfield moraine.—Till occupies almost the whole of this area. About the Oranges it is red and sometimes very sandy, locally indeed, being composed of little but sand. At other places and more commonly it has the usual clayey matrix, with abundant sandstone masses. In many parts of this area the surface has been so much modified by the grading and filling incident to the development of the region, that the original character of the surface is no longer shown. Common depths of till in this region are thirty and forty feet. Loam frequently mantles the till, though it is not always notably yellow. Good exposures of temporary character abound at most localities in the vicinity, where grading and building are constantly in progress.

About Irvington, the till is of the red, sandy and stony type, with depths varying from two feet to forty feet, with an average perhaps about midway between these extremes.

Between the Oranges and Irvington five drumloidal aggregations of till occur. All of them are elongate hills, their longest diameters being approximately parallel, and having a direction 15° to 20° west of south. They vary in height from about twenty-five to fifty feet. By selecting certain low points from which to measure, the maximum height could be made somewhat greater. Their lengths vary from half a mile to nearly a mile, and their widths are a third to a fourth as great as their lengths. The drumlins are as follows: 1) The elongate hill commencing a quarter of a mile northeast of Brick Church station, and extending thence three-fourths of a mile to the north-northeast, and traversed lengthwise by Prospect street. It is about forty feet high, three-sixteenths of a mile wide, and three fourths of a mile long. Its ends have gentler slopes than its sides. The material of the drumlin is similar to that of the other till of the vicinity.

2) The wider hill of comparable length just north of the East Orange station of the D., L. & W. railway. Arlington avenue runs along its east slope and at its east base. Its height is about fifty feet, its length nearly a mile, and it maximum width rather more than a fourth of a mile. Data from wells show the till of this drumloid to be but twenty-five to thirty feet thick, so that the ridge has a core of rock. Its main mass is, however, till. 3) The similar though narrower hill south of East Orange, traversed lengthwise by Munn avenue. Its height is about twenty-five feet. No good exposures occur in it, but well records show the hill to be entirely of till. 4) A shorter hill parallel with the others, a mile east of Mountain and south of Orange Park, its north end crossed by Tremont avenue. Its height is about forty feet, and its horizontal dimensions five-eighths and three-sixteenths of a mile. 5) A less well-marked drumloidal ridge lies half a mile south of Silver Lake station. 6) A sixth hill, which may be a drumloid, occurs just south of Avondale. Its length is about half a mile and its width a third as much. It has a height of about thirty-five feet above its western base and seventy-five feet above its eastern. The till of which it is composed is compact, with a red matrix. Well data give a maximum depth of seventy-five feet of till in the vicinity, but no data were obtained concerning the depth in the ridge itself. The hill may have a rock core, but if so the till covering it is probably thick.

Good exposures of till in this vicinity were seen about a mile south by east of the Mountain station of the D., L. & W. railway, where, in addition to the varieties of rocks common to this locality, there are white quartz pebbles; half a mile northwest of South Orange, in a ravine on the west side of the East Branch of the Rahway river; in the north end of the 235-foot hill about two miles northeast of Irvington; west of Hilton, where the variety of stony material is greater than common, and a mile east of Irvington, on the Newark road. Some of these cuts are probably no longer open, but others probably are. The grading and building incident to the improvement of the region for residence purposes are making and destroying cuts at frequent intervals.

About Newark the till is of the red type, often with much stony material from the underlying sandstone. Common depths are ten, fifteen and twenty feet. Within the limits of the city various sections show all types of till common to the red sandstone region. Here it is clayey, and there stony, and in the latter case it may be made up largely of little worn and little moved rock debris derived from the underlying rock.

East of First mountain and south of the Waverly-Union-Springfield moraine.—In no considerable area of the Piedmont plain has the surface of the till so little relief as here, and as a result there are few exposures, and data are often meager. Along the northern border of this area, from Springfield to Milltown, and thence east *via* Union to Waverly, there is abundant stratified drift associated with much which is poorly or not at all stratified. Elsewhere, most of the surface is covered with till, even at low levels. Here, indeed, is found the most striking exception to the general rule applicable to most of the region farther north, that till is found on the higher lands, while stratified drift occupies the lower. Here this rule fails altogether. Some of the highest parts of the area are covered with stratified drift, while till extends down to sea-level at many points.

South of the Waverly-Union belt, the thickness of the till is known to range from zero to ninety feet, but its average thickness is probably not more than thirty feet. The till is always of the red type, but its surface is sometimes so masked with a thin mantle of loam, that its real character is not shown except in section. In this region the loam is often red, instead of yellow, as farther north.

Good exposures about Elizabeth, Cranford and Westfield were seen at the following points: A mile southeast of Westfield, where the red type of till is well shown; on the railway a mile southwest of Roselle; at Tremley, a short distance east of the junction of the B. & N. Y. and the N. Y. & L. B. railways, where two feet of loam covers the till; in the 187-foot hill north of Menlo Park, where the till is more stony than is common in this vicinity, and between Iselin and Houtenville, along the railway.

The surface of the till about Rahway is so sandy that, with good exposures, it is difficult or even impossible to distinguish it from stratified drift. The topography is often so nearly flat as to resemble that of stratified drift rather than till, and even where the underlying drift is till, the surface is frequently covered with sandy loam which belies the true character of its substratum. Even where the loam is present, bowlders are not altogether lacking. In the vicinity of Rahway the depth of the till varies from a few feet to a known depth of forty-eight feet, with an average which probably lies between twenty-five and thirty feet.

About Tremley and Linden the till often has a sandy surface, and wells are frequently reported to penetrate clay beneath the stony drift. The clay was nowhere seen.

TILL ON FIRST MOUNTAIN.

Darlington to Paterson.—From its north end at Darlington to about the latitude of Midland Park the till of this mountain is generally of the gneissic type, especially where it is thick. Where thin, the trappean material is more in evidence at the surface, and is probably more abundant in the basal parts of the thick till than in the superficial parts. While the rock is sometimes exposed in this part of the mountain, it is generally concealed. At one place a depth of fifty-five feet of till is recorded, the greatest thickness known on this part of the mountain.

Between the latitude of Midland Park and Haledon, the west slope and crest of the mountain have relatively little till, and the outcrops of rock are frequent. At the east base, on the other hand, the body of the till is much greater. It is sometimes thick up to the crest, especially in the passes. Just north of Paterson the heavy drift of the east face obscures the steep slope of the rock of the ridge, and has something of morainic topography for two or three miles above the city. This thick body of drift appears to have lodged against the mountain, as the ice from the northeast crowded against and over it. Locally, however, the drift is so thin that the rock appears, as at the quarries about a mile west of Van Winkle and southwest of Midland Park. Between Midland Park and Paterson the drift is not generally of the gneissic type, though gneissic material is still abundant, along with that derived from trap and Triassic sandstone. The materials derived from these several formations vary notably in their proportions.

In the gap in First mountain at Paterson, a large part of the drift is stratified, though till is sometimes connected with the sand and gravel. Both north and south of the falls of the Passaic, the trap rock outcrops frequently. For half a mile east of the reservoir, below the falls, the drift is thicker. On the north side of the river it is partly till and partly stratified, the two types being more or less intermixed, and often having a morainic topography.

Paterson to Montclair.—Between Paterson and Great notch the upper part of the east face of the mountain is an escarpment of trap, and, together with the summit and west slope, has little drift.

Between Great notch and Montclair the crest and eastern slope of the mountain have little drift, though its amount increases somewhat to the south. Known thicknesses near the eastern base of the ridge, range from five to thirty feet. On the steeper parts of the slope, bed rock is shown in ravines and road cuts. The till of this slope is almost always distinctly red, and here, as well as on the mountain, is sometimes covered with yellowish loam. The west slope between Great notch and Montclair has more drift than the west slope farther north, though not enough to wholly conceal the rock, which frequently appears in the fields and road cuts. Between Great notch and Verona, and still farther south, thicknesses of eighteen to thirty feet of till are known, but these are probably more nearly maximum than average thickness.

Where thick, or where not very thin, the till of the crest and west slope is often red or reddish, though trappean till appears at some points, as at the west end of the tunnel for the Jersey City water works, south of Great notch, and in a trap quarry a little to the south. A little higher up the slope a thin body of trappean till was observed to overlie a few feet of reddish till, which, in turn, rested on the rock.

The better exposures seen, showing the character of the till on First mountain, were along the road west of Crystal Lake, where the gneissic type of till occurs; at Sicomac, where a yellowish loam overlies foliated red till, though most of the till of the region, so far as the surface shows, is of the gneissic type; at the sandstone quarry at the east base of the mountain, about a mile north of Paterson, where about ten feet of reddish till overlies the rock; on Haledon avenue in Paterson, where the mixed character of the drift of the region is shown, and where the Triassic constituents are predominant; at numerous points in road cuts in the eastern and southern parts of Paterson; on the N. Y. & G. L. railway southeast of Great notch, where six feet of yellow sandy loam overlies ten feet of foliated red till; south of Caldwell Junction, in the west end of the tunnel for the Jersey City water pipe, where trappean material predominates, many of the stones being angular; at a stone quarry southeast of the last locality, where about three feet of trappean till overlies an equal thickness of red till; on the east and west road at Verona, where the matrix of the till is reddish but where trap predominates among the stony constituents.

Striæ.—The numerous striæ recorded on First mountain show that the ice moved over it in a general southwest direction. The directions of the striæ range from S. 15° W. to S. 77° W. Corrected for magnetic variation, they are as follows: Two and one-fourth miles north of Haledon on the western slope (roadside), S. 60° W. One mile northeast of above, near east base (on sandstone), S. 37° W. One and one-half miles north of Haledon at the western base of the mountain (roadside), S. 42° W. Five-eighths of a mile north of Haledon at the western base of the mountain (roadside), S. 32° W. and S. 77° W. Three-fourths of a mile south of Haledon in the gap of the mountain, S. 67° W. One-sixth of a mile southwest of old Paterson reservoir, south of the D., L. & W. railway, S. 68° W. One-sixth of a mile southwest of the same reservoir, north of D., L. & W. railway, S. 68° W. One-sixth of a mile west of the same reservoir, near river, S. 71° W. One-half and two-thirds miles southwest of same reservoir (roadside), S. 52° W. Five-sixths of a mile southwest of same reservoir east of the road, near the river, S. 52° W. North of the above, near river (roadside), S. 62° W. At the west base of mountain, three-fourths of a mile northwest of Great notch station, west of canal (by roadside), S. 37° W. On the west slope, east of the canal, and west of Great notch station S. 42° W. and S. 15° W. One-half of a mile southeast of Great notch station, west of the crest, S. 67° W. East of the crest, south of the Verona-Montclair road, S. 39° W. On the crest at Eagle Rock, S. 44° W. East of the crest at Eagle Rock, S. 39° W.

TILL BETWEEN FIRST AND SECOND MOUNTAINS.

Between the Highlands and Paterson.—The sandstone or shale in the bottom of the valley between First and Second mountains does not often appear at the surface. The bottom of the valley is largely occupied by stratified drift, the belt between Haledon and Franklin lake being the principal exception. Till is, however, not wanting between the mountains north of Franklin lake, and is exposed in railway cuts between Crystal Lake and Oakland.

About a mile east of Oakland the drift is said to have a thickness exceeding sixty-eight feet. South of Franklin lake the till is thinner, rock frequently appearing at the surface on the lower slopes of both mountains. In the vicinity of Haledon the drift between the mountains is twenty to thirty feet in thickness.

Between Crystal Lake and Oakland, on the N. Y., S. & W. railway, till with a trap matrix is exposed in various cuts. Among the stony ingredients gneiss predominates. Other constituents are trap, purple quartzite and Hudson River sandstone Between Crystal Lake and the Passaic river, the exposures are mainly shallow road cuts above the level of the stratified drift.

South of Paterson.—South of Paterson, thicknesses of ten to fifteen feet are common, but rock outcrops are also numerous, and excavations no more than five feet in depth frequently reveal it. About a third of a mile southeast of the Little Falls depot the N. Y. & G. L. railway makes a cut of twenty to twenty-five feet in the till. Half the material is stony and many of the stones are striated. Of the stony material, nearly half is red sandstone and shale, half as much trap, with Hudson River shale and sandstone and gneiss the minor components. The surface in the vicinity has a coating of a few inches to two or three feet of sandy loam of yellowish color, while the till below is red or reddish.

About half a mile northeast of Cedar Grove on the Caldwell Branch railroad, reddish, stony till, containing trap and sandstone in about equal proportions, is exposed. A single limestone bowlder was seen here. Here, again, is a little of the yellowish loam, similar to that common to the east, overlying the stony till. In this position, the loam might be wash from the trap ridge above. Other railroad cuts in the vicinity show till with some stratified material interbedded. East of the Cedar Grove station of the N. Y. & G. L. railway, a cut shows (in its eastern part) six to eight feet of till over stratified gravel and sand. The till contains bowlders, one of trap being at least fifteen feet in diameter. The till is made up largely of sandstone and trap. Other cuts occur along the railroad eastward toward Great notch.

TILL ON SECOND MOUNTAIN.

North of the Passaic.—In many respects the till of Second mountain is similar in kind and distribution to that of First mountain. The trappean type predominates, though at the north end of the mountain, there are places where the gneissic type prevails. In general it is thinner on the crest than on the slopes, and especially the lower slope. For the greater part of the distance from the moraine at Short Hills to Pompton lake, trap outcrops are of frequent occurrence along the crest, and many long, narrow areas are almost free from drift. In a few places only has the summit of the mountain more drift than the slopes.

At the northeastern base of the north end of the mountain, there is usually a rather heavy body of till. The steep face against which the ice moved seems to have caused the ice to leave much of its basal debris in this position. The till here contains a large percentage of gneissic material both among its stony constituents and in the matrix. At the base of the mountain, near the south end of Franklin lake, the red sedimentary rock lies near the surface, and the till has a red or reddish color. From this point to the Passaic there is a heavy coating of till, predominantly of the trappean type, which sometimes reaches thicknesses of forty to sixty feet, and averages at least thirty feet. The material of this till probably came largely from First mountain, though preglacial accumulations of talus at the east base of Second mountain doubtless entered into its make-up. Above this relatively thick body of till at the eastern base of the mountain rises the steep and often nearly bare escarpment of its eastern face.

Southwest of Haledon, and occasionally north of that point, this belt of thick till has a topography somewhat resembling that of a terminal moraine, and perhaps marks a halting place of the edge of the ice in its retreat. This suggestion gains some force from the fact that this belt of thick till connects northward with kames, and other aggregations of drift morainic in their nature, east and north of Franklin lake. The thick drift runs up to and occupies the notch in Second mountain west of Haledon, thinning out with increase of altitude. Smaller notches in the mountain for nearly two miles north of Haledon are also occupied by thick bodies of drift.

On the lower west slope of the mountain west of Haledon, the drift is also relatively (twenty-five to seventy feet) thick. It is partly stratified and partly not, and often has a morainic or semi-morainic aspect. Suggestions of similar topography, affecting both stratified drift and till, are seen at intervals along the west base of the mountain northwest to a point about two and a half miles north of Preakness, where a well-developed moraine occurs at the head of the Preakness delta. In many places in this belt the thickness of the drift is at least thirty-five feet, a thickness well above the average for the region.

South of the latitude of Preakness deposits of gravel occupy the lowland, and the lower part of the slope above is poorly covered with till.

In the gap in Second mountain at Little Falls, the till is generally thin near the river, and outcrops of rock are frequent. On the lowland north of the river the till has a thickness of as much as twenty-five feet, and south of Little Falls wells indicate thicknesses of thirty to forty-five feet on the slope between the village and the mountain south of it.

South of the Passaic.—Between Little Falls and Caldwell, the mountain is double crested, and the crests, especially the eastern, have little drift. The rock is often either bare, or merely strewn with bowlders. Although less thinly covered with drift than to the northward, the top of the mountain south of Caldwell has frequent outcrops of rock as far south as the moraine, and only where the moraine crosses it, is the drift of the summit thick. Recorded depths of drift on the mountain top are as follows: Northeast of Caldwell, twenty feet; north of Caldwell, ten feet; east of Caldwell along the road to Verona, thirty and thirty-eight feet; west of Livingston, fifteen feet.

The east face of Second mountain, south of Paterson, is generally well covered with drift. From the N. Y. & G. L. branch of the Erie railway, nearly to Pleasantdale, stratified drift occupies a large part of the lower slope. From Pleasantdale to the moraine, till and stratified drift are more or less associated on the east slope, though the former is usually above the latter. The till is thin northwest of Cedar Grove, near Pleasantdale, one and a third miles south of Pleasantdale, and west of the Orange reservoir.

On the east slope the following depths are recorded: South of Little Falls, fifty feet; between Verona station and Cedar Grove, eighty feet (gravel). These figures more nearly represent maxima than averages, as they do not take account of the scores and hundreds of places where there is no drift.

South of Caldwell the lower west slope is in places heavily covered with drift, which is now of the stratified type and now of the unstratified. The topography of the drift on the west slope between Caldwell and Livingston is sometimes notably undulatory. Recorded depths on the lower west slope are as follows: South of Little Falls, thicknesses of thirty and forty-five feet between the village and the mountain; two miles southwest of Little Falls, and northeast of Green brook at an elevation of about 400 feet, 30+ feet; in a drumloidal aggregation of till south of Westville, forty feet; in Caldwell, two wells 100 feet and 180 feet deep, respectively, all in drift (gravel); north of Roseland, on the 444-foot hill, thirty-five feet; at Roseland the drift is (gravel) seventy-five feet deep; and southwest of that place thirty feet of till cover twenty feet of gravel. Mention has already been made of the depths of forty-five and sixty-four feet between Second and Third mountain, south and southeast of

Livingston. A mile south of Livingston the upper part of the till, to the depth of twenty feet, is said to be trappean, while below, as far as penetrated (forty-four feet), the till is red or reddish.

Between Livingston and Roseland, the till along the western bank of Second mountain has a gravelly surface which often suggests that the underlying material is stratified, but this appearance is deceptive, for fresh cuts at several points, as south of Livingston, show the material, though gravelly, to be angular, unassorted and compact.

South of Roseland the topography is semi-morainic. South of Livingston the same type of topography, though less pronounced, occurs. As a whole it is rather level, but from this level there rise up low ridges of the gravelly till. The unusual thickness of the drift here, taken in connection with the topography, may mark a position where the edge of the ice made a temporary halt during its retreat.

Two drumloidal aggregations of till occur on the western slope of the mountain, one a little south of Westville, the 265-foot hill of the topographic map, and the other at Franklin, the 240-foot hill. The trends of the hills are S. 15° W. and S. 25° to 30° W. respectively.

South of the Passaic, as north of it, the till of Second mountain is predominantly of the trappean type, though red till, or till to which the Triassic sandstone contributed, is to be seen at the numerous points, as at the D., L. & W. railway station at Little Falls; at Pleasantdale, where the red till extends up the mountain somewhat above the stone quarry; a mile south of Pleasantdale on the lower east slope of the mountain, where the till has a red color, though a very large proportion of the stony material is trap; north of Short Hills, on the road from Northfield to Millburn, where the till is red near the summit, though trappean on the west slope.

Exposures.—The exposures of till on Second mountain are not numerous. At the north end of the mountain, the road along the southeast side of Pompton lake furnishes some cuts. An exposure along the road just east of the bridge across the lake, shows till of a gneissic character, with an ashy-grey matrix, and about ninety-nine per cent. of gneiss among the stony constituents. A few pieces of red ferruginous slate, a constituent not elsewhere noticed in the drift, is to be seen here. Southeast of Franklin lake, along the road to Haledon, roadside exposures show till of the mixed trappean and red Triassic type, with the surface bowlders largely of gneiss. North of Haledon, exposures show trappean till with a reddish tinge, to the depth of several feet.

About a third of a mile east of Haledon, a road having a winding course down the east side of Second mountain affords exposures of till, six to eight feet deep. The till has a sandy trappean matrix, with many trap pebbles and bowlders and some gneiss and Triassic and Hudson River sandstone. The bowlders are striated to an unusual degree.

Half a mile south of Haledon, along the road over the mountain, trappean till is again exposed on the east slope of the mountain. In the vicinity of Little Falls, at the stone quarries north of the river, and in a railroad cut south of the village, there are further exposures of till. One and three-fourths miles south of Little Falls on the top of the mountain a roadside exposure shows till with a trappean sandy-clay matrix. Nearly half its material is stony, and of the stony part, trap constitutes three-fourths. Material from the Hudson River formation shows that some debris on the mountain has come far, while material from the Triassic formation at the base of the mountain illustrates the ability of the ice to carry material upward.

About two miles north of Caldwell, and about the same distance southwest of Little Falls, just south of Green brook, are exposures of compact till about ten feet in depth. At Caldwell, and east along the Verona road, and also a mile east of Livingston, there are several exposures of till in which trappean material predominates.

Striæ.—Numerous striæ on Second mountain have been recorded. The general direction of movement was to the southwest. The range of direction is from S. 27° W. to S. 68° W. The recorded striæ, corrected for magnetic variation, are as follows: One and three-fourths miles northwest of Haledon, near the west base of the mountain, one-fourth of a mile north of road,

S. 59° W. One mile northwest of Haledon, on the west slope of the mountain (roadside), S. 60° W. Half a mile west of Haledon, near the crest of the mountain (roadside), S. 67° W. A mile southeast of Preakness, south of the road (on the west slope of mountain), S. 57° W. One and one-fourth miles southeast of Preakness, south of road (on crest of mountain), S. 78° W. One and one-half miles southeast of Preakness, on the west slope of the mountain (roadside), S. 57° W. Three-eighths of a mile southwest of the above, near the crest, S. 68° W. Three-fourths of a mile north of Totowa, near the west base of the mountain, S. 46° W. Half a mile west of Totowa, north of the road and on the crest of the mountain, S. 66° W. In the pass, five-eighths of a mile northeast of Little Falls bridge, on left bank of the river, S. 52° W. and S. 56° W. In the pass of mountain, on the south side of river, a fourth of a mile east of Little Falls bridge (roadside), S. 58° W. Three-eighths of a mile west of above on road to Singac (roadside), S. 67° W. One and one-eighth miles south of Little Falls station, on the eastern crest, S. 37° W. One and one-fourth miles southwest of the Little Falls station, on the east side of the western crest, S. 30° W. and S. 34° W. Two miles southwest of the Little Falls station, on the western crest (roadside), S. 28° W. One and one-fourth miles northeast of Caldwell, on the north side of the 567-foot point, on the western crest (roadside), S. 27° W. One and one-fourth miles northeast of above (in field), S. 28° W. Two miles southwest of Pleasantdale, west of crest (roadside), S. 44° W. One and one-half miles southwest of Pleasantdale, west of the crest (in field), S. 44° W. and S. 46° W.

TILL WEST OF SECOND MOUNTAIN.

Most of the area of the Triassic plain west of Second mountain was covered by the waters of Lake Passaic, so long as the ice remained in a position to obstruct the valley of the Passaic at Little Falls. The presence of the standing water, into which abundant drainage from the ice was discharged, introduced complications of various sorts in the character and disposition of the drift. The most notable of these complications were the development of deltas at various points, and a slight modification of the till, over which the water stood on the retreat of the ice. Further, there is evidence that the ice did not simply advance to the Morristown-Chatham moraine, and then retreat from the basin. Whatever may have been the state of things during the advance of the ice, its edge probably oscillated more or less during the general period of retreat. The evidence of this is found especially in the large body of stratified drift which underlies a thin body of till in much of the Passaic basin, between the moraine and Little Falls. This is interpreted to mean that deltas and other bodies of stratified drift deposited during some retreat of the ice, were buried by the till of a later advance. In at least two places, lacustrine clay is known to occur beneath till, and as the lake could not have existed before the ice reached Short Hills, the lacustrine clay must have been deposited not only after the drift had blocked that outlet, but after the ice had retreated north of the positions where the clay occurs. One of the localities where lacustrine clay occurs is two miles east of Whippany, east of the Whippany river, and the other rather less than a mile northwest of Little Falls. These oscillations of the edge of the ice may have been considerable. Some retreat of the ice before the final one may have been sufficient to allow Lake Passaic to be drained to the level of the Little Falls outlet, for the lacustrine clays north of Little Falls, presumably deposited when the edge of the ice was some distance farther north, are overlain by till. When the ice was far enough to the north to allow of the deposition of lacustrine clay in this area, it may well have been far enough north to have opened the outlet. If for two miles east of the site of the clay, the edge of the ice was a mile north of the latitude of the clay, the outlet was surely open. The clay referred to is at so low a level (about 180 feet) that it might have been deposited in the small shallow lake which lingered in the basin after the outlet was opened, and the main body of the lake drained. On the other hand, if the ice in its retreat had a north-south front, instead of an east-west one, the Passaic might have been blocked at First mountain while the clay was depositing. The fact that the till over the clay is largely of Triassic material would, however, point to advance of the ice from the north rather than from the east, though it would not be conclusive.

In general. the till of the area west of Second mountain is rather thick, though by no means uniformly so. It is generally thin on Third mountain, including Riker Hill and Long Hill, and at some other points.

Between Third and Second mountains.—Much of the lowland between Second and Third mountains, both north and south of Passaic river, is occupied by stratified drift and alluvial lands, but till is not wanting on the lowlands, and is prevalent on the higher.

On the southeast shore of Pompton lake the till contains much gneiss and trap, and a small amount of material derived from the Newark sedimentary beds. Towards Preakness, and at some other points where the shale comes near the surface, the till becomes red, or reddish.

South of the Passaic, till is usually of the trappean, rather than the red type, and bowlders abound on the surface.

The depth of the drift between Second and Third mountains is considerable, as shown by the following data: Two miles southwest of Little Falls and northeast of Green brook, at an elevation of about 400 feet, a well was sunk thirty feet without reaching rock; about a mile north of Caldwell the depth of till is ten feet; in a drumloidal aggregation of till south of Westville, a well was sunk forty feet to rock; north of Roseland, on the 444-foot hill, thirty-five feet of till is reported.

South of Livingston the topography is peculiar. As a whole it is rather level, but above the general level there are short, low ridges of gravelly till (?), which have a common northwest-southeast direction. The material of the ridges is nowhere well exposed, but the slight exposures suggest that it is gravelly till with a clayey matrix. Bowlders are, however, not lacking. No explanation of this peculiar topography was worked out. Some of the larger hills resemble small drumlins, but their direction is nearly perpendicular to the direction of ice movement.

Exposures between the Second and Third mountains are not numerous. Only a few of the more considerable are mentioned. Shallow ones are to be seen along the roads and in temporary excavations. The more important are as follows: Along the D., L. & W. railway, between Little Falls station and the brook coming down from Preakness; at the clay pit a little more than a mile northwest of Little Falls where red till overlies blue laminated lacustrine clay, and about a mile north of Franklin, on the road at the west base of Second mountain leading toward Fairfield, where the till has a gritty, foliated matrix, with thin laminæ of blue clay, and where the stony material is mostly of trap. The surface in the vicinity has many trap bowlders five to six feet in diameter. Striated material in the exposure and on the surface is rare.

On Third mountain.—This trap ridge, starting near Pompton, has a southerly course nearly to Mountain View, where it swings west to Whitehall and then southward to Pine brook, where it terminates. Its continuation between Swinefield Bridge and West Livingston is known as Riker hill.

The till of this ridge is characterized chiefly by its thinness, and by the large number of trap bowlders which abound on the surface, many of them in an almost unworn condition. The summit of the ridge is frequently nearly bare of drift, and the outcrops of rock are correspondingly numerous. From Pompton to Mountain View the lower slopes of the ridge have a much heavier coating of drift than the summit, though there are occasionally small areas near the summit which have more till than the more thinly covered portions of the lower slopes.

The few exposures show that the till of this ridge is largely trappean. This may be seen a mile south of Pompton on the road across the trap ridge. Of the stony matter, trap makes up about sixty per cent., gneiss about thirty per cent. and Triassic sandstone most of the remainder. The pieces of trap are frequently striated. Half a mile farther south other exposures show till of similar composition, though more gravelly. Temporary exposures a mile east of Mountain View also showed till of trappean type.

From Mountain View to Pine Brook, the east and south face of the ridge is the steeper, and has less drift than the north and west sides. Sandstone and shale occasionally outcrop at the east base of the mountain. Where the rock is near the surface the drift has a red or reddish color. Toms point is underlaid by sandstone, and its till covering has a reddish color. On the north and west slopes of the ridge, the drift is not so thick but that the rock frequently outcrops. The till is commonly of the trappean type, and there are many trap bowlders at the surface.

Riker hill.—The till of Riker hill has the same characteristics as that of the ridge to the north. At its summit the rock is ill-concealed, but on the west slope the till is thick enough to cover the rock most of the way. Depths of fifteen feet and forty feet of till are shown by wells on the west slope and south end of the hill, respectively.

Striæ.—Striæ are common on Third mountain. In all cases their direction is west of south, the range being from S. 7° W. to S. 62° W. The recorded striæ, corrected for magnetic variation, are as follows:

About one and one-half miles northwest of Preakness, on the crest of the mountain, S. 30° W. About three-fourths of a mile west by north of Preakness, on the crest of the mountain, S. 62° W. West of Preakness, on the mountain crest, S. 42° W. Nearly three-fourths of a mile south by west of the last, on the crest of the mountain, S. 7° to 9° W. At Mountain View, on top of the mountain, due S. Two miles west of Mountain View and south of Lincoln Park, on the north slope of the mountain, S. 17° W. Two miles west of Mountain View and south of Lincoln Park, on the south slope of the mountain, S. 15° W. and S. 20° W. Half a mile southwest of Lincoln Park station, near the north base of the mountain, S. 39° W. One-eighth of a mile or less west of the above, S. 47° W. East of Whitehall station, on the north slope of the mountain, S. 42° W. East by north of Whitehall station, on the north slope of the mountain, S. 62° W. At Whitehall station, S. 62° W. Three-eighths of a mile south of Whitehall station, on the northwest slope of the mountain, S. 15° W. Five-eighths of a mile south of Whitehall station, on the northwest slope of the mountain, S. 17° W. One and one-half miles southwest of Whitehall station, near the west base of the mountain, S. 58° W. One and three-fourths miles southwest of Whitehall station, near the west base of the mountain, S. 37°–42° W. Northwest of Horse Neck bridge, on the crest of the mountain, S. 58° W. At Pine Brook, at the southeast base of the mountain, S. 27° W. At Pine Brook, on the west slope of the mountain, S. 52°–62° W.

Between Third mountain and the Highlands.—Till appears at the surface over about half the area between Third mountain and the Highlands, the lowlands being generally occupied by stratified drift and alluvium. In the northeastern part of the area the underlying Triassic formation is largely conglomeratic, and often but poorly cemented. The till over the conglomerate consists largely of material derived from it, and has a gravelly character, often giving the surface the false appearance of stratified drift. Because of the variations in the constitution of the conglomerate, and because of its more subdued color, the till derived from it is less red than that farther east, especially that east of First mountain.

North of the Passaic, the conglomerate itself sometimes appears as small hills having the general form of kames, and the gravelliness of the material adds to the illusive effect. Bowlders abound at the surface.

The till of the area north of the Passaic is not thick. The data from wells frequently show depths of twelve to eighteen feet, and often less. Trap outcrops in a few places north of Whitehall, and the conglomerate not infrequently northeast of Montville.

At the west base of Third mountain, north of Wayne, till occupies the lowland above the Pompton. It is of the reddish type, though somewhat less red than the normal red sandstone till, because of the large admixture of trappean debris. Bowlders abound on the surface. The depths reported from wells are from twelve to twenty-four feet. Exposures are rare.

In the area between the Passaic on the east, the Rockaway on the northeast, and the highlands and the moraine on the west and southwest, respectively, the till presents considerable variety. On the lowlands it is primarily of the Triassic type; that is, it is made up for the most part of material derived from the Triassic shale. Yet among the bowlders of this area, those derived from the highlands predominate. Those derived from the Green Pond mountain belt and from the trap ridges are present in subordinate but notable quantity. The sedimentary part of the Triassic formation has furnished relatively little of the larger stony material, though material from this source makes up a large part of the matrix of the drift. Near the Highlands, on the other hand, the till is primarily of the gneissic type. For some distance east of the zone where the gneissic type of till prevails, gneissic debris is most abundant in the surface portions of the drift, while the material of Triassic origin is more abundant below. Thus east of Morristown, the surface material is mostly gneissic, but at a depth of two or three feet the redness due to the admixture of Triassic material becomes noticeable, and at depths of ten to twenty feet it predominates. This shows that the ice which advanced obliquely from the Highlands to the Triassic plain brought out gneissic material from the former to the latter, and that such part of the load as was higher up in the ice was carried out farther from the Highlands than that which was in the bottom of the ice. At a distance of two to four miles from the Highlands, the redness becomes more notable even in the surface part of the till.

Over the area about the Troy meadows, and between Whippany and Parsippany, the drift was modified somewhat by the waters of Lake Passaic. The effect of the lake was apparently to make the surface more clayey. Fine mud seems to have settled out of the lake water over the surface of the drift previously deposited. In many parts of this area, too, stratified drift and unstratified are but poorly separated from each other. This lack of definition is in part because of the obliteration of the distinctive surface marks of the two types of drift by the waters of the lake. Nearly all the more prominent hills of drift in the region show stratified drift either at their tops or on their slopes, as if they were really kames partly buried by till.

Except about the borders of Lake Passaic, the topography of the upper Passaic basin does not appear to have been notably modified by the lake. Except at the upper limit of the lake, shore features are ill-marked or altogether wanting throughout the area.

There is a very considerable belt inside the moraine where a slight thickness of drift, which is not distinctly, if at all, stratified, overlies a considerable body of stratified drift. This, in turn, overlies till. This relationship prevails to such an extent north of the moraine as to lead to the belief that the edge of the ice fluctuated in position, drawing back from the main moraine and allowing stratified drift to be deposited between its edge and the moraine, and advancing again at a later time, burying the stratified drift with a new deposit of till.

The till of the low-lying part of the Passaic basin north of the moraine is rather thick, but its thickness is not well known, since wells and other excavations rarely reach its base. Numerous excavations of this sort extending to depths of twenty to thirty feet, do not reach its bottom. Its full thickness is known in but few places. At these points it ranges up to seventy feet. It is probable that the average thickness of the drift between the moraine and the Highlands on the one hand, and the Rockaway and Passaic rivers on the other, is not less than from thirty to fifty feet, though much of this is not till. Perhaps there is no other part of the State in which stratified drift and unstratified alternate in vertical section to the same extent as in this basin.

The proportion of bowlders of the different sorts of rock vary notably from point to point. Thus east of Convent, gneiss bowlders are more numerous than all others, those from the Green Pond mountain belt are half as abundant, while those from other sources make up but a small fraction of the whole. As the trap ridges to the east are approached, trap bowlders become notably more abundant, but except in the vicinity of the trap ridges, bowlders of this type are not conspicuous.

Between Third mountain and the Highlands, striæ have been recorded at but one point, namely, east-northeast of Montville, where their direction is S. 62° W.

STRATIFIED DRIFT OF THE TRIASSIC PLAIN.

IN THE VALLEY OF RAMAPO RIVER.

The Ramapo river is bordered by terraces of stratified drift, chiefly gravel, most of the way from the State line to Pompton. Their width varies from less than a quarter of a mile to nearly a mile, with an average of about half a mile. The surface of the stratified drift has an elevation of about 300 feet at the State line, and declines rather more than 100 feet to the point where the Ramapo joins the Wanaque at Pompton Plains. At the State line the stratified drift of this valley connects with that of the valley followed by the Erie railway from the State line to Ramseys.

Suffern to Darlington.—For a mile below the State line, the stratified drift is mainly on the west side of the stream, where it forms a terrace about three-eighths of a mile wide, and twenty to twenty-five feet above the flood plain. The gravel is here coarse, cobbles eight inches in diameter being abundant. For the first mile below the State line, the surface of the terrace is nearly plane, with a slight decline (about ten feet) to the southward, accompanied by a notable decrease in the coarseness of the material. Slight elevations, composed of material coarser than that of the body of the terrace, rise above its general level, and a bowlder-strewn gravel ridge of eskerine form rises twenty feet or more above the terrace next to the highland.

About a mile from the State line, the topography of the terrace becomes irregular, and kames, one of which on the immediate bank of the river is thirty to forty feet high, appear. For half a mile down stream the topography on both sides of the river is rolling, being sometimes almost morainic, with a relief of about fifteen feet. The stratified drift here runs up to an elevation of 310 feet, or a little above its level at the State line. Bowlders abound on the surface, and the gravel is largely of angular bits of gneiss. This constitution points to the poor assortment of the drift, which perhaps marks a temporary halting place of the ice during its recession.

Between this area of irregular, kamy topography, and Darlington, the larger part of the stratified drift is on the east side of the stream. It has not the form of a regular river terrace, though it declines down stream. Its surface is more or less undulatory, and kame-like topography frequently affects not only the surface of the terrace, but its slope to the stream. The gravel, though deposited by water, was probably deposited against ice which lay in the valley. This occasioned its irregular disposition at the outset, and its irregularities were enhanced when the ice melted.

Darlington to Oakland.—Between Darlington and Oakland the surface of the stratified drift is undulatory, and the level of its upper surface irregular. On the east side of the stream, kames occur at several points, and though the altitude of the irregular terraces is generally but thirty to forty feet above the stream, the stratified drift rises locally to a height of seventy feet above the river, and to altitudes greater than those attained by the corresponding phase of drift at the State line. This is true at the debouchures of the little brooks coming down from the mountain opposite Darlington, and again a mile below. Locally the gravel assumes the distinct kame terrace type. These phenomena indicate that drainage through the valley was not free when the sand and gravel were deposited.

East of the river at Oakland, the gravel occurs up to elevations of about 300 feet, and the rude terrace which it makes has a width of more than half a mile. North of the railroad, the gravel plain breaks off with steep slopes, not only to the river on the west, but to the northwest and south as well. On these latter slopes the surface is notably undulatory and the material often coarse. The material must have been deposited in the immediate presence of the ice. For a short distance south of Oakland, the gravel on the east side of the river maintains a nearly constant level against the side of the valley, and slopes toward the river. Its generally plane surface breaks up, now and then, into irregular undulations. On the whole, its surface is rougher near the highland than near the stream.

Just below Oakland the surface declines abruptly from about 260 feet to 230 feet. On the topographic map this abrupt decline suggests a delta front, but the details of the topography seen in the field do not support the suggestion.

West of the river at Oakland, the surface of the gravel has an elevation of 260 feet instead of 300 feet, as on the other side of the stream. This is another evidence of the obstructed condition of the drainage when the stratified drift of the valley was deposited.

Between Darlington and Oakland the gravel is generally angular, or, at any rate, ill-rounded. While gneiss predominates, trap is locally abundant, the trappean material having its source in the north end of First mountain, immediately east of the valley. Locally, too, Triassic sandstone is a minor constituent of the gravel.

Oakland to Pompton.—From the high terrace just south of Oakland to the lower end of Pompton lake, the gravel continues in a narrow belt along the east side of the river, its surface declining to 220 feet where it joins the plain of the Wanaque river. The topography is generally plane, though sometimes undulatory. Locally, too, kames rise above the general level, especially near the borders of the valley on the east side. About the head of Pompton lake on the west side the plain is more or less pitted.

Composition.—Throughout the valley, the sand and gravel are chiefly of gneissic origin. In composition, they are in keeping with the till of the region. Between the State line and Oakland there is no steady decrease in the coarseness of the gravel, but between Oakland and Pompton it becomes progressively finer.

Summary.—On the whole, the disposition of the stratified drift of this valley does not show well-marked halting places in the retreat of the ice, though one such stage is, perhaps, shown a mile below the State line. On the other hand, the gravel is so disposed as to indicate that ice still lay in the valley while the drainage which deposited the gravels coursed through it. This valley ice probably endured after the ice from the uplands adjacent had been melted. The gravel of the valley was not chiefly deposited after the ice front had retreated beyond the State line, but the gravel of each part of the valley was deposited chiefly while the ice edge was close at hand. Thus the gravels at Oakland are a little older than those at Darlington, and those at Darlington antedated, by some short interval of time, those farther north. Some of the gravel and sand below Oakland were, perhaps, deposited after the higher terraces farther up the valley were formed.

IN THE POMPTON RIVER VALLEY.

At Pompton the valleys of the Ramapo, the Wanaque and the Pequannock come together, and their united valley plains are continued as the plain of the Pompton river. The broad plain of stratified drift along this stream constitutes Pompton plains, an area some six miles long and two or more wide. Most of the plain lies west of the river.

The area of Pompton plains was covered by Lake Passaic, and some of the drift was deposited in that body of water, but much of that which now lies at the surface was brought down by the Pequannock, the Wanaque and the Ramapo, after the lake was chiefly or wholly drained, and bears the marks of subaerial rather than subaqueous deposition.

At Pompton village the regularity of the plain is interrupted by deep sinks and slight elevations, which perhaps mark the position of the ice front when the plain below was forming. This is indicated both by the slope of the plain below and by its constitution. At Pompton village the elevation of the plain is about 220 feet. It declines to 190 feet at Pompton plains two miles below, and to 180 feet at Mountain View, four miles below Pompton plains.

Where the topography is uneven, the stones of the gravel are often six to ten inches in diameter, larger than in the lower parts of any one of the valleys above, and coarser than down stream in the Pompton valley. The coarseness decreases southward from Pompton village with the decreasing elevation of the plain. At Pompton Plains, the material is a fine gravel, with pebbles ranging up to three inches or so in diameter. At Mountain View, it is chiefly sand. Both gravel and sand are chiefly of gneissic origin.

The depth of the material is unknown. Numerous wells twenty feet in depth do not reach its bottom, and at Wayne it is known to exceed thirty-two feet in depth. East of the canal at Wayne there is a little fine sand which is probably of eolian origin.

Over considerable areas along the stream and adjacent lowlands, alluvial and humus deposits of post-glacial age have accumulated, concealing the sand and gravel of glacial age. The depth of the drift on this plain is not known.

Lacustrine clay deposited in Lake Passaic, or its diminutive successor, underlies some parts of this plain. It is rarely exposed, and if its presence is general, it is so deeply covered with sand as to be generally unknown. It was seen at only two points, two miles and a quarter north of Wayne, east of the canal, at an elevation of 190 feet, and half a mile south by east of Wayne, at an elevation of 180 feet. In one part of the exposure at the former place, the clay was overlain by sand, and in another by till. Clay of the same type is known to underlie the sand-covered flat three-fourths of a mile north of Wayne, and again a third of a mile east of Lincoln Park station. All these places are near the border of the flat. The clay probably underlies most of it, being more deeply buried away from the borders.

STRATIFIED DRIFT BETWEEN THE RAMAPO AND THE POMPTON ON THE WEST, THE PASSAIC ABOVE PATERSON ON THE SOUTH, AND THE SADDLE ON THE EAST.

Stratified drift occurs at many points within this general area, notably between Second and Third mountains; about Franklin lake, in an area extending from Wortendyke through Wyckoff to Camp Gaw, and northward nearly to Ramseys, and in the valley north of Ramseys.

Between Second and Third mountain.—Most of the stratified drift of the valley between these mountains was deposited in Lake Passaic. In origin, therefore, it is somewhat unlike most of the stratified drift of the area north of the Passaic. The stratified drift of this valley heads in a well-defined recessional moraine about three miles north of Preakness, and is disposed partly in the form of deltas, and partly as a plain without distinctive topographic features other than its planeness.

"At Upper Preakness is the largest and most typical glacial delta plain found within the lake (Passaic) area. Its surface is nearly flat. Its margin is strongly lobate, falling off abruptly fifty to fifty-five feet. Its area is about a square mile. Its altitude at its front is from 330 to 335 feet, from which elevation its surface rises gradually for nearly a mile, to 360 feet. To the northwest the plain abuts against a strongly-marked kame area (moraine), the knolls of which rise to 420 feet. On the northeastern side the plain falls off very abruptly eighty feet to a swamp. The margin here presents, to a slight degree, the concave, steep and billowy appearance characteristic of deposits built against an irregular ice front. The material of which the plain is built varies from fine sand to coarse gravel and cobbles, but bowlders are uncommon, or altogether wanting.

"Just north of this plain is a moraine-like kame belt half a mile in width. The hillocks are of coarse material, and in general thickly strewn with bowlders. During the time that the Upper Preakness delta was being built by glacial streams, which flowed into a lake whose waters stood at a height of between 335 and 340 feet,[1] the kame belt would seem to have been forming just beneath and at the irregular margin of the ice. A large ice mass perhaps occupied the area of the swamp just north of the plain.

"North of the kame (moraine) belt is another but more irregular plain of sand and gravel. While it was probably not fashioned entirely beneath water, and perhaps not principally, its surface still seems to have been more or less modified by the action of standing water. But this is not beyond question; to have extended over it, Lake Passaic must have had an elevation of about 412 feet. The surface of this plain is not strewn with bowlders, and in this respect it is in marked contrast with the half-buried moraine-like kames which, near its southern margin, rise above its surface. The evenness of the surface of the plain

[1] It is to be noted that this was not the highest stand of the lake. See Report on Lake Passaic, Annual Report for 1893.

is further broken by numerous sinks and hollows, which may find a partial explanation in the unequal settling of the sand and gravel of the plain during their deposition."[2]

Just southeast of the well-defined delta at Upper Preakness, a mile and a half northeast of Preakness, there are considerable bodies of stratified drift accumulated at the shore of the old lake, but not now in the form of a distinct delta. With the shore gravels are kames, perhaps to be connected with the kame moraine to the north of the main delta.

South of and below the deltas, stratified drift of less distinctive character occupies the lower part of the valley between the mountains. It constitutes a southward sloping plain, ranging from an altitude of 260 feet at the north to 180 feet at the Passaic. The lower part of this plain nearly as far north as Preakness is known to be underlaid by lacustrine clay.

About Franklin lake.—The stratified drift of this area lies between First and Second mountains, though it is connected northward with the stratified drift north of First mountain, at Crystal Lake.

Most of it is in the form of a plain about two square miles in extent, reaching from the Ramapo valley on the northwest to a point a mile or so east of the lake. Near the eastern border, and again north of the lake, the plain is interrupted by conspicuous kames. Franklin lake occupies a greater depression in the surface of the plain, and the smaller lakes and ponds farther west occupy lesser depressions.

The greater part of this plain appears to be of lacustrine origin. It appears to be a delta, but the delta building went so far as to nearly fill the basin in which it was made. The elevation of the plain is inconstant, ranging from about 470 feet to 420 feet; but in spite of this range the surface in most places is nearly flat, with gentle southward slope. The greater variations of altitude come from abrupt changes, where a plain at one level descends abruptly to a lower one, as if the level of the water in which the deposits were made changed while deposition was going on.

[2] An. Report, 1893, pp. 284-85.

Apart from these abrupt changes of level, the most notable departure from planeness, in most parts of the plain, is occasioned by the sinks which affect its surface. Some of them, aside from the depressions occupied by the lake, are forty feet deep, and though this is exceptional, not a few of them are deep enough to contain ponds or marshes. Northwest of the lake the depressions are so numerous as to make the plain pitted. Near its northwest border a single kame rises above the general level. The surface of the plain is usually free from bowlders, and in this respect is in marked contrast with the surface of the area to the north. The material of the plain is coarse at the north and fine to the south. North of the lake, cobbles six to eight inches in diameter are common, while on its southwest side the material is fine gravel (pebbles one to two inches in diameter) and sand. North of the plain there are areas of till with morainic topography, and northwest of the lake there is a group of pronounced kames.

The plain has the general characteristics of a delta, but as a whole it lacks the steep fronts which usually characterize deltas. Its structure is nowhere exposed. In spite of these deficiencies in the evidence, it seems probable that the plain represents the site of a lake formed at the margin of the ice. The basin was hemmed in partly by the adjacent mountains and partly by ice. The edge of the ice probably lay along the line of kames north of the present lake, blocking drainage in that direction. Ice must also be supposed to have occupied the valley of the Ramapo as far south as the head of Pompton lake, so as to obstruct free drainage in that direction. The altitude of the divide between the lake and the valley of the creek flowing southeast, *via* Haledon to the Passaic, is but 424 feet, and does not appear to have been sensibly lowered since the plain was made. In order to have a lake at the level of the higher part of the plain, it is therefore necessary to suppose that ice blocked this pass, as well as the Ramapo valley, while its edge lay just north of the plain. This hypothesis calls for some degree of irregularity of the edge of the ice, but perhaps not more than was common in a region of so great relief. The higher part of the plain (460-469 feet) lies to the west of a line of sinks and elongate depressions northwest of the lake. When this part of the plain was formed, the edge of the ice probably stood along this line of depressions, occupying the site of the lake and the lower part of the plain. In this position the ice would have blocked the outlets to the east and south. The lower part of the plain (420-440 feet) was perhaps built after the upper, and after the ice had retreated to the position of the kames north and east of the lake.

South of the lake there is a pass in the mountain, the bottom of which has an elevation of 420 to 440 feet. When the ice had melted back so as to open this outlet, the lake was lowered to its level, and at this time the building of the eastern end of the plain was effected. This narrow gorge is in trap rock, and is free from drift fine enough to be readily moved by water. Its form and its surface material indicate the flow of a strong current through it, and are evidence of the existence of the lake, in which the gravel and sand were deposited.

If this hypothesis be right, the delta was built so far into the lake in each of its two stages as to nearly fill its basin. While the higher part of the plain was building, only the southwest corner of the lake remained unfilled, and perhaps not even that. The sinks of the plain were probably occupied by blocks of ice while the deposits were being made, and perhaps all the unfilled part of the basin was so occupied. The basin of the present lake represents either the part of the basin which was not filled by delta deposits, or the site of an exceptionally large ice block left behind as the main body of ice withdrew.

Kames about Franklin lake.—Near the southeastern limit of the Franklin Lake plain, a mile east of the lake, there is an elongate, steep-sided undulatory kame ridge thirty to fifty feet high and half a mile long, composed of gravel and coarse sand, similar in composition to the rest of the stratified drift of the vicinity, except for a lesser percentage of trap. The kames just north of the lake are among the most pronounced kames of the State. They have a morainic aspect, and are composed of coarse, angular gravel, chiefly of gneiss and trap, but with some quartzite and Triassic sandstone. Bowlders of gneiss occur on their surfaces, and there is probably some till associated with the stratified drift. The north slope of the group is notably abrupt.

For a mile north of the lake the topography of the heavy accumulations of stratified drift, perhaps mingled with some which is not stratified, is undulatory, with a kame-like, morainic aspect. Above the level of the kames, and especially west of them, the till likewise has a morainic aspect. All these phenomena point to the conclusion that the edge of the ice made a somewhat prolonged halt, with a northwest-northeast front, in the vicinity of Franklin lake.

About Crystal Lake.—Just north of Crystal Lake station there is a group of kames, bordered both to east and west by stratified drift not aggregated into pronounced hillocks. The kame area is elongate, its greatest diameter, nearly a mile, being north-northeast by south-southwest. The kames rise up promptly from their lower surroundings. From the higher summits a great succession of gravel hillocks is in sight, now huddled so closely together that their slopes are steep, and now more widely separated and their slopes correspondingly gentle. The relief of adjacent hills and hollows is twenty-five to thirty feet, but in the area as a whole, the relief is fully forty feet. The elevations are sometimes ridges, especially just north of Crystal Lake station, and sometimes mounds.

The kames are composed of coarse, sub-angular gravel three to ten inches in diameter, with occasional bowlders of gneiss. Good exposures are wanting, the best being on the north side of the road at Crystal Lake. Striated material is not abundant. It is not unlikely that there is some unstratified drift in this group of hills.

Associated with the pronounced kames are gravels of undulatory topography, often showing a tendency to kame-like aggregations. Gravel of this sort lies south of the N. Y. S. & W. railway at Crystal Lake, and connects southward, through drift, of mixed type, with the kames north of Franklin lake.

On the south side of the railroad a short distance west of Crystal Lake, there is an esker-like ridge with north-south course, 300 to 400 yards long, and twenty to thirty feet in height, composed of rather angular gravel, chiefly gneiss and trap, with occasional bowlders. Southeast of it is a small kame, twenty to thirty feet in height, surrounded by gravel of undulatory topography, but not belonging distinctly to the category of kames.

To the south, the topography of the stratified drift repeatedly manifests a kame or moraine tendency, though distinct kames are rare north of the pond a mile north of Franklin.

About Camp Gaw.—East of Crystal Lake a little stratified drift borders the low land to Camp Gaw. From Camp Gaw the stratified drift is continued eastward and southeastward to Wyckoff and Wortendyke, and northeastward nearly to Ramseys, always occupying the lower lands. It assumes various complex forms, among which are a number of short eskers, some notable kames, and moraine patches where stratified drift and till are not clearly separated.

South of the railroad, about three-fourths of a mile from the Camp Gaw station on the road to Wyckoff, an eskerine ridge descends to the northeast from the highlands on the southwest, and, crossing the road, curves northwestward and follows the west border of the swamp. At its southwest end its east slope is abrupt, but its northwest slope is not conspicuous. Where it crosses the road it has a height of about ten feet, and a width of 100. It remains narrow and of about the same height to its terminus. It is something more than a fourth of a mile in length, and is composed of loose, angular gravel. The gravel about the ridge has a slightly undulatory surface, and is continuous with that north of the railway at Camp Gaw.

Northeast of the Camp Gaw station there are low knolls of stratified drift rising from level surroundings, and a little farther north, about a quarter of a mile from the station, the gravel assumes a kame-like habit, with a relief of fifteen feet.

A mile or less northeast of Camp Gaw there is an esker. Its course is essentially parallel to the wagon road for three-fourths of a mile, and it terminates where the road turns to the east, a mile and a quarter north-northeast of the Camp. Its northern end is forty or fifty feet higher than its southern. Its maximum height is about thirty feet, and its crest so uneven that the ridge may be said to be somewhat interrupted. As it widens its slope becomes less abrupt. Its distinctive esker character is best seen at the south, while to the north it manifests a tendency to spread. At its northern terminus it passes into an area of kame-like topography, with hills and hollows of fifteen feet relief. At its south end, the gravel of the esker is relatively fine, and composed largely of gneiss and purple quartzite. To the north, the material is coarser, and one gneiss bowlder six feet in diameter rests on its surface. Where it breaks up into knolls the gravel is coarse, and gneiss bowlders abound. The gravel is ill-rounded, and, on the surface, is generally loose. Another ridge somewhat resembling an esker, occurs a quarter of a mile east of the above.

About two miles farther northeast there is another esker, its north end being about a mile and a half west-northwest of Ramseys. The altitude of its northern end is about 350 feet, and that of its southern about 400 feet. At the north it heads in an undulatory gravel tract which contracts to a narrow ridge about twenty-five feet high, 120 to 140 feet wide at its base, and twenty-five to fifty feet wide at its top. It has a winding course as far south as the brook, which crosses and interrupts it south of the road leading from Darlington to Ramseys. At the brook it is a conspicuous ridge, rising abruptly from the lower land on either side. After a short course south of the brook, where it is twenty-five to thirty-five feet in height, it spreads out until its slopes become so gentle as to be cultivable, but farther on it again assumes the form of an interrupted ridge, made up of hills arranged like beads on a string, expanding and contracting in width as well as in height. Nearly a mile and a half from its north end it breaks into hillocks of the kame type. Like many other ill-defined eskers, it begins in a more or less kame-like area, and ends in one. Exposures at the road crossings show the esker to be made of rather coarse, compact, fairly well rounded and unstriated gravel. The main constituents are gneiss, of which there are small bowlders, Hudson River sandstone and slate, conglomerate and quartzite, and Triassic sandstone.

Associated with this esker and extending south of it toward Camp Gaw is much gravelly drift, some of which has a distinctly morainic habit, some of which is aggregated into kames, and some of which has no distinctive topography. The morainic habit is most pronounced about midway between Camp Gaw and Ramseys, where there are knolls of coarse gravel and bowlders, associated with some till twenty-five or more feet high. The stratified drift here is not always separable from the unstratified.

About Wyckoff.—North of Wyckoff is another area of morainic drift made up largely of kames, associated with stratified drift which has not this habit. These kames are among the most conspicuous aggregations of this sort in the State. The center of the group is about a mile northwest of the village, and it has an area of about a square mile. It ranges in altitude from 370 to 498 feet. As indicated by its relief, the topography of the area is rough. Adjacent knobs and basins have a relief of thirty to forty feet. The elevations are often ridge-like, with some resemblance to eskers, and one ridge in the east central part of the area may fairly be so classed.

The material of the kames varies from fine sand to coarse gravel, with not a few bowlders, some of which are large. With the gravel and sand there is some unstratified drift associated, but in the absence of good exposures the two types of drift are not separable. In this, as in all the associated stratified drift, the material is largely gneissic with a somewhat generous admixture of quartzite and quartzitic conglomerate from the Green Pond (or Bellvale or Skunnemunk) mountain series, and a small amount of material from the Newark formation. The surface is generally of loose gravel. Where best exposed, the material is distinctly stratified.

From the Wyckoff kame-moraine area a plain of stratified drift extends southward to and beyond the village, surrounding the 382-foot hill just south of the village. West of this hill the stratified drift is continued southward to the swamp a mile or more due west of Midland Park, while east of it it is continuous along the railway to Wortendyke. This stratified drift south of the Wyckoff kame group is disposed in the form of an overwash plain, the surface of which is more or less pitted, as is well shown three-fourths of a mile southwest of Wyckoff. This material was undoubtedly deposited while the ice front stood where the kames are. The decline of the surface of that part of the plain south of Wyckoff is thirty feet in two and one-half miles. That part of the plain which extends northeastward toward Wortendyke declines more rapidly, but is less regular in its disposition. Half a mile north of Wortendyke it has a somewhat undulatory tendency, but south of this point it declines from 280 feet to 240 feet in less than a mile. The stratified drift has little extension north of Wortendyke, and its surface is so covered with loamy clay that its presence is known only by the records of excavations. At Wortendyke the gravel is eighteen feet or more deep.

Just east of the main Wyckoff kame-moraine area, and separated from it only by the narrow valley of the brook, is another small area of conspicuous kames with which eskers are associated. The slopes, as well as the summit of the area, show the characteristic kame undulations.

The esker (see Plate XXXV, p. 137) is but poorly developed. It joins the kames on the east, about a mile northeast of Wyckoff, as a sharp ridge, fifty to sixty feet in height and 300 feet across. It has a northeast course for about a fourth of a mile, declining in height to about thirty-five feet above its surroundings, but maintaining an approximately constant summit level. At its northeast end it is about twenty feet above its surroundings and seventy feet broad. The top, particularly at its south end, is not so narrow as is common to eskers. The esker ends in a mass of gravel, the form of which was determined by deposition in the immediate presence of the ice. Half a mile northwest of this esker is another, a quarter of a mile or so in length (see Plate XXXV).

Just south of this esker there are three small gravelly hills of kame character, two north, and one south of the wagon road.

The Mahwah-Ramseys area.

From the State line north of Mahwah to Ramseys and beyond, the lowland along the line of the Erie railway is largely covered with stratified drift, some of which is disposed in the form of eskers and kames. The belt occupied by this stratified drift is very irregular in outline, but it has an average width of something like half a mile. At the north, this gravel connects with that along the Ramapo, south of Suffern. The eskers of the belt will be noted first.

Eskers.—In no other part of the State are eskers so numerous as in this part of Bergen county. The eskers northeast of Camp

Gaw have already been mentioned, the northernmost being but little more than a mile west of Ramseys. Other eskers north and northeast of Wyckoff, leading off toward Allendale, have also been mentioned. The other eskers of the region occur at intervals from Mahwah to Ramseys, south and southwest of that place, and west of Allendale. The position of the eskers is shown on Plate XXXV.

Most of the eskers are short, and few of them are continuous throughout even their short lengths. Locally, however, their definition is very sharp. All of them have a general north-south, or northeast-southwest trend, not departing widely from the direction of ice movement.

North of Ramseys the eskers and esker-like kames are mainly on the lower eastern slope of the valley, but at Ramseys they descend into the valley and cross to the other side, rising a little above its bottom.

North and east of Mahwah there are several short ridges on the eastern slope of the valley. In general, they run from a higher level at the north to a lower level at the south. One of them, about three-fourths of a mile north of Mahwah station, is notably curved on the slope of the valley, its ends being about forty feet lower on the slope than the point of the curve. This particular esker has a length of about a sixth of a mile, a height of about thirty feet, and a width of about 100 feet. It is composed of angular gravel (of gneiss, purple quartzite and Hudson River sandstone), and is surrounded by gravel of undulatory topography.

Another short esker commences a little east of the south end of the curved esker mentioned above, and lies obliquely on the slope within a northeast-southwest course. Its length is 400 to 500 feet, and its lower end is about thirty feet below its upper. A little farther south, at the road corners east of the Mahwah depot, is another short gravel ridge lying obliquely on the slope. In the case of each of these eskers the north end is higher than the south.

Half a mile southeast of the Mahwah depot there is a longer esker on the east slope of the valley, with a northeast-southwest course. Its upper end, where it has a height of about ten feet and a width of sixty, is about 100 feet above the valley bottom. Where it crosses the road half a mile southeast of Mahwah, it has a height of forty feet, and below this point it curves more to the west, widening and narrowing, until it crosses the railway half a mile south of Mahwah. After a short course beyond the railway, it breaks up into kames on the south side of the brook. This esker is nearly a mile in length, and is composed of coarse gravel, mainly from the Highlands. Another small ridge lying north of the central portion of the one last described, and parallel with it, between the railway and the road to the east, is somewhat eskerine in form.

Midway between Mahwah and Ramseys, on the east side of the railway, is the beginning of another series of short eskers, which are, perhaps, to be looked on as one. The northernmost parts lie just east of the railway. They have curved forms and are oblique to the slope, and have heights ranging from twenty-five to thirty feet. Rather more than a mile north of Ramseys, and east of the railroad, there is a swamp near the road leading northeast toward Masonicus, which interrupts the ridges. South of it, and about fifty rods from the end of the esker last mentioned, the esker is continued. It is here associated with aggregations of gravel, of the kame, rather than the esker type, though the two types are here not clearly differentiated. The esker is continued, in an interrupted way, to a point half a mile north of Ramseys. To the east of the esker as mapped (Plate XXXV) are other ridge-like aggregations of gravel which might almost be regarded as eskers.

The most continuous esker begins about a mile north of Ramseys, and has a sinuous southwest course, terminating about a mile southwest of Ramseys station. It has a height of twenty-five feet in places, and is bordered, sometimes on one side and sometimes on both, by till. It suffers some interruption a quarter of a mile northwest of Ramseys, but promptly reappears. West of Ramseys, the esker twice shows a tendency to divide. At one point, just north of the Darlington-Ramseys road, it really becomes two ridges, but they soon coalesce. At the other point a little farther south, the same tendency is shown by a long hollow in the top of the esker. Finally, three-fourths of a mile southwest of the railway station, the esker does branch, the lesser branch lying along the road leading southwest from Ramseys, or just east of it, while the main branch lies to the west of the same road. The lesser branch starts with a height of fifteen feet, but soon breaks up into kame-like aggregations of gravel. The main branch has a height of twenty-five to thirty feet above the swamp at the point of division. Beyond the swamp it widens, and its crest becomes slightly undulatory, but it soon contracts again to a narrow ridge with a height of about forty-five feet. Beyond this point its crest rises and falls, its height varying from twenty to thirty-five feet, and its width from 125 to 200 feet. The esker ranges in altitude from 350 to about 410 feet. The esker is well seen west of the station, where it rises abruptly twenty to twenty-five feet above the swamp at its western base; but it has its strongest development west of the brook and a little farther south, where it has a height of thirty to thirty-five feet.

Northwest of the northern end of this esker there are gravels of eskerine tendency, and without great license the esker might be regarded as continuing another half mile to the north. Just north of the church at Ramseys there is also an eskerine ridge which might be looked on as a branch of the main esker.

In constitution, the esker varies from fine gravel and sand to coarse gravel with bowlders. Several bowlders as much as six feet in diameter lie on its surface. The gravel is generally ill-rounded. Gneiss is the major constituent, making two-thirds to three-fourths of the whole. Quartzites, Hudson River sandstone and Triassic sandstone are of importance in the order named. There are also occasional pieces of limestone. The gravel is usually rather loose and incoherent, a characteristic of water-deposited drift, but stratification is rarely distinct in the exposures seen.

Kames.—Southwest and west of the Mahwah station on the west side of the brook, there is an area of kames half a mile long, with a width equal to half its length. The topography is undulatory, of the knob and basin type. At the south end a conspicuous kame rises about eighty feet above the swamp along the brook. The gravel of the kames is rather fine and angular with much sand.

Farther south, a mile and a half to two miles above Ramseys, there are kames on either side of the brook. Those on the east are just west of the railway at an elevation of 350 feet, and have a rough topography with a relief of thirty feet. West of the brook there are two kame areas, separated only by the narrow valley. The kames of the northern area rise abruptly about fifty feet above the stream, while those of the southern area have less relief, and are less conspicuous. Three other isolated kames of small size occur farther south, rising above a tract of stratified drift of nearly plane topography. In more than one case the eskers seem to take their source in kames at the one end, and to break up into them at the other.

Throughout the valley there is a considerable body of stratified drift without distinctive topographic form associated with the kames and eskers.

The disposition of the stratified drift between Mahwah and Ramseys is such as to show that it was deposited at the edge of the ice, or while ice still encumbered the valley. It nowhere takes the form of a distinct valley plain such as would have been developed had the gravel and sand been deposited when drainage was southward and unobstructed. It is true that the valley now drains northward, but the divide between the drainage which flows north through Mahwah and that which flows south to Allendale is so low that it would scarcely have interfered with southward drainage so long as ice lay in the north end of the valley above its junction with the Ramapo near the State line. The creeks flowing north and south respectively head in the same marsh northwest of Ramseys.

STRATIFIED DRIFT IN THE VALLEY OF HOHOKUS CREEK, ABOVE HOHOKUS.

About Allendale there is a further development of eskers, associated with kames and other phases of stratified drift, in the valleys of the Hohokus creek and its tributaries.

Eskers.—The most northerly of these eskers is at Ramseys. Half a mile south of Ramseys station it appears as a low gravel ridge about six feet in height, trending southwestward. It is interrupted at the road, southwest of which it assumes the form of a sharp ridge, with a height of twenty feet. It follows the brook southwestward for about a third of a mile, and ends abruptly. An inconspicuous gravel knoll on the east side of the railroad half a mile south of Ramseys station may, perhaps, be regarded as its northern end, though the break is considerable.

Half a mile farther down stream another esker (or, perhaps, a continuation of this one), with several branches, appears on the west side of the brook, with a height of fifteen to twenty feet. Its course is southward. It here and there expands into an undulatory tract of gravel, out of which other eskers or branch eskers arise. This continues southward to the brook, where the esker group is interrupted. On the opposite side of the brook the esker is continued as a sharp ridge of coarse gravel, twenty feet in height. The total length of this esker group is something more than a mile.

From a point half a mile northeast of Allendale, a discontinuous esker runs southwestward to a point rather more than a mile west-southwest of the village. Its length, including its sinuosities, is considerably more than a mile. Its southwest end is less than a mile from the esker a mile northeast of Wyckoff, and an ill-defined intermediate ridge suggests their connection.

At its northeast end the esker has two arms. These come together at the railway. Where the esker crosses the railway it is about thirty feet high. Thence its course is southerly to the brook, where it is interrupted. Beyond the brook its course is to the southwest, and its height often twenty to thirty feet. Where it crosses the road half a mile west of Allendale station it has a height of no more than six feet. To the southwest, along the north side of the Hohokus creek, it is more distinct, being often ten feet or more high, and narrow.

Throughout its course the esker keeps to the low ground, its range of altitude being between 290 and 340 feet, and much of this variation is due to variations in the height of the esker itself rather than to variations in the height of its base.

A number of pits and cuts show its material to be chiefly of gneissic origin, though Hudson River sandstone, Green Pond mountain (or more northerly) quartzite and conglomerate, and Triassic sandstone are represented. In size, the material ranges from sand to coarse gravel, but large bowlders are not wanting. One of them is 20 x 25 x 7 feet. The large bowlders were probably let down on the eskers from the ice above. So far as the exposures show, the material is poorly and irregularly stratified.

Northeast of the northern end of the esker there is gravel, which fails of concentration into a ridge, but which was, perhaps, formed at the same time as the esker by subglacial waters which were not so well confined to a definite channel.

A quarter of a mile north of Allendale station there is a cluster of kames with which two small esker ridges are associated. The one has a southwest and the other a southeast course. The former is distinct where it crosses the road leading northwest from Allendale station, and half a mile or less from it. It is interrupted at the railroad, but reappears to the southwest, where it is fifteen to twenty feet high, and has an uneven crest. Its total length is about half a mile. The other ridge is nearly parallel to the wagon road, rather more than a quarter of a mile east of the railway station. After a course of a quarter of a mile on the west side of the road, it curves eastward, and after an interruption at the road, reappears on the east side of the road, with a height of twenty-five feet. Its length is about half a mile. It is bordered on the east by an undulatory area of gravel.

With the eskers there is more or less gravel of irregular disposition, some of which has something of the kame habit. In its coarseness and ill-assortment it shows, like the material of the eskers themselves, that the waters concerned in its deposition were impeded in their flow, and failed to assort and stratify materials, as freely flowing streams do.

Other areas of stratified drift.—Between Allendale and Hohokus there is some stratified drift not in the form of eskers.

Some of it is disposed as a plain, or without distinctive topography, and some of it as kames. One small group of kames is a mile south-southwest of Allendale, just east of the road to Midland Park. The area has an undulatory topography with a maximum relief of fifteen to twenty feet. The material is fine, well-rounded gravel. The surface lacks the bowlders which frequent many of the kames of the region.

About two miles south of Allendale is a gravel area of greater extent. In its northern part there is a well-marked kame, but in the larger part of the area the gravel forms a plain, from which the kame is separated by a low swale. It has an elevation of about 290 feet, and a height of forty feet above the road at its east side. It is flat-topped, and its east front is steep, and appears to be depositional. Its eastern margin is lobate after the manner of a delta plain. The south side is likewise steep, though less so than the east. A sand pit on the east side shows twenty to thirty feet of sand and gravel, the beds dipping easterly, or perhaps a little north of east. Over its surface many bowlders are scattered.

The obstruction of the Hohokus valley below this point might have given rise to a lake, and such obstruction may have occurred if the ice front had a general north-south direction; but the evidence that this body of gravel is a delta is inconclusive, and the bowlders at the surface are against this interpretation.

Ridges of gravel which approach without attaining the esker form are found at several other places in the vicinity. Such a ridge occurs a mile northeast of Midland Park on the road to Hohokus, in a region where the topography has a tendency to the morainic habit. A similar ridge occurs a mile and a half west-northwest of Hohokus.

STRATIFIED DRIFT IN THE SADDLE RIVER VALLEY.

Stratified drift occurs in the valley of the Saddle river from the State line to its junction with the Passaic at Garfield, but it has not the form of a continuous valley plain, with a surface declining steadily down stream. It is sometimes in the form of terraces, sometimes aggregated into kames, at one point there is an esker, and at other points it is spread out in plains, the surfaces of which are sometimes undulatory, and sometimes pitted. Between these types there are various, if not all, gradations. In the narrower parts of the valley, that is, between the State line and Hohokus, and again between Lodi and the Passaic, the stratified drift forms a narrow belt half a mile or less wide, but between Hohokus and Rochelle Park, where the valley is wide, the stratified drift is less confined.

Above Hohokus.—Near the State line, above the union of the streams which form the Saddle river, the stratified drift has an undulatory topography, with occasional kames and gravel knolls but little above the stream. About the junction of the tributary streams, and for half a mile or more to the south, the gravel is disposed as terraces descending from an elevation of 270 feet to 230 feet, within a mile. The terraces are the remnants of the plain of gravel which once filled the bottom of the valley, but which has been partially removed by the stream, whose channel has been lowered as much as thirty feet in some places, since the gravel was deposited.

On the west side of the river, a mile south of the State line, a kame rises above the terrace, and others occur a mile farther south on the same side of the stream. Below them, the terrace is not well defined on the west side of the valley. On the east side it narrows and declines, and finally merges into the alluvial plain of the river, a mile above Saddle River village, at an altitude of 180 feet. To this point there is no systematic decrease in the coarseness of the gravel, though the material at the south is finer than to the north.

South of Saddle River village the gravel belt is wider than above, and wider on the east side than on the west. At Saddle River its elevation is about 170 feet. South of the village a wide alluvial plain, doubtless underlain by stratified drift, divides the terrace gravel of the one side from that of the other. The gravel above the alluvial plain has an undulatory surface, and the undulations affect the slopes down to the alluvial plain. It is not unlikely that masses of ice existed in the axis of the valley at this point when the gravel on either side was deposited, for the slopes to the alluvial plain were developed by deposition, not erosion.

The surface of the gravel declines to the southward, though somewhat irregularly. A mile south of Saddle River village it rises on the slope west of the river to 180 or 190 feet, and its topography is undulatory and of morainic type. South of this point it spreads out, and is continuous with the Paramus plain between Saddle river and Hohokus creek.

The Paramus plain.—This plain heads in the undulatory tract a mile or so south of Saddle River village. The undulatory tract has something of a morainic or kame-morainic aspect, and from it the gravel spreads to the southward as a broad plain, with a southward slope. In its general position and relations it has the characteristics of an overwash plain, though in some of its details it departs from this type of drift.

From an elevation of 140 to 150 feet at its head a mile and a half below Saddle River village, its surface declines to 100 feet in two miles, and then above the junction of the Saddle and Hohokus it declines thirty to forty feet more in another quarter of a mile. The descent of the plain to the joint alluvial plain of Hohokus creek and Saddle river is by a slope which appears to be due to deposition, not to erosion. Such a slope could have been developed only by the deposition of the gravel and sand in a body of standing water, or against masses of ice which encumbered the valley. While, therefore, the gentle slope of much of the plain is consistent with its interpretation as an outwash plain, its southern terminus does not seem consistent with this interpretation. Near the junction of the Saddle river and Hohokus creek the plain is broken into ridges or lobes with north-south axes.

As the surface of the plain declines, its materials become notably finer, and toward its southern end the surface material is sand, rather than gravel. The sand is in notable contrast with the till of the region in the matter of color. While the till is red, the sand is yellowish or brownish, and contains relatively little Triassic material.

The surface of the Paramus plain is often nearly level, though the departures from planeness are locally notable. It is here and there somewhat pitted, and occasionally somewhat undulatory. The depressions are sometimes in groups or belts elongate in a general north-south direction. Such depressions may be seen east of Hohokus creek from Undercliff to Ridgewood; southeast of Ridgewood; near the head of the plain, where they lie in a belt extending north by east and south by west, and at some points in the midst of the plain.

Again, the slopes of the plain to the Hohokus on the one hand, and to the Saddle river on the other, are in many places depositional slopes. This is conspicuously true of the slope to the Hohokus northeast of Ridgewood, and of the slope to the Saddle at some points half a mile to a mile south of Paramus. The steep slope of the plain at the south, where it descends from ninety or 100 feet to sixty or seventy feet, by a depositional slope, has already been mentioned. The depositional slope of the Paramus plain along parts of its east and west sides and at its south end clearly indicates that the plain was never continuous with the surface of the stratified drift west and east of the Hohokus and Saddle respectively. The abrupt slopes might mean either of two things, 1) delta fronts, or 2) deposition against standing ice which remained in the valley after drainage began to flow through it. The latter hypothesis would, perhaps, explain the sinks in the plain. Between these hypotheses there are no decisive data. So far as the phenomena of the plain are concerned, either or both may be true. It should be said, however, that no distinctive delta features are known.

Near the Saddle river, in the latitude of Hohokus, a till hill rises a few feet above the gravel plain, which here has an elevation of 140 feet. The gravel seems to have been deposited about the hill, burying its base, but not reaching to its upper slopes.

Farther north, also, about a mile above the junction of the Hohokus with the Saddle, two slight swells of till show themselves, neither rising more than five feet above the plain. Just west of one of these low swells, ten to fifteen feet of sand, chiefly gneissic, overlies red till. In this part of the plain the sand is not thick.

For a mile south of the head of the Paramus plain there is a narrow terrace of gravel, on the east side of the Saddle river.

Here it widens out at an elevation of 130 feet—the same as that of the Paramus plain to the west—but narrows again just north of Paramus.

Southeast of Paramus, the stratified drift of the valley has great expansion to the eastward, connecting, by way of the Musquapsink, with that of the Pascack valley at Westwood. The stratified drift east of the river is separated from that on the west only by the broad alluvial flat, but the slopes to this flat, sometimes on one side of the stream and sometimes on the other, appear to be depositional.

Southeast of Paramus, the surface of the plain is generally level, but to the east, near the head of the Musquapsink creek, it becomes undulatory, and at the head of the southern tributary to the Musquapsink, kames are developed on a large scale. As in the Paramus plain, the gravel here decreases in coarseness as the surface declines to the south. To the southward, indeed, sand is more abundant than gravel, but occasional knolls of coarser gravel rise above the general level, especially about the swamp in which Sprout brook has its source. These knolls may represent hillocks of gravel but partially buried by the sand of the plain which was deposited at a later time.

The stratified drift on the west side of Hohokus creek, opposite the Paramus plain, seems to have been deposited somewhat independently of that on the east side. It is of coarser materials, has a more undulatory topography, and its level is not in strict correspondence with that on the east side. Here, again, the slope of the stratified drift down to the Hohokus is locally at least a depositional slope.

South of Ridgewood, the gravel and sand on the west side of the creek sometimes takes on the form of a kame terrace, which extends south beyond the junction of the Hohokus with the Saddle. Opposite the lower end of the Paramus plain, the height of the terrace is considerably greater than that of the plain.

South of Ridgewood, distinct kame knolls and sometimes eskerine kames are present. The seventy seven-foot hill of the topographic map, one and three fourths miles southeast of Ridgewood, is one of the more conspicuous knolls, and ridges which are somewhat eskerine occur just southwest of the junction of Hohokus creek with the Saddle river.

South of these topographic irregularities, and north of the brook tributary to the Saddle river below the Hohokus, the topography of the stratified drift is plane. The material of the plain is sand and fine gravel. West and south of the brook the topography again becomes undulatory.

Between the junction of the Hohokus with the Saddle, and Lodi.—Below the Hohokus, stratified drift covers wide areas on both sides of the river, but especially on the west as far south as Lodi. On the east side as far south as Arcola, the stratified drift occupies most of the surface below seventy feet in altitude, while the higher areas are of till. Below Arcola, the stratified drift has its upper limit at about sixty feet. The surface of the stratified drift east of the river is sometimes nearly plain, but from the south end of the hill just east of Arcola, an area of stratified drift of kame tendency, having an altitude of fifty to sixty feet, runs southeastward to Sprout brook. It is composed of coarse gravel, and is bordered on the southwest by a plain of fine sand with pebbles. This area is separated by an area of smoother topography from a similar area south of the brook.

West of the river the stratified drift has the form of a terrace or plain, the surface of which is often somewhat undulatory. The planeness of surface is interrupted both by sinks and kame-like knolls, mostly inconspicuous. There are three kames northeast of Fairlawn, their longer axes in a northeast-southwest direction. Two of them are composed of fine gravel and sand, while the third, on the bank of the Saddle, is of coarser material, and has bowlders a foot in diameter on its surface. It is associated with an undulatory area of gravel to the northwest, in which the materials are sand and coarse gravel, with Hudson River sandstone, gneiss, quartzite and conglomerate and Triassic sandstone the principal constituents. Three or four feet of red clay covers the gravel at this point. On the edge of the plain a mile above Arcola there is another kame thirty to forty feet from the alluvial plain of the river, and twenty feet above the plain to the west.

West and northwest of Arcola there is a considerable area, elongate in a northwest-southeast direction, the surface of which is slightly morainic. Stratified drift prevails, but there is some till associated.

The esker at Rochelle Park.—In the valley of the Saddle river at Rochelle Park, there is a low esker, its northern end being at the N. Y. S. & W. railway just west of the river. From this point it extends southward for a mile and a half, its course being essentially parallel with the river. At its northern end, and again where it crosses the road half a mile south of the railway, it has a height of only six to ten feet. Farther south it has a height of fifteen feet in places, though often less. It is frequently associated on either side with gravel of undulatory topography. Where it crosses the road leading west to Clifton, it is offset to the west, but continues southward, where it breaks up into three short ridges. The gravel of the esker is often notably coarser than that with which it is associated in the valley.

Bordering the stream on the west between Rochelle Park and Lodi, there is a narrow belt of coarse gravel, both above and below the esker.

On the east side of the river, just north of Rochelle Park, stratified drift, sometimes with a kame tendency, is widespread. The continuation of this gravel to the south is spread out in the form of a plain over the lowland northeast of Lodi, where sand overlies gravel.

The stratified drift extends southward over the lower land, but not with a steadily declining or even plane surface. It occupies most of the surface below sixty feet, though a mile northeast of Lodi it is confined chiefly to levels below forty feet.

Lodi to the Passaic.—Below Lodi, on the west side of the stream, there appear to be two levels of stratified drift, the upper of coarse gravel, similar to the esker gravel at Rochelle Park, with a topography more or less undulatory; the lower, probably of post-glacial origin, is of finer material and has a more nearly plane surface. On the east side of the river, the stratified drift has a similar disposition.

At Garfield, there are some small kames which perhaps belong more properly with the stratified drift of the Pasasic, than with that of the Saddle river.

Post-Glacial Changes in the Saddle River and Hohokus Creek Valleys.

Alluvial plains.—The Saddle river is bordered by an alluvial plain almost continuously from the State line to its junction with the Passaic. Its width is, in general, about an eighth of a mile, though it narrows locally to a few rods, and widens locally to three-eighths of a mile. From near the State line to near Rochelle Park, portions of the plain are more or less swampy. South of Rochelle Park, and at the head of the Paramus plain, it is narrow or wanting. The alluvial plain is farther below the level of the bordering gravel plains and terraces in the northern part of the valley than in the southern.

Hohokus creek has no well-developed alluvial plain above Hohokus, but below that point it is generally an eighth of a mile or more in width.

Post-glacial erosion.—The amount of post-glacial erosion in the Saddle River valley varies from zero to forty or possibly fifty feet. It is relatively great, thirty to forty feet, about the junction of the streams, the union of which makes the Saddle river. From this point to the head of the Paramus plain, the erosion has been slight, though not easily measured. At some points in this part of its course, the site of the alluvial plain was probably occupied by ice when the terraces on either side were built; at other points, the channel has been lowered ten feet at least. South of the head of the Paramus plain, for a mile or so, the erosion has been greater, probably as much as thirty or forty feet at a maximum, in a vertical sense. South of the road running east from Hohokus, post-glacial erosion has nowhere lowered the channel more than twenty feet, and often less, or even none at all.

STRATIFIED DRIFT BETWEEN THE SADDLE AND PASSAIC RIVERS.

Just west of Ridgewood, at the head of the Glen Rock valley, there is some stratified drift of kame-like habit. Associated with it are areas of till and mixed gravel and till, with semi-morainic topography. Drift of this type extends southward across the head of the Glen Rock plain to the kame (the 121-foot hill of the topographic map) a mile northwest of Fairlawn station. It includes a distinctly morainic tract a mile or so west of Glen Rock, and thence west to the head of the Van Winkle plain just above Van Winkle.

From the kames near the head of the Glen Rock plain southeast to the kame above Fairlawn, the topography is gently undulatory. The kame or kame group above Fairlawn, a mile northwest of Hawthorne, is rather prominent, and has a rolling topography, with a relief of twenty to thirty feet. The materials are gravel and sand, which has known depths of forty-seven and sixty feet. Bowlders four to ten feet in diameter are also present. From it, a plain of gravel and sand slopes away to the southwest, the materials decreasing in size with increasing distance from the kames. Throughout much of this distance, a gravel and sand plain spreads out to the west and southwest of the kames in the form of an outwash plain, but at its southern front, next the little creek a mile east of Hawthorne, its terminus locally suggests a delta front.

Mr. Peet is of the opinion that this belt from Ridgewood to the kames mentioned, northwest of Fairlawn, should be regarded as an indistinct moraine belt. Its continuation to the southeast is uncertain. He thinks it is to be looked on as having its continuation southeastward to a point a little west of Arcola. Along this belt there are some areas, especially southeast of Fairlawn, where there is some suggestion of moraine topography, though it is nowhere pronounced. South of Arcola, its connections are still more uncertain.

West and southwest of this belt south of Fairlawn, there is a plain in the relations of an outwash plain (Peet), but it is so heavily covered with loam that its constitution is not revealed. Southwest and west of the slightly moraine tract a mile west of Arcola, there is also a plain of gravel and sand having the general nature of an overwash plain, both in its topography and constitution.

On the whole, Mr. Peet's suggestion that the belt from a point west of Arcola to Ridgewood *via* Glen Rock represents a stand of the edge of the ice during its retreat, does not seem to be demonstrated, though something may be said for it.

STRATIFIED DRIFT IN THE VALLEY OF THE PASCACK.

Stratified drift borders the Pascack from its junction with the Pearl river near the State line to its junction with the Hackensack. From the State line nearly to Hillsdale it is confined to the valley, its width being about half a mile; but just above Hillsdale it expands greatly, connecting to the east with the stratified drift of the Hackensack valley and to the southwest with that of the Saddle valley.

North of the junction of the Pascack and Pearl, there is stratified drift in the valley of the latter.

Above Hillsdale.—From the State line to Park Ridge, the gravel in the valley has not the form of normal terraces. Its surface is undulatory, and it sometimes takes on a distinct kame phase. Three kames or groups of kames occur between Montvale and Park Ridge. The first is half a mile southwest of Montvale station on the east side of the river, where the kames are ten or fifteen feet above the southward sloping gravel plain, which here has an elevation of about 160 feet. The area has a length of about three-eighths of a mile, with its longer axis parallel to the valley. There are no good exposures, but the surface material is coarse gravel, with occasional bowlders. On the west side of the river, opposite the north end of the above, is a kame twenty to thirty feet high, and on the west side of the stream opposite Park Ridge there is another, just above the level of the terrace. It has an undulating surface with a relief of twenty feet, and is made up of sand and gravel, with surface bowlders. These kames, and the associated undulatory topography of the terrace toward Upper Montvale, probably mark a halting place of the ice during its retreat.

Between Park Ridge and Hillsdale Manor, the terrace form is more distinct, especially on the east, and declines from 160 feet at the former place, to 110 feet at the latter. At Hillsdale Manor, a trough running lengthwise of the terrace west of the railroad affects its surface. The depression was, perhaps, occupied by an ice block during the deposition of the gravel. The channel of the stream to the west probably represents the position of a similar depression, which determined the course of drainage. This inference is based on the fact that the slope from the terrace to the stream is due to deposition, not to later erosion. North of Hillsdale, the level of the terrace has declined to 100 feet, and sinks and undulations affect its surface, which declines towards the river, as well as down stream. In a distance of three miles above Hillsdale, the level of the terrace has declined about eighty feet. In the first mile, the fall is forty feet, in the second, thirty feet, and in the third, ten feet. This is a fairly normal slope for a valley train. With the decline of surface, the gravel changes from coarse (cobbles three to four inches in diameter), to fine (pebbles one inch in diameter).

On the west side of the valley, the surface of the gravel likewise declines southward from Park Ridge. Here there are flat stretches of terrace next the bluff, while the slope to the river is undulatory, depressions due to deposition affecting it even down to the present flood plain. The topography is, however, not always flat, for distinct gravel ridges with a general north-south trend sometimes rise above the general terrace level, next the highland. One of these ridges opposite Hillsdale has somewhat the form of an esker. The decrease in the size of materials is not so distinct on this side of the river as on the other.

The materials of the gravel and sand of this valley are largely of gneissic origin. With this material, fragments of Hudson River sandstone, purple quartzite and conglomerate, and Triassic sandstone are associated. The structure is best shown in the gravel pit on the east side of the N. J. & N. Y. railway, a little south of the station at Hillsdale Manor. The gravel here fits down over the irregular surface of till shown in the lower part of the section. Of the twenty-two feet exposed, the lower eight to ten feet is rather coarse gravel, with pebbles three inches and less in diameter. The middle six to eight feet is sand, and the upper six to eight feet gravel, but finer than that below. The layers are nearly horizontal, except where cross-bedded.

A quarter of a mile east of the station at Hillsdale, at an elevation of eighty feet, there is a small kame about ten feet high, in an undulating plain of stratified drift. In the north end of the kame the beds of gravel dip both east and west, while on the west side they dip to the south. The spaces between the pebbles are frequently unfilled, indicating rapid deposition. The pebbles are well rounded, unstriated, and largely of gneiss, with subordinate quantities of Hudson River sandstone and quartzite. Half a mile north of the above, on the Hillsdale-Rivervale road, is another kame or kame area of morainic aspect, with undulatory surface and fifteen feet relief. The till adjacent has a semi-morainic topography.

There is one small esker in the Pascack valley, about a mile west by northwest of Hillsdale, at an elevation of 100 to 110 feet. It is ten feet to twenty feet above its surroundings. It has a sinuous course, and a length of 300 to 400 yards. It is about 150 feet broad at its base where highest, but narrows notably where low. Associated with it on the north are less well-defined ridges, with a northwest and southeast direction.

Southwest of Hillsdale.—Southwest of Hillsdale, the stratified drift of the valley, chiefly of coarse, loose sand, is continuous over the low land to the head of the Musquapsink. It covers most of the surface below ninety to 100 feet. Within this area there are undrained depressions, on the slopes of which till sometimes appears. The depressions were probably occupied by ice, when the surrounding gravel was deposited.

North of the Musquapsink, and a mile and a half to two miles southwest of Westwood, there are three kames, or groups of kames, fifteen to thirty feet above the surrounding plain, which here has an elevation of seventy to eighty feet. Other parts of the stratified drift also show something of the kame habit. The material of the kames is distinctly coarser than that of the surrounding plain. Both bowlders and sand are associated with the gravel, and some of the stones are striated.

South of the marsh along the Musquapsink, on the northern border of which the above kames are situated, there is an undulatory gravel plain, ranging in elevation from sixty to eighty feet. This is bordered on the east by the till-covered ridge west of

Etna, and on the south by a tract where the gravel assumes a kame habit of slight relief. West of the above marsh, an undulatory plain of gravel, affected by sinks more than knolls, extends to the valley of the Saddle.

Southwest of the swamp, and between the headwaters of the southerly branches of the Musquapsink and Sprout brook, is a very conspicuous group of kames of morainic habit, covering an area of nearly a square mile. The area is about equally distant from Oradell, Westwood and Paramus, being northwest of the first place, southwest of the second, and southeast of the third. The kames reach a maximum elevation of 149 feet, and have a rough topography with a relief of at least thirty feet. They are ninety feet above the swamp to the north and forty to fifty feet above the surrounding plain. They are composed of coarse materials, predominantly gneiss and Hudson River sandstone, with some Triassic material and quartzite. While there are no good exposures, the material is probably not all stratified.

On the south side of the kames, there are narrow lobate flats which resemble deltas. They have but little extension from the kames, and their materials are coarse gravel, so far as exposures show, but their general configuration is deltaform. They occur at a level of about 100 feet. The steep south slopes of these flats are not of erosion origin, and the only alternative interpretation which seems to be at all adequate to explain them, is that of the deposition of the gravels, etc., against standing ice to the south, and the form of the lobation is rather against this view. In deltas, the lobes are round and the re-entrants acute; in steep fronts deposited against stagnant ice, the lobes should be cuspate, and the re-entrants round if the front simulates a delta at all. The configuration of the gravel front at this point is of the delta type.

South of the east end of the kames there is a gravel plain, which, beginning with an elevation of 100 feet, declines southward to sixty feet in less than a mile, and terminates with a rather abrupt, lobate front, which, in places, at least, is not of erosion origin. The materials decrease in size from three or four-inch cobbles near the kames, to coarse sand with small pebbles at the south end. Sinks occur in its surface, oftenest near the kames. A single exposure on the west side shows the sand to be stratified, with the beds dipping to the south.

The sand in the lowland south and west of the plain along Sprout brook may have been deposited by the waters which built up the plain.

The plain about Westfield.—South and east of Hillsdale, the stratified drift of the Pascack expands notably and becomes continuous with that of the Hackensack. It forms a rather remarkable plain or series of plains about Westwood, not only north and south of the Pascack, but south of the Musquapsink as well, extending south nearly to the Hackensack, above Oradell.

The plains of the locality are separated from one another by the valleys of the Pascack and Musquapsink creeks, one plain lying north of the former, one between the two, and one south of the latter. This separation might be thought to be the result of post-glacial erosion, but this does not seem to be the case. The plains separated by the valleys, seem never to have been united.

That plain, or that part of the plain, which lies north of the Pascack, lies east and southeast of a small area of moraine habit, a little to the northeast of Hillsdale, but its highest part is a mile farther east, separated from the moraine tract by a broad depression twenty feet or so deep, and not of post-glacial origin. The dominant material of the plain is coarse sand, which is generally loose. A mile north of Westwood, the plain is affected by notable sinks, not of erosion origin. Some of them are large, and their slopes have something of a deltoid outline. The plain extends off to the east and southeast, with declining surface, well toward but not to the Hackensack. Between it and the river, areas of till intervene at levels below that of the sand.

The slope of the plain to the Pascack is generally abrupt. At some points it has been fashioned by the erosion of the creek, but at other points this is not the case. East of Hillsdale, the northern edge of the plain has an elevation of seventy to eighty feet, but falls off abruptly to the north to the tributary which joins the Hackensack below Rivervale. The slope to the brook is in some places till. Locally the surface of the plain has been affected by the wind. There is such a place east of the Pascack, a little north of the junction of the Musquapsink.

The plain between the Pascack and the Musquapsink at Westwood, is, in a general way, similar to that north of the Pascack. It is on this flat that Westwood is situated. The highest points in this flat are just above eighty feet, and the surface above this level is slightly undulatory, and of a coarser material than most of that which is a little lower and flatter. The undulations are most notable in the eastern part of Westwood. Wherever the coarser material appears, it contains a much larger proportion of Triassic sandstone than the finer part.

The swells of coarser material probably antedate the development of the plain. They are thought to represent the drift deposited by the ice at its edge, and not subsequently buried by the finer material which covers most of the plain.

The slopes of this plain, like those of the plain north of the Pascack, are often depositional, and almost everywhere steep, the amount of the fall being twenty-five to thirty feet. At many points, the slopes simulate delta fronts, both in profile and outline. This may be seen north, northwest and southwest of the village. At some points, on the other hand, the slopes are not deltoid. No exposures which show the structure of the material have been seen. Most of the surface material of the plain is sand, rather than gravel, and to the sand, gneiss and the Hudson River formation seem to have been the principal contributors.

The plain south and east of the Musquapsink stretches off to the south, and ends with a rather abrupt slope near Etna (Kinderkamac). At the north, the level corresponds with that of the Westwood plain. Its surface declines southward to sixty feet east of Etna, where it drops off rather abruptly to fifty feet on the south, and to forty feet or less on the southeast and east. While the terminus is not an erosion slope, nor yet a slope made by subaerial deposition, it is not distinctly deltoid.

Post-glacial changes in Pascack and the Musquapsink valleys.

Erosion.—The amount of post-glacial erosion accomplished by the Pascack is slight. On the average, the stream has probably not lowered its channel more than ten or fifteen feet since the glacial period. Above Montvale, the amount has been less than twenty feet; about Park Ridge, about twenty feet; from Park Ridge to Hillsdale Manor, little or none; from Hillsdale Manor to the east end of the swamp north of Westwood, probably none; between this point and the mouth of the Musquapsink, fifteen to twenty feet, with a possible local maximum of thirty-five feet; for a mile below the mouth of the Musquapsink, there has been filling, rather than erosion, and between that point and the Hackensack, the downward cutting has probably nowhere exceeded ten feet.

Above Westwood, the Musquapsink has been filling rather than eroding. This part of its course was probably determined by a depression in the surface of the stratified drift, as left by the ice and the glacial waters. East of Westwood, the Musquapsink has lowered its channel ten feet or more. Before this was done, a small and very shallow lake occupied the marshy tract above Westwood, through which the creek now flows.

The alluvial plains.—The Pascack is bordered by an alluvial plain almost continuously from above Montvale to the junction with the Hackensack. Its width is least northeast of Westwood, where it cuts through the Westwood gravel plain. Both above and below this point, it varies in width from less than an eighth of a mile to more than a quarter. The broader portions of the plain are frequently swampy. Little can be said of the depth of alluvium and peat which have accumulated on the plain.

The valley of the Musquapsink is also bordered by a wide swampy plain above Westwood, and by a narrower one below. In this swamp there are considerable accumulations of organic matter, and some alluvium.

STRATIFIED DRIFT BETWEEN THE VALLEYS OF SADDLE RIVER AND PASCACK CREEK.

Most of the stratified drift between these valleys has been referred to in connection with the valleys themselves, for between them it is continuous below Westwood. There are, however, two areas of gravel on the highlands between these valleys.

They are both small, and without distinctive topographic form. One occurs more than a mile west of Park Ridge, in the valley of Bear brook; the other about a mile farther south, near the head waters of a branch of the Musquapsink.

STRATIFIED DRIFT OF THE HACKENSACK VALLEY.

For the first mile of its course in New Jersey, the Hackensack river flows through a broad swamp, bordered on the west by a narrow belt of stratified drift. This depression was left on the retreat of the ice, not made by the stream. From this swamp to Overton, the course of the river is through a wide area of gravel and sand, some of which is aggregated into kames. While much of the gravel and sand are disposed as plains, the plains are not continuous, and different parts are unlike in origin, in topography, and in general relations. From Overton to Cherry Hill, the plain of stratified drift is narrower, but still approaches a mile in width. Below Cherry Hill it expands again, and continues, usually with a width of more than a mile, to the meadows below Little Ferry.

North of Etna.—The surface of the gravel plain along the Hackensack above Rivervale has an elevation of about ninety feet, and is about fifty feet above the river. East of Rivervale, its altitude is seventy to eighty feet. Farther south its disposition is irregular as far south as Old Hook, being now higher, and now lower, with no constant upper limit. South of Old Hook, its surface declines from an elevation of thirty or forty feet to tide level at the meadows below Hackensack. Its surface usually slopes more noticeably toward the stream than down stream. Its upper limit, indeed, has little variation from Old Hook to Hackensack.

Above Rivervale, on the west side of the river, some of the stratified drift is disposed as kames. Such a group of kames lies a mile above Rivervale, and another kame occurs a little farther south. The kames are of coarse gravel, surrounded by finer material with a nearly level surface.

About a mile east of Rivervale there is a crescentic shaped kame area, or kame-moraine, a mile and a half long and an eighth to a fourth of a mile wide. It has a maximum height above its surroundings of about 105 feet. It is characterized by high, knob-like hills, one remarkable kettle, and many lesser ones. As seen from the road crossing it about a mile east of Rivervale, the undulations of the surface amount to twenty-five or thirty feet. The kames are composed of coarse gravel, with occasional bowlders, one of which is ten feet in diameter. Till covers the surface in the crescent on the north, coming up sharply to the moraine belt, and from the convex side of the crescent a gravel and sand plain stretches off to the south. The kames and the plain to the south sustain to each other the relation of moraine and outwash plain.

South of the kames northwest of Rivervale, on the west side of the river, there is likewise a plain extending off to the south. These two areas are separated only by the valley of the Hackensack. These kame groups on both sides of the Hackensack were formed at the edge of the ice, probably contemporaneously, and mark a position of temporary halt.

The plain south of the Rivervale kames has at the north an elevation of about ninety feet, and is composed of rather coarse gravel, as shown by its cobble-strewn surface. Locally, however, the gravel is covered with loam and thus concealed. To the south the material becomes finer promptly, and, at no great distance from the kames, sand predominates, at least at the surface. When this change has been accomplished, the plain resembles those about Westwood. This plain is separated from those about Westwood, much as they are separated from one another.

The plains about Westwood.—The origin of the remarkable plains about Westwood and Rivervale in the vicinity of the junction of the Hackensack and the Pascack, has not been satisfactorily worked out. It is clear that they are, for the most part, not made of material deposited by running water which was unobstructed in its flow. Their surfaces have too little slope to the south; their material is too fine, considering the position and relation of the plains; and their surfaces are affected by depressions which cannot be accounted for on this basis. It is clear that the several plains, or the several parts of the plain, were never continuous, and that their separation along the valleys was original, and not the work of the streams. The streams appropriated, but did not make, the valleys between the plains through which they flow.

The crests of older drift hillocks, of different material, occasionally come to the surface, showing that the material of the plain was deposited on an uneven surface, tending to level it up. The drift buried by the sand of the plain is coarser than that by which it was buried, and contains a large percentage of Triassic material, which is nearly wanting in the surface sands.

There seem to be but two hypotheses to be seriously considered in connection with the origin of these plains; the one that they were built up in a body of standing water, and the other that their materials were deposited by streams, the flow of which was so obstructed by bodies of stagnant ice, which remained south of the main ice sheet after its retreat from this region, that they were now and again ponded, giving rise to lakes, and so to several bodies of standing water. If there were a single body of water, it is difficult to see how it could have been anything less than a bay, extending northward from the site of the present Newark bay. This bay may have been of fresh water, for its connection with the sea was perhaps narrow and shallow, and the supply of fresh water from the north great.

If there was such a body of water, it may have been burdened at its northward end by masses of ice, more or less isolated from the main body, and against and about these the sands of the plains may have been deposited. The separation of the several plains from one another may be the result of such bodies of ice, about which the sands were deposited; or the plains may have been built at different stages, as the ice withdrew to the north, the deltas built out from one front failing to reach the deltas of the preceding stage at many points.

The alternative hypothesis that the steep fronts of the several plains represent deposition against bodies of standing ice which obstructed drainage, making small lakes, seems, on the whole, less satisfactory. The steep slopes rarely have the marks of deposits made in this way. Their outlines are more commonly deltoid. This is, however, not conclusive, since deltoid fronts could be developed in the local lakes as well as in a single body of water.

While the evidence for the hypothesis that a body of water covered the area is not conclusive, it seems to be the best suggestion that can now be offered for the Westwood plains, and is consistent with various phenomena farther south, which point to standing water over a great area west of the Palisade ridge after the retreat of the ice. If such a body of water existed, its level was about seventy to eighty feet above the present sea level when the plains about Westwood were made.

The surface sand of the Hackensack valley has the character of molding sand at several places. This is notably the case at Old Hook, and for a short distance south, and again southeast of Etna, and at Fairmount. In other places the surface has a coating of loam so heavy as to be almost clay. This is true south of the Etna plain, on the west side of the river.

South of Etna.—The stratified drift of the valley south of the plain at Etna seems to have been measurably independent of that to the north, in origin. Below this point, the plain of stratified drift, chiefly sand, does not rise above forty feet, and maintains a practically constant upper limit to the meadows. Above the valley plain there are irregular bodies of stratified drift, kames, etc. Below Etna, the sand is mainly on the east side of the valley.

For a quarter of a mile north of Oradell, a terrace of gravel occurs west of the railroad, at an elevation of fifty feet. The material has the grey color due to the abundance of gneiss and Hudson River sandstone, and is in contrast with the red color of the till of the vicinity. The greater redness of the till is, in part, at least, due to the presence of the red matrix. At Hackensack, for example, the till appears much redder than the gravel, but the actual proportions of stony constituents are much the same, though from the gravels the red clayey matrix has been washed away.

Just *south of New Milford,* coarse gravel re-appears on the west side of the Hackensack. It has more of the red-colored stony materials, but is covered by the sand of the Hackensack plain.

East of Oradell and New Milford, the low sand plain extends eastward nearly to the West Shore railway. For more than a mile east of Oradell, its elevation is less than forty feet, or slightly below the level of that on the west side of the stream. Beyond this flat, the surface is rougher, and kames make their appearance. Between New Milford and Hackensack, the stratified drift keeps to the lowland, but has little southward slope. As far south as Hackensack, the valley drift presents few notable features.

The Hackensack delta (?).—At the Anderson street station of the N. Y. and N. J. railway, in Hackensack, there is a gravel plain, at an elevation of between forty and fifty feet, which has somewhat the form of a delta. It has a length in a northwest-southeast direction of nearly half a mile, and a width about half as great. Its north side descends abruptly about twenty feet, and its southern slope, though less abrupt, falls off somewhat promptly to a lower level. Between this plain and the highland to the northeast there is an inconspicuous trough-like depression. An exposure in the plain near the railway shows the structure of the plain to be deltoid. The upper five to ten feet of gravel are horizontally stratified, while the lower layers dip south and west. Exposures farther north, not now to be seen, have shown layers dipping north. The surface gravels are from one inch to four and six inches in diameter near the north end of the flat, and slightly smaller to the south. The surface of the plain, both north and south, is made of finer materials, mainly sand. This plain lacks the characteristic marginal lobation of a well-developed delta, but, on the whole, the evidence at hand seems to favor this interpretation of its origin.[1] Below this plain there is stratified drift over the lowland next the Hackensack, up to levels of twenty to thirty feet, and, except for dunes, its surface is nearly plane.

The surface of the sand in the lower part of the valley has been modified by the wind in several places. West of the clay pits above Little Ferry, there are some dunes, and small ones also

[1] Much of the surface of the delta has been modified by human agency in the last year, so that the deltoid features are less distinct than formerly.

occur on the east side of the stream above Bogota and New Bridge. Even as far north as Old Hook, there are small dunes, and for a mile or so south of there the wind has produced some modification of the surface.

The clays of the Hackensack valley.—Beneath the stratified sand and gravel of much of the Hackensack valley there is a considerable body of laminated clay. It is well exposed only about Hackensack, especially in the pits at the brick yards below the city, on the west side of the river, and at a few points in the river bank north of the city. It is known to occur at Riveredge and New Milford on the Henry Bartch place, is reported to lie beneath Oradell, and is present just south of Old Hook. It is not known north of this point in the valley of the Hackensack itself, but it is said to occur north of Closter, at Norwood, and at Neuvy. At Neuvy the clay was formerly worked, and its thickness is said to be twenty-eight feet. The clay at this point is not now accessible.

In the valley of Overpeck creek, the clay is also present, as far north as Englewood, and probably beyond.

This laminated clay was deposited in standing water which was moderately quiet. Into the water, masses of ice carrying bowlders were sometimes floated, as shown by the occasional large, glaciated bowlders in the clay.

The clay is known to overlie till at many points, and its deposition is therefore later than the occupancy of the region by the ice. At the north, the surface of the clay is some thirty feet above sea level, while at Little Ferry its surface is about at sea level. Its surface, therefore, declines slightly to the south.

The depth of the clay is one of its most remarkable features. The following data on this point have been reported:

At Neuvy, surface elevation twenty to thirty feet, twenty-eight feet of clay.

North of Closter, surface elevation about forty feet, ten feet of clay.

At Oradell, surface elevation about thirty feet, 185 feet of clay, beneath fifteen feet of sand.[1]

---

[1] It is suspected that the boring here may have been in soft shale, not distinguished, in the drilling from clay.

At Hackensack, numerous borings have tested the depth of clay, which varies from a few feet at the more northerly brick yards, to eighty-five feet at Merhof's lower yard, and at the gas works.

West of Bogota, on the east side of the river, the clay is reported to be 215 feet thick. These figures make it clear that the surface of the rock east and north of Hackensack is far below sea level, and that, if the drift were removed, or even that part of it which lies above the till, a great bay would cover the Hackensack meadows, and extend far to the north. A branch of the bay would run up the valley of Overpeck creek, for the surface of the rock at Englewood is known to be locally as much as sixty feet below sea level. Even as far north as Closter, the surface of the rock is at least twenty feet below the sea level, according to the records of wells.

The records of borings in the vicinity of Newark are in keeping with the above figures.

This clay was deposited in standing water. Such a body of water, therefore, covered the lower lands west of the Palisade ridge, probably as far north as Neuvy, after the departure of the ice. The surface of the clay at the north is about thirty feet above sea level. The surface of the water in which the clay was deposited was, therefore, at least this much above present sea level, in the latitude of Neuvy. Not only this, but the water in which the clay was deposited was probably not extremely shallow. While no considerable depth need be assumed for it, it is safe to conclude that the surface of the clay is somewhat below the surface of the water in which it was deposited. Furthermore, the clay was deposited after the ice was sufficiently far north of the site of deposition so that coarse materials were not readily available. It is not certain that the clay at Hackensack and below was strictly contemporaneous with that at Neuvy. The deposition of clay to the south may well have begun earlier than its deposition to the north.

It is commonly believed that the ice-sheet depressed the surface on which it rested, and that, as it melted, the unburdened earth-crust reacted by rising. Before the deposition of the clay in the northern part of the Hackensack basin, the land may have risen so as to make the water shallower than at an earlier time. At any rate, there is good evidence of post-glacial submergence to the extent of fully thirty feet near the northeastern corner of the State. Considering the depth of water necessary for the deposition of the clay, and the rise which may have taken place as the ice melted back, it is not unreasonable to suppose that the region about Westwood was submerged to the extent of sixty to eighty feet, the height of what appear to be delta fronts (p. 613), at the time the ice was retreating; for these deltas, if such they are, were probably made while the edge of the ice was in the immediate vicinity, and somewhat before the deposition of the clay.

The hypothesis that the water which covered this area was a lake, rather than a bay, is worthy of consideration, though it is, on the whole, less satisfactory. The moraine and other drift deposits may have blocked the southern outlet of this region to the height of twenty-five or thirty feet, between New Jersey and Staten Island. If a similar dam obstructed Kill van Kull, or the Narrows and East river, a lake would have come into existence in the tract where the clay is. As the outlet was cut down, the lake was drained. But even on this hypothesis, differential movement of the surface must be supposed, for the surface of the clay is higher to the north than to the south.

It may here be added that there is abundant evidence of a late submergence, at least to the extent of forty feet, at various points about the coast of southern New Jersey. The date of this submergence was not earlier than the close of the last glacial epoch.

The clay of the Hackensack valley is everywhere covered by sand, generally eight to fifteen feet in depth. At some points the surface of the clay below the sand is leached and oxidized. It is, in most places, not possible to say whether this leaching and oxidation is the result of exposure before the deposition of the sand, or whether it has taken place beneath the sand. The latter would be somewhat out of keeping with the extent to which the drift so far beneath the surface has generally been altered since its deposition.

At two points specific evidence on this point has been obtained. In 1893, one of the clay pits below Hackensack showed the following section:

(5) Eight feet of fine, stratified sand, containing a few gneiss bowlders.

(4) Stratified sand, two feet in depth, overlain by a few inches of blue clay containing fragments of leaves and woody stems.

(3) One foot of black soil.

(2) Six feet of laminated clay, containing an occasional bowlder, calcareous up to within a foot of its upper limit.

(1) Till, seen in the bottom of the pit on its west side.

The old soil (3) was not far from sea level. A similar section, so far as the old soil was concerned, was seen by Mr. Peet, at Riveredge, a little south of the depot, in a temporary excavation. Here the section was as follows:

(3) Sand, four feet.

(2) Clay and sand, interlaminated, six feet.

(1) Clay, black from the presence of organic matter.

The old soil in this case was about ten feet above sea level.

These sections show that after the clay was deposited, the surface was exposed for a time, and that vegetation grew upon it, after which it was depressed sufficiently to allow of the deposition of the overlying sand.[1]

Bordering the Hackensack meadows.—West of the Hackensack meadows there is a little stratified drift. At Corona it makes a sort of terrace thirty to forty feet above tide, but it is not continuous, and is without exposures. From Woodridge to Kingsland and below, a narrow border of gravel or sand skirts the highland most of the way. At Carlstadt, it makes a distinct terrace at an elevation of about thirty-five feet, though the stratified material extends somewhat higher. At Kingsland, the terrace is distinct at thirty feet, and its material is gravel and sand. Its surface here has been somewhat modified by the wind.

Less than half a mile south of Kingsland, there is a gravel ridge at an elevation of thirty feet, having a width of about 200 to 250 feet, which resembles a spit (Peet). It has a rather level top, but a sag near its north end separates it slightly from the higher land from which its gravel would have been derived, were it a spit.

[1] For further discussion of these clays see Chapter VII.

Between Kingsland and Schuyler Corner, till prevails to the edge of the swamp, but at the Corner, south of the Arlington cemetery, there is a gravel ridge 100 to 200 feet wide and about six feet in height, near the tide marsh, which may be a spit (Peet).

South of this, stratified drift is wanting along the west side of the meadows, nearly to Harrison. At this point, gravel appears facing the meadows, with an elevation of about thirty feet, and connects with that at Harrison.

Moonachie.—The land rising above the swamp at Moonachie is largely covered with sand, though till appears at the summit of the forty-five foot ridge, and northeast of the thirty-one foot hill. There is a terrace at the southeast side, at an elevation of about twenty to thirty feet. The surface of Moonachie has been more or less modified by the wind, and is often so covered with loam that the real nature of the drift below is uncertain.

Secaucus.—The islands in the swamp from Secaucus to Snake Hill are mainly covered by till. On the north and northeast side of Secaucus, there is a little gravel below thirty feet, but it has no distinct topographic form, and does not appear to run up to the same height at all points. On the east side also there are small patches of gravel with a suggestion of terrace form, always at levels below forty feet.

At the southern point of the island, and east of the Erie railway, there is a spit-like ridge of sandstone gravel, the higher end of which is between ten and twenty feet A. T.

Just south of the Snake Hill station of the D., L. & W. railway, there is also a spit-like ridge at about ten feet A. T. It has a level top and an oval cross-section, and is composed of sandstone shingle. It is now slightly disconnected from the higher land east of the depot from which the material must have been derived, if the ridge is a spit, but grading for the railroad may have caused the break.

On the north side of Snake Hill gravel occurs up to an elevation of ten to twenty feet. It is composed largely of sandstone or shale, and is covered by heavy loam. It does not form a terrace.

A mile northwest of Norwood station, on the road to Rivervale, and west of the West Shore railroad, there are two kames, one on the northeast side of the road, and the other on the southwest. The first is twenty feet high, and its surface has some gneiss bowlders two to three feet in diameter. The kame (or kames) on the opposite side of the road is less conspicuous.

West of Randell station there is a gravel area with a kame-like topography, and ill-defined limits. The materials are rather coarse gravel. About an eighth to a fourth of a mile south of the above is another more prominent kame. It has an elevation of about thirty feet, and its longer north-south diameter is between one-eighth and one-fourth of a mile. It has smooth slopes, and is composed of sand and well-rounded gravel. Bowlders occur on its surface.

Between the kames and associated gravels west and southwest of Randell station, and the kames northwest of Norwood, there is an elongate kame area east of the West Shore railroad. The gravel in it is reported to be fifty feet deep. Below this, thirty-two feet of material not known to be gravel, was penetrated, and no rock found.

Between Haworth and Schraalenburg there are three single kames and one kame group. The single kames are west of the railway, and the area is cut by it. The northernmost kame, about a mile southwest of Haworth, and half a mile from the railway, is twenty-five to thirty feet above the plain, which here has an elevation of seventy to eighty feet. A few hundred yards southeast of it, and about a mile north of Schraalenburg, is the kame group. It has a length of about half a mile, and is nearly bisected by the railway. Its topography is rough, especially west of the railroad, where there are sharp sinks and some hillocks. The material is coarse, the surface being strewn with cobbles and small bowlders, with an occasional large one. The exposures on the railway show that the kame contains large bowlders, along with the finer material. The materials are gneiss, Hudson River and Triassic sandstone, with quartzites and occasional pieces of limestone. The upper part of the section contains foreign material in greater proportion than the lower. Triassic sandstone is rare in the upper part, though not entirely absent. Another exposure on the east side, shows seven feet of gravel overlying three feet of stratified sand.

Stratified drift near the Hackensack valley.—There are a few kames and other ill-defined patches of stratified drift near the Hackensack which have not been mentioned in the preceding account of the stratified drift of this valley. One of them, a small one, occurs about a mile northeast of Etna, at an elevation of 70 to 80 feet.

About Spring Valley.—In the valley of the brook joining the Hackensack at Cherry Hill, there is some gravel and sand from a point opposite New Milford to Fairmount. It has not the form of an aggradation plain, and its topography varies from that of a plain to that which is more or less undulatory.

A quarter of a mile west of the kame group is another kame about twenty feet high. It is less than a quarter of a mile long and half as wide. Like most kames in the vicinity, its surface has some bowlders. The other kame, a third of a mile west of the Schraalenburg station, is small, being but ten to fifteen feet high.

There are five small kames in the valley of the small stream flowing north from West Englewood, all of them within a mile of that village, and all near the brook. Three of the five are cut through by the West Shore railway. Triassic sandstone is their chief ingredient. Associated with them there is a considerable body of sand and gravel without distinctive topographic form. The entire area of stratified drift associated with the kames has a length of one and three-fourths miles and a width of about one-half mile.

Post-glacial changes in the valley of the Hackensack.

Alluvial Plain.—From the State line to about a mile above Rivervale, the Hackensack is bordered by a wide swampy alluvial plain. From this point to Rivervale and below, the alluvial plain is either narrow or wanting. Between a point just below Rivervale and Pascack, it is first wide (nearly half a mile) and then narrow. From the junction of the Pascack to the meadows below Little Ferry, it varies from an eighth to a half mile in width. Below Old Hook the plain is locally swampy.

Post-glacial erosion.—The amount of post-glacial erosion in the valley of the Hackensack, like that in all the streams crossing the drift, is variable, but the average is slight. At several points it is practically nil.

From the State line to a point about a mile above Rivervale, the river has done practically no eroding. From that point to a point less than half a mile below Rivervale the amount of erosion is often indeterminate, but the river has nowhere lowered its channel more than about twenty feet, and generally less. For a mile below the point last named, the channel has been lowered less than five feet, and much of the way probably not at all. For a mile and a half below the south turn of the river a mile and a half southeast of Rivervale, the valley has been deepened less than twenty feet. South of Old Hook, the post-glacial deepening varies from ten to fifteen or twenty feet, and from this point to Little Ferry the average is not more than ten feet.

STRATIFIED DRIFT EAST OF THE HACKENSACK VALLEY.

East of the Hackensack valley, the stratified drift is chiefly confined to the lowlands at the west base of the Palisade ridge. From Highwood, the valley is drained northward *via* Closter, to the Hackensack at Old Hook. South of Highwood the drainage is southward, through Overpeck creek. The divide between the Tienekill and the Overpeck creek, is made by the aggregation of kames at Highwood. The lowest point of the divide is barely sixty feet above tide. The highest of the kames at Highwood reaches an altitude of 105 feet. Above the valley at the west base of the ridge, half a mile northeast of Highwood, are other kame knolls, the highest of which reaches an altitude of 127 feet. This group of kames is of morainic character, and probably marks a halting place of the ice during its retreat.

South of Highwood.—From the kames at Highwood, a distinct plain extends southward. Beginning at the kames with an elevation of sixty to seventy feet, it declines to ten feet west of Englewood, a distance of but little more than a mile. The surface of the plain is generally flat, though minor irregularities are not wanting. These take the form of sinks and, less commonly, of low knolls or gentle swells. The surface descends with little interruption to an altitude of twenty to twenty-five feet. At two points step-like descents of slight extent interrupt the otherwise regular southward slope. The east face of the plain is in sharp contrast to the southerly slope. From Highwood to Englewood this slope is abrupt, with a descent of twenty feet or more. The western face of the plain is also steep. The slopes of the plain at some points are clearly depositional, not degradational. That is, the material was deposited as it now is, and not carved into its present form by surface erosion in subsequent time. This is shown by the profiles of the slopes and the lobate character of the margins. The material was deposited either as a delta, or against standing ice.

At its head against the Highwood kames, the material of the plain is in part gravel, the pebbles frequently having a diameter of three inches. To the south, the material becomes finer, and finally altogether sand.

At a gravel pit south of Highwood, the sand and gravel of the plain have the structure of a delta plain. That is, the upper beds are nearly horizontal, while the beds below dip rather steeply to the south. A similar structure was seen a block north and west of the Englewood depot (Fig. 75). Sections seen at

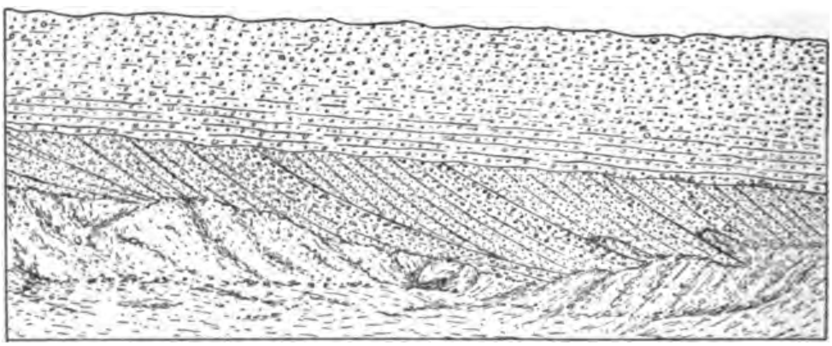


Fig. 75.

other points, one near Highwood and one on the west face of the plain, are not in harmony with those mentioned, for at these points the beds of sand and gravel dip in toward the center of the plain. Formerly[1], the delta origin of the plain was considered improbable, because of the discordant testimony of the sections just mentioned. In the light of subsequent studies it seems possible that the plain is a delta. Delta deposits in such positions, buried whatever deposits were on the ground before them, and these earlier deposits may have had irregular structures, discordant with those of a delta. Again, it is possible that the delta was built in water in which there were bodies of ice. These would have interfered with the regularity of the development of the deltas.

West of the brook west of the Englewood plain, there is a terrace-like flat against the highland at a corresponding level. This terrace has a sandy coating, though it is not known to be composed of sand. It continues southward to Tea Neck. On the east side of the valley, east of the plain, near Highwood there is a terrace, for a short distance, at an elevation of about sixty feet. At Englewood, no distinct terrace exists at the base of Palisade ridge, but stratified drift occurs above an elevation of about fifty feet.

North of Highwood.—North of the divide at Highwood, the surface declines promptly, and the stratified drift is continued northward at a level distinctly below that of the kames. Stratified drift occupies the bottom of the valley to the State line. There is a suggestion of a terrace west of the railway at an elevation of about sixty feet, running northward toward Tenafly. At Tenafly, stratified drift runs to a height of ninety feet, and from this point to Cresskill, its upper level, except for the kames which rise to higher levels, is between sixty and seventy feet. Most of the stratified drift of the valley is below this level, but not all of the surface below this level is covered with gravel and sand. Terraces are rarely distinct.

The most notable group of kames in the valley of the Tienekill, is that near Demarest. They occupy a belt a mile and a half long, and extend from a point half a mile west of the station, to a point nearly a mile northeast of it, the highest part being 168 feet. The kames, especially those northeast of Demarest, are

[1] Ann. Report of State Geologist, 1893, p. 201.

of the distinctly morainic type, knobs and depressions both being pronounced. Short as the kame belt is, its length is much greater than its width, and its greatest extension is approximately at right angles to the direction of the ice movement. It seems highly probable that these kames were developed at the immediate margin of the ice, and that the roughness of the terminal moraine belt, at some points, is due to a like activity of the same agents, working under similar conditions. Occasional bowlders occur on the surface of the kames. The kames west of the village are less morainic in their aspect, but are probably to be connected, in time and mode of origin, with those to the northeast. About half way between Highwood and Tenafly there are two kames standing up above the till surface. The southernmost, with a height of thirty to forty feet, is well exposed in a deep railroad excavation. The surface is covered with yellow loam to a maximum depth of five feet. The loam appears to be devoid of stratification, and it is apparently free from stones except in its lower part, where it begins to grade into sand. At the junction of the loam and sand, there are occasional sandstone blocks partly buried in the stratified gravel, but projecting up into the loam. Below the loam, the material is not always well stratified, and in places it is altogether without structure. The pebbles range up to three and four inches in diameter. Bowlders of Triassic sandstone, gneiss, granite, limestone, trap and quartzite occur, and some of them are striated. A few hundred feet to the north there is another kame, twenty to thirty feet high and 500 feet in diameter.

Laminated clay.—In the valley south of Englewood there is laminated clay beneath the sand. Knowledge concerning it is confined to rather meager data from such deep borings as have been recorded. Just west of the Englewood station, and twenty feet above tide, seventy feet of clay are said to underlie fifteen feet of sand. The rock surface here is about sixty-five feet below sea level. It is not definitely known that all this clay is of the laminated, Hackensack type.

In the northern continuation of this valley, now drained by the Tienekill, clay is also known to underlie the stratified drift at some points. Near Neuvy, thirty feet above tide, there are abandoned clay pits now filled with water. The greatest depth of clay reported is twenty-eight feet. It is said to rest on material, which, from the description, is judged to be till. The clays here are said to be similar to those at Haverstraw and Hackensack. It should be noticed, in this connection, that there is a valley connection between the Hudson valley and Neuvy, via Sparkill and Piedmont. A depression of less than thirty feet would cause the waters of the Hudson to cover these Neuvy clay pits, and pass down the Hackensack to Newark bay. A depression of sixty feet would connect the Hudson river with Newark bay, via Demarest and Englewood, and a depth of drift greater than this is known to exist at Englewood, where the surface is only about twenty feet above tide. It is possible that the Hudson once flowed down the west side of the Palisade ridge instead of the east.

Below Englewood.—South of Englewood there is some stratified drift along the west base of the Palisade ridge. It is often in the form of terraces, sometimes distinct, but often ill-defined. Between Englewood and Granton the terraces are at elevations of thirty to thirty-five feet, and locally clearly marked. The stratified drift is not continuous, and some of the terraces appear to be of till. There is nothing to show whether they are wave-cut, or due simply to the manner in which the till was originally deposited.

Between Granton and Scheutzen Park there is a considerable area of sand, below forty feet, disposed as an indistinct terrace. To the depth of seventeen feet the section is as follows:

4. Three feet of yellow loam, without structure.
3. Two feet of horizontally stratified fine sand.
2. A bed of coarse stratified sand, ranging from a few inches to three or four feet in thickness.
1. Horizontally bedded sand.

Between Scheutzen Park and Marion there is little stratified drift, but between Marion and Bergen Point, stratified drift is nearly continuous next the bay. It is mostly below thirty to forty feet, sometimes distinctly terraciform, but oftener not. Its surface is locally modified by the work of the wind. Small dunes occur at several points, especially about West Bergen.[1]

STRATIFIED RRIFT OF THE LOWER PASSAIC VALLEY AND ITS TRIBUTARIES.

The stratified drift of the upper and lower parts of the Passaic systems are somewhat notably unlike, chiefly because of the influence of Lake Passaic in the former part of the basin. The lower part of the Passaic is here regarded as the portion below the borders of Lake Passaic; that is, the part below Totowa.

Between Totowa and Paterson.—At Totowa the stratified drift on the left bank of the Passaic takes the form of kames, with which some till of morainic habit is associated. It is possible that the drift here once blocked the valley up to an elevation of about 220 feet. If so, the dam was cut through when Lake Passaic was drained. Below the kames, the stratified drift on the northwest side of the stream spreads out on the plain which extends northeast to Haledon brook. The plain is interrupted a mile east of Totowa by a kame ten to fifteen feet high, and to the northeast by the valley of Haledon brook and its tributary. The upper limit of the plain is 130 to 140 feet, or only about twenty feet above the river. It rises northward along the brook, where it gives place to irregular ridges and knolls of morainic habit. East of Haledon brook, the stratified drift is largely sand, with gravel appearing in the knolls wherever the topography becomes irregular. Even in the plain, gravel may be more plentiful than the surface shows.

On the right bank of the Passaic between Totowa and Paterson, gravel and low knolls and ridges of stratified drift and till, not clearly differentiated, reach an elevation greater than that of the plain on the left bank. Bosses of trap sometimes project above the drift.

The stratified drift of the Passaic valley consists of two parts: that deposited while the ice lay in the valley, and that brought in by its tributaries after the ice had melted from the valley. So

[1] For the stratified drift at west base of Palisade ridge, see Report of 1893.

much of the former as can be identified consists of kames and associated gravel areas. The latter locally covered and partially buried the drift deposited earlier by the ice, or by water at its edge. The surface material of the plain between Totowa and West Paterson was largely deposited by waters directly from the ice when its front stood at the line of kames in West Paterson and the south part of Haledon, and after Lake Passaic was drained. Some of it may be material eroded by the Passaic from the gorge at Totowa.

In the valley of Haledon creek.—There are a few small areas of gravel in this valley above Haledon, and below the village is a continuous body of stratified drift. Near the village it has a rather plain topography, relieved by a few low knolls. Half a mile or more below, the plane develops into a kame area, which is continuous with morainic drift above the plain to the west. From this area, a prominent ridge of gravel, with semi-morainic aspect, projects southeastward into the valley, nearly to the creek at West Paterson. Below this ridge, the topography of the stratified drift on the right bank of the creek is generally plain, and that on the left bank more irregular, with knolls of fine, stratified gravel.

Stratified drift west of Haledon creek.—A mile northwest of Haledon, the pass between the 623-foot and 643-foot points of Second mountain is occupied by steep-sided hillocks and ridges, which are probably of stratified drift, of kame-type. Small areas or knolls of stratified drift occur at a number of other points just west and north of Haledon. They are, perhaps, to be regarded as a southeasterly extension of the morainic belt north of the Upper Preakness delta.

Still farther west, but still east of the shore line of Lake Passaic, there is stratified drift in the form of kames at the head of the tributary joining the Pompton at Mountain View; a small gravel area on the ridge a mile northeast of Mountain View, on Third mountain, and a small kame on Second mountain north of Singac.

The kames at the head of the tributary joining Pompton river at Mountain View consist of steep-sides ridges with rather smooth slopes. They run out from the highland into the valley, and are prominent features. The gravel of the surface is loose, and bowlders are not lacking. They are not widely separated from the kame-moraine north of the Upper Preakness delta, and perhaps belong with it in time of origin.

The gravel on Third mountain, a mile northeast of Mountain View, is not extensive, and has no distinct topographic form. The gravel is largely of trap. A small kame-like area of drift occurs east of this, near Preakness creek.

Stratified drift in the valley of Peckman brook.—This brook follows the depression between First and Second mountains. In its valley stratified drift is continuous from a point a mile or more south of Verona, to the Passaic river. Above Cedar Grove it is chiefly on the west side of the valley. It is disposed in the form of kames, kame terraces, plains, and possibly deltas, and there are all gradations between these types.

Between the head of the gravel area and Cedar Grove, the kame terrace type prevails. The upper surface of the gravel does not maintain a constant level, but ranges from 440 feet or a little less, to 500 feet, the higher parts being to the northward, near Cedar Grove. At few points in this part of the State is the kame-terrace type of stratified drift better shown. The slope of the terrace indicates drainage to the south, but the evidence is not conclusive that it passed over the low divide at Pleasantdale, or that there was any outlet in this direction. Above Verona there are a number of kames somewhat isolated from the main terrace.

It is probable that the stratified drift of this valley, at least that above Cedar Grove, was deposited while a more or less isolated body of ice lay in the valley, the gravel being deposited between it and the mountain to the west.

At Cedar Grove, the gravel west of the stream rises about 150 feet above its level, to an elevation of 360 feet. There is here a flat-topped ridge, with subordinate parallel ridges of like constitution, of coarse gravel and sand. The form of this body of gravel suggests its deposition in a body of standing water (Peet). Its elevation is about that of Lake Passaic. While the ice still lay against the north end of First mountain, the waters of the lake may have extended up the valley, making a narrow bay. It is also possible that a narrow lake existed in the valley independent of Lake Passaic. Such a lake might have existed when the ice abutted against the ends of both First and Second mountains south of the Passaic. The waters in such a lake, if it existed, should have risen to 392 feet, the level of the divide at Pleasantdale between the head waters of Peckman brook and the Rahway river. Of drainage over this divide into the Rahway there is little evidence.

North of the canal, which crosses the valley of Peckman brook near Little Falls, the topography of the stratified drift assumes a level topography, and merges into the plain of the Passaic. It has an elevation of about 200 feet at the railroad, and declines to 140 feet at the river. The surface has a heavy loam coating, from three to six feet in depth. In the upper part of the plain, the loam overlies gravel, and in the lower part sand.

A number of kames occur in the valley. One lies just south of the canal on the east side of the brook, another half a mile to the northeast, also east of the brook and near the canal, and another on the plain south of Ryle park. Half a mile east of the last, some kames are banked against the slope of the mountain, just east of the canal.

Stratified drift in the vicinity of Paterson.—From the mouth of Haledon brook to the meadows near the head of Newark bay, the Passaic is bordered, generally on both sides, by stratified drift. It is disposed in the form of kames, plains, possibly deltas, and undulatory areas without distinctive topography. The surface of the stratified drift declines down-stream, but not continuously or regularly, and the materials are not always disposed after the manner of river deposits. The shifting position of the edge of the ice while deposition was in progress, will account for some of its irregularities of disposition, but not for all.

On the east side of Haledon brook, near the West Side park, in Paterson, the gravels (associated with some till) above the falls have an undulatory kame-like topography, and are probably connected in origin with the irregularly disposed drift west of the brook, near the County house.

There were formerly several conspicuous kames south of the river in Paterson. Their positions are shown on the old topographic map, sheet 7. One of them was about two blocks west of the Market Street station of the Erie railway; another was north of Market street near the south end of East 18th street; another is east of Vine street and north of Bond, and is partly occupied by Sandy Hill cemetery; and a smaller one lies east of the north end of the last near Market street. The first two of these kames have been removed, and the third is undergoing destruction. North, and east of north of these kames, the till has something of a morainic aspect. These morainic features are perhaps to be associated with those north of the river, east of the lower end of Haledon brook, and are believed to mark a position where the edge of the ice halted for a time in its retreat. These morainic accumulations about Paterson are perhaps contemporaneous with the moraine above the Preakness delta.

The Van Winkle plain.—The Van Winkle plain heads a little north of Van Winkle, at an elevation of about 120 feet, and with a width of about a quarter mile. It widens to the southward, and its surface declines until it joins the Glen Rock plain at Hawthorne. It falls off abruptly from a level of sixty feet to forty feet, just north of the east and west road at Hawthorne. The lower plain has some gentle undulations of surface, which suggest that its origin was similar to that of the more strongly marked undulatory area on the south side of the Passaic; but its topography is not sufficiently distinctive to make it certain that the plain is not of post-glacial origin.

At the head of the Van Winkle plain, there are knolls and ridges of rather compact gravel. Between them and the kames west of Glen Rock, the topography has enough of morainic tendency to suggest a connection between them. The connection, however, is not very distinct.

At Van Winkle, the gravel of the plain is ten to twenty feet above the brook. It is coarse, with cobbles and small bowlders. Half a mile to the south, the material has become notably finer (three-inch pebbles with sand), and the diminution continues to the abrupt south edge.

At the southwest border of the plain at the mill pond, there is an elevation a few feet above the plain where the materials are coarser. This elevation was apparently once continuous with a ridge on the west side of the mill pond.

East and southeast of the mill pond, the surface of the plain is affected by sinks and troughs, ten to fifteen feet deep, which apparently mark the sites of ice masses, buried when the gravel of the plain was deposited. In the depressions and about their margins are bowlders, which otherwise are absent from the surface of the plain.

West of the creek, above the mill pond, there is evidence of the presence of ice masses during the building of the plain. The broad lowland here is thought not to have been developed by the stream, but to owe its origin to the presence of ice when the adjoining plain was building. There are here a series of kame-like knolls twenty to forty feet above the mill pond, and higher than the plain on the east. They rise from the plain along the brook, and except the southernmost, are unchanged by the erosion of the stream. The materials of these ridges are coarser than those of the adjoining plain, and bowlders, absent from the plain except as noted above, are present. These ridges apparently antedate the plain, and were but partly buried during its building. They may be connected in origin with the semi-morainic tract on the highlands to the west. In this immediate vicinity, the brook has accomplished little erosion since the ice disappeared. Farther up stream, however, the stream has lowered its channel fifteen to twenty feet.

Near Hawthorne, where the Erie railroad crosses the eighty-foot contour line, a low, broad, flat-topped ridge of stratified drift extends southeast from the plain. Next to the highland. it merges into the Glen Rock plain. The material of this ridge. or narrow extension of the flat, decreases in size southeastward from its point of departure from the Van Winkle plain. The ridge, or narrow flat, has rather steep sides, and ends abruptly at the ice pond east of Hawthorne. West of the pond and north of the ridge, there is a series of troughs parallel to the ridge which are probably not due to erosion. This ridge, or narrow flat, has some features which suggest its development beneath standing water.

The Glen Rock plain.—This plain heads in deposits of gravel which mark a halting place of the ice in its retreat. At its head, the plain has an elevation of ninety feet. It slopes southwest and south, and joins the Van Winkle plain at an elevation of seventy to eighty feet, half a mile or less north of the Passaic. The material of the plain decreases from moderately coarse gravel (pebbles two to five inches in diameter), near the head of the plain, to fine (largely sand), near its southern terminus. At the northwest the plain does not continue unbrokenly to the highland, but is interrupted by knolls and depressions. The plain falls off abruptly ten to twenty feet on the south and southwest, and the steep slope is thought not to have been produced entirely by erosion, although part of the steep edge is bordered by the alluvial plain of the Passaic river.

The structure of the plain is best shown in a gravel pit near the Ferndale station, where horizontally stratified gravels are seen to a depth of about twenty feet. The materials range up to five inches in diameter, but are mainly less than two. Gneiss and Hudson River sandstone probably make up about one-third each, Triassic sandstone about one-fourth, and quartzites and conglomerates most of the remainder.

Erosion.—While the melting of buried ice masses left some of the lowlands along the brooks flowing through this plain, there are places where the streams have lowered their channels fifteen to twenty feet in post-glacial time.

In the Passaic valley below Paterson.—Between Paterson and Dundee dam, stratified drift has not extensive development along the Passaic, and what there is is somewhat irregularly disposed. On the left bank of the river, north of the Fairlawn road, a ridge rises steeply from the river, which here swings against it. Its surface is till in some places, but gravel and sand in others. Some of the sand is eolian. Undulatory topography, with a suggestion of morainic tendency, continues southward to Bellair, the material being sometimes till and sometimes gravel and sand. West of the river, opposite Bellair, the topography of the till is notably undulatory, of the morainic type, in the 115-foot and the neighboring hills. Similar topography, with stratified drift and till more or less mingled, occurs on the west side of the river, on either side of the N. Y., S. & W. railway, at Dundee lake. On the left bank of the river, above Dundee lake, there is some stratified drift next the river, but it is not continuous, the till locally coming down to the flood plain. Between Dundee lake and Dundee dam, the topography of the stratified drift is rather plane, though not confined to definite levels.

Below Dundee dam, the topography of the stratified drift is undulatory and kame-like on both sides of the river, with a relief of ten to fifteen feet. Undulations of surface, of non-erosion type, reach down to within twenty feet or less of the river. From this point to the bend of the river at Passaic, the topography has little of the kame phase, but while the surface is not rough, the gravel and sand are not confined to definite levels, as would be the case were they deposited by the stream flowing freely. Furthermore, the height of the stratified drift on opposite sides of the stream do not correspond.

Near Garfield, the topography of the stratified drift in the valley again becomes more undulatory, and distinct kames, associated with till knolls and ridges of morainic habit, are found. This topography continues for a short distance south of the Saddle river and up its valley.

For a short distance south of the Saddle river, the topography of the stratified drift along the Passaic is plane, and its materials finer to the southward, but the twenty nine foot area (see topographic map) northeast of Passaic Bridge has irregularities of topography which indicate deposition in the presence of ice, and similar features continue, with interruptions, to the forty six foot hill southwest of West Rutherford. South of this point, the stratified drift on the east side of the valley has a plane topography.

Stratified drift borders the river on the west below Dundee dam, its upper surface having an altitude ranging from sixty eight feet down to thirty, but appearing to follow no law. From the bend of the Passaic, at Passaic, to Delawanna, there is a gravel terrace, with a generally plane surface, though broken by distinct kames south of Passaic bridge.

At Delawanna the gravel spreads out notably to the west. East of the D., L. & W. railway, it has the form of a plain, with a maximum elevation of sixty eight feet. Its south and east faces are steep, falling off abruptly twenty or thirty to sixty feet. The east slope of the plain is probably an erosion slope developed by the Passaic, but the south one may not be. It is enough like a delta to suggest, but not prove, this origin.

Its outline is not lobate, but has rather the curves of a river cliff. It would be interpreted as an erosion slope if there seemed to be any adequate stream at hand. The little creek to the south can hardly be supposed to be the agent of erosion, and the surface of the lower flat is not clearly of post-glacial development. It can hardly be supposed that the Passaic formerly swung west at this point, developing the steep south face of the plain. The material of the plain is rather coarse for delta material, considering the area of the plain and the distance which some of the material must have been carried. On the whole, the evidence that the plain is a delta is slight.

The west slope of the plain is not steep. To the north and northwest it falls off in gentle undulations to an area of mixed gravel and till, extending to the kames near Passaic Bridge. At the southwest, the plain ends rather abruptly at the border of the lowland along the brook.

The surface of the plain is broken by remarkable depressions, some of which are forty to fifty feet deep.

The material of the plain is chiefly coarse gravel, somewhat finer to the south than to the north. Till comes close to the surface at some points, suggesting that an irregular till surface was buried by the gravel. The gravel and sand are said to exceed 108 feet (the depth of a boring) in depth. The base of the stratified drift is, therefore, more than forty feet below sea level. The material of the plain was chiefly derived from the Triassic sandstone.

At the north edge of this plain, in the valley of the little creek joining the Passaic half a mile or more below Passaic bridge, a clay pit was once opened at an elevation of between ten and twenty feet. At the surface there are several feet of coarse gravel of the red sandstone type. Beneath the gravel, eight to ten feet of laminated clay, of the same type as that below Hackensack, is exposed. The upper part of it, to the depth of six or eight feet, is yellow, and the lower part blue. The thickness of the clay is said to be thirteen feet. Its bottom is, therefore, near sea level. The clay carries no stony material, so far as seen, and shows some faulting. This is the only laminated clay which has been seen in the lower part of the Passaic valley. The clay here appears to go back under the Delawanna plain.

South of the steep face of the Delawanna plain, the stratified drift has a nearly level surface at about forty feet. The lower plain is chiefly of sand, to the depth of twenty feet, at least. The plain continues southward as a terrace a short distance below Third river, with an elevation of thirty to forty feet, its surface being affected by some undulations. A lower terrace, a post-glacial alluvial plain, is also present at this point, and extends south below the old Newark Water works. Below this point, there is a narrow belt of gravel, chiefly below forty feet, down to the bend of the river at Newark.

North of the D., L. & W. railway, and south of the lower part of Second river, stratified drift and till are mingled, so that neither type can be said to prevail below a level of sixty or seventy feet. South of the railway, the gravel declines southward and eastward, but north of that point no aggradation level is made out. The gravel, especially next to the highland, is coarse, sometimes containing bowlders one to two feet in diameter, but it becomes finer eastward and southeastward.

In the southern part of Newark the stratified drift, chiefly sand, spreads out extensively, and underlies the low land on which the eastern part of the city is built. It connects southward along the border of the meadows with the Waverley-Union gravel belt to be described later.

From the latitude of the old Newark Water works down to Harrison, there is little stratified drift on the left bank of the Passaic. In Harrison, stratified drift occupies most of the surface below twenty feet, and till and stratified drift are mingled up to somewhat higher levels. The drift here has a morainic phase. In the south part of Harrison, stratified drift occupies most of the surface below twenty feet, but above this level, especially between the twenty and the forty foot contours, stratified drift and till are more or less mixed. The topography here is somewhat morainic, but the tops of the hillocks come to about a common level. The surface is frequently covered with yellow loam two feet or so in depth, overlying both gravel and till. Even where till lies at the surface, or beneath the loam, it is usually thin, and beneath it is stratified sand and gravel.

Deltas near Clifton and Athenia.—West of Clifton and east of Athenia there is a body of stratified drift which is worthy of especial note.

North and northwest of Clifton, the topography of the drift has a semi-morainic aspect. The same is true, to some extent, just east of the railway, west of the village. The village itself stands on lower land, mostly below eighty feet. West of the village, the surface rises somewhat promptly to 130 feet. Where this abrupt rise from the lower level to the higher takes place, the drift is stratified. The belt of stratified drift between the till and the steep slope above the Clifton flat is generally no more than a few rods wide. The flat below the steep slope is not the result of post-glacial erosion, as its topography and general field relations show.

The striking feature of this body of stratified drift is its abrupt eastward front. To the west it grades into drift of semi-morainic aspect, without abrupt topographic break. The abrupt eastward front of stratified drift has been modified somewhat by excavations, but still preserves some suggestion of lobation. This is shown on both sides of the road leading from Clifton to Athenia.

Just east of the station of Athenia, the stratified drift falls off in an abrupt front, which, at more than one point, appears to have the characteristics of a delta. To the west, the stratified drift grades back topographically into till; that is, the till to the west, passes into stratified drift to the east, and still farther east the stratified drift ends in a slope which has the appearance of being a delta front. The surface of the stratified drift is plane, and is sharply separated from the till hills to the east. The distinctive features of the topography are not brought out by the topographic map.

The disposition and the configuration of the stratified drift at these points leaves little doubt as to its delta origin. The altitude of the delta-like fronts is 120 to 130 feet.

If these bodies of stratified drift be really deltas, it means that standing water existed at these levels as the ice melted, the position of the edge of the ice not remaining constant sufficiently long for the deltas to become extensive. It is not easy to see how a local body of water could have existed in this situation. The alternative, if the apparent deltas be really such, is to suppose that the land was submerged to the extent of 120 or 130 feet as the ice receded. On the whole, this seems to be the most satisfactory explanation of these bodies of stratified drift (see p. 508).

Stratified drift in the valley of Third river.—North of Bloomfield, east of Third river and west of the canal, there is an area of stratified drift, which may be regarded as the head of the plain of stratified drift which extends south through Bloomfield. Its surface is undulatory, and somewhat higher than that of the plain to the south, and is loam covered. To the north, the stratified drift passes into till of morainic habit, with no sharp line of demarkation. In the loop of Third river, northeast of Bloomfield, stratified drift and till are mingled, with semi-morainic habit. Morainic topography, with drift which is partly stratified and partly till, also occurs north of the river half way between Bloomfield and Nutley, and between Second and Third river, a mile east of Bloomfield. Locally, the moraine topography is pronounced.

East of this morainic area, gravel continues down the valley of Third river to Franklin and below, where it becomes continuous with that of the Delawanna plain. Along the valley, it is in the form of a narrow, discontinuous, and often ill-marked terrace. Just east of the moraine areas there is an ill-developed terrace at an elevation of about 110 feet. Below this upper bench, there is a lower terrace a few hundred feet wide, with an elevation of about ninety feet. This level is maintained for a mile or so down-stream, and then falls off to seventy feet. On the opposite or right bank, there is a narrow, discontinuous terrace commencing on the north side of the morainic area east of Bloomfield, at an elevation of 110 feet. It continues at approximately that level for a third of a mile, and then disappears. Two-thirds of a mile farther down the stream a terrace appears at an elevation of ninety feet. Its surface is clayey to the depth of a few feet, but the body of the material below is gravel and sand. A mile farther down stream, a gravel and sand terrace occurs at an elevation of eighty feet. It declines to seventy feet opposite Franklin, east of which it joins an extended gravel area which includes the Delawanna gravel plain already noted.

Stratified drift in the valley of Second river, and its tributaries. —The stratified drift of this valley includes a number of kames, and considerable areas of gravel and sand, which have a nearly plane topography. There is a small area of kames at the cemetery in Orange, just north of the Orange station of the N. Y. & G. L. railway (Orange branch). The area is about a quarter of a mile in diameter, and is composed of several hillocks. The topography has been somewhat modified artificially, but the hillocks are twenty to forty feet above their surroundings. They are surrounded on all sides by stratified drift with a nearly plane topography. The surrounding plain is in places covered with clay.

A fourth of a mile north of the kames there is something of morainic suggestion in the topography, and the material is till. There is a similar suggestion a fourth of a mile west of the kames, at the foot of the mountain, from Llewellyn park nearly to West Orange, and again west of Wigwam brook. north of Llewellyn. The kames referred to, therefore, are a part of a considerable belt, which has such a topography as to indicate that its drift was accumulated at or near the edge of the ice. while the latter was stationary or nearly so.

Half a mile or so east of the kame area at the Orange cemetery, and about an equal distance west of Watsessing, there is an area of stratified drift of kame tendency. There are some well-marked hillocks and hollows, which in some cases, are elongate. This area of kame habit is surrounded by stratified drift of plane topography. The numerous exposures made by excavations for sand show a surface coating, often several feet deep (two to eight), of loamy material, which shows little sign of stratification, but the body of the gravel and sand below are distinctly stratified. Bowlders, even large ones, are of occasional occurrence on the surface, though not abundant.

Half a mile or so east of Bloomfield, between Second and Third rivers, there is an area of morainic habit. Some of the hillocks are kames, though the material of the area is by no means all stratified. The area centers about the 129-foot hill shown on the topographic map, and has a diameter of about three-fourths of a mile in either direction. Similar morainic patches occur south of Second river, at Forest Hill, south of Soho. West of the canal, near Soho, there is (or was) a pronounced kame, now largely destroyed by excavations. About Silver lake, southwest of Forest Hill and the kame just mentioned, there is some stratified drift disposed like an overwash plain. The maximum elevation of the undulatory belt is 189 feet, half a mile northeast of Bloomfield. From this the surface of the plain ranges down to the level of Third river.

The kame and the morainic patches in the vicinity of Bloomfield were probably developed at or near the edge of the ice at about the same time. They were probably essentially contemporaneous with the morainic or semi-morainic patches about Woodside and Riverside, where knolls, partly of till and partly of stratified drift, occur, and with the drift of morainic habit at Harrison. The exact contemporaneity of all these moraine deposits cannot, however, be affirmed.

A single kame-like hillock occurs a quarter of a mile south of the East Orange station of the Orange branch of the N. Y. & G. L. railway. It is about twenty feet in height. An exposure at its northeast end shows three feet of till over four feet of sand.

Silver lake gravel plain.—This plain extends from Second river, west of Soho, southwest to a point about a quarter of a mile south of the N. Y. & G. L. railway (Orange branch), a distance of about a mile. Its east-west extent is hardly less. Near Second river its altitude is about 110 feet. It rises toward the kame a fourth of a mile southwest of Soho, where it has an elevation of about 120 feet, and thence declines southward. Along the west side, north of the Orange branch of the railway, its surface is broken by some shallow depressions, and farther south it is sometimes slightly undulatory, though its surface is generally plane. The material is coarser to the north than to the south. Near its southwestern edge, exposures along the railroad show sand overlain by yellow loam to the depth of two feet. This loam is also found in spots in the northern portion of the plain, but it is not continuous. Bowlders are not wholly lacking on the plain, and are more abundant on its western margin than elsewhere.

The depth of drift in this plain, so far as shown by information at hand, is greater in the northern part than in the southern. In the former position, wells twenty-five and thirty feet in depth do not reach the bottom of the stratified material, while near the southern margin, rock is known to be no more than ten feet from the surface at some points.

Bloomfield gravel plain.—This plain extends from Third river, north of Bloomfield, to Second river. It has a length of a mile and a quarter in a north-south direction, and a width ranging from a quarter of a mile, to one and a quarter miles. Its topography is generally plane. At the north, its altitude is about 140 feet, and the west margin of the plain follows that contour from Second river to the D., L. & W. railway. Farther south, gravel appears a little higher on the slope, in a bench which probably antedates the plain.

At Second river, the altitude of the plain is 100 to 110 feet, and its slope is, therefore, southward. Near the north end of the plain its material is compact and till-like at the surface, but gravelly beneath. Farther south the material is finer. A gravel pit half a block north of Second river, and a block west of the canal formerly showed about twenty feet of gravel and sand overlain by a thin layer of loam. Beneath the loam there is six to eight feet of coarse gravel, with indistinct stratification. This in turn is underlain by ten to eleven feet of stratified sand and gravel.

The depth of the drift in the plain is known to vary from five feet near Third river at the north, to thirty-nine feet at the D., L. & W. railway station at Bloomfield. In the northeastern part of Bloomfield, the depth of the sand and gravel is twenty to twenty-five feet, so far as shown by known data. West of the canal, and three blocks north of Second river, the stratified drift is sixteen feet deep.

POST-GLACIAL EROSION IN THE VALLEY OF THE PASSAIC BELOW LITTLE FALLS.

The amount of post-glacial erosion in the Passaic valley has been variable, but generally not great. There has been considerable erosion at Little Falls and Paterson, in each case below the falls. At Little Falls, the channel has been lowered about forty feet in post-glacial time, largely in trap.[1] Except at Totowa, the river has lowered its channel but a few feet in post-glacial time between Ryle Park and Paterson.

Midway between Little Falls and West Paterson, near Totowa, the river, which is flowing northwest, makes a sharp turn to the southeast, and then, half a mile beyond, makes a sharp turn to the left, resuming its northeasterly direction. These turns are about two enormous kames, which are built, like a dam, almost across the valley. At the second bend, the river flows around the southeastern end of this dam in a narrow valley between the drift and the trap of First mountain. Examination of the valley at this point indicates that while the drift never completely filled it, its bottom was built to some considerable height above the present channel. The amount of post-glacial cutting here is probably not less than fifty feet, and may be as much as ninety feet. At no other point in its course has the channel been lowered so much by post-glacial erosion.

From Haledon avenue in Paterson to the Fairlawn road, the amount of post-glacial erosion (vertical) varies from eight to twenty feet. At Dundee lake, above the dam, it ranges from ten to twenty feet (Peet); below the dam, twenty to thirty feet; in the northern part of Garfield, less than twenty feet. In Passaic, and south of the mouth of the Saddle river, it does not generally exceed twenty feet, and locally is not more than half that amount. North of Passaic Bridge, it is less than thirty feet, but probably

[1] Report of the State Geologist for 1893, p. 301.

not less than twenty feet. From Passaic Bridge to the north side of the Delawanna gravel plain, it may be ten to fifteen feet in places, and from the Delawanna gravel plain to Lyndhurst, it may be locally forty to sixty feet, though there is no certain evidence of so much. From Lyndhurst to the old Newark water-works, the lowering of the channel has been slight, perhaps ten to fifteen feet. From this point to the meadows at Newark, the average is probably not more than ten feet, though the banks here have been so much changed by human agencies, that determinations are not now possible.

STRATIFIED DRIFT IN THE UPPER PASSAIC BASIN.

There is a large amount of stratified drift in the upper basin of the Passaic, much of which is connected in origin with the lake which formerly occupied this basin. The history of this lake has already been published,[1] and in connection with it, an account was given of much of the stratified drift developed about its shores. Apart from the shore gravels, which are disposed largely as deltas, there are numerous kames within the area of the Upper Passaic basin, two considerable eskers, and considerable areas of stratified drift which are not readily classified.

In addition to the stratified drift which appears at the surface, there is a large body of stratified drift intimately associated with the till. Few considerable vertical sections of drift where stratified drift does not appear, are known in this region.

The stratified drift deposited about the shores of Lake Passaic has its most extensive development west and southwest of Parsippany, east of Boonton, about Caldwell, and above Preakness, though distinct deltas are found at some other points, especially northeast of Montville.

There are extensive areas of stratified drift over the low lands southeast of Great Piece meadows, and along the Rockaway river for some miles above its junction with the Passaic. There is also a very considerable belt of stratified drift between Madison and Hanover Neck, though the sand and gravel here are not always well differentiated from the till.

---

[1]Annual Report for 1893. See also pp. 151-158 of this report.

In addition to the sand and gravel, there is some lacustrine clay in the basin of the Upper Passaic. Such clay underlies the meadows to some extent, and extends somewhat above their borders over the adjacent low lands.

North of the Passaic, laminated clay occurs north of Little Falls, and underlies part of the plain along the lower course of the Pompton, as already noted. At various other points in the basin, thin layers of clay are interbedded with sand.

The clay about Wayne and Little Falls was deposited in Lake Passaic while the ice edge lay not far to the north, and while glacial waters still flowed into the lake. The clays of the meadows and the extreme low lands were partly, and perhaps chiefly, deposited after the main part of Lake Pasasic was drained, but while small shallow bodies of water still lingered in the Upper Passaic basin (see Plate XLII).

Stratified Drift Deposited along the Shores of Lake Passaic.

1. *Between Morristown and Littleton.*—During the lake period, the high hill midway between Littleton and Morristown formed the northern headland of a curving bay a mile in width. At the head of this bay is a small, wave-built terrace, sloping gently to the southeast, and connected with higher ground to the northwest. A few hundred yards east of this terrace is a spit 200 yards long, forty yards wide at its free end, but increasing in width northward to its junction with a wave-built terrace, which rapidly passes into the wave-cut terrace at the south end of the hill.

The spit rises eighteen or twenty feet above the low ground around it. At its free end, the height of its surface is 369 feet. This increases to 378 feet at its upper limit. This spit, which is on the property of John Pearson, furnishes much gravel for use on the roads. The material, as is the case in all the constructional shore features of this half of the lake, is glacial sand and gravel.

2. Just west of the three corners, half a mile south of Littleton, is a flat-topped spur of sand and fine gravel, having an ele-

vation of 382 feet. Its form strongly suggests a lacustrine origin. Its height, and its close association with the wave-cut terrace along the side of the hill to the southeast, gives weight to the suggestion. The association of these two spits with the wave-cut terrace, the first at its souhtwestern end and the second near its northern end, is a characteristic combination of shore phenomena.

3. A mile northeast of Littleton, along the road to Boonton, is a gently-undulating plain of sand and gravel, containing some bowlders, and passing, at its upper edge, into the moraine. The elevation of this plain is about 380 to 385 feet, and although its form does not point positively to a lacustrine origin, it seems most probable that it is the result of the combined cutting and building action of the waves working upon stratified drift. Towards the northeast, this plain merges into a broad, flat-topped, spit-like ridge of gravel and sand, over a mile in length. Its crest is followed to its end by the road to Parsippany and Boonton. Where the road to Tabor turns off from the Boonton road, the ridge is broken by a gap which does not appear to be due to erosion subsequent to the development of the ridge, but to lack of development at this point. The average height of the part connected with the terrace is 360 to 370 feet, while that of the isolated portion is ten feet higher. In front and beyond the distal end of the isolated portion, there is a lower terrace, about 350 feet in height, or eighteen to twenty feet lower than the higher ridge at this point. In view of the fact that this ridge is many times larger than any well-defined spit in the lake basin, and in view of the fact that it is interrupted by a gap across which material could not have been transported by waves and littoral currents, it is not probable that this ridge is a spit. It does not seem to have been due primarily to lake agencies. It may, however, well represent a ridge or kame, or line of kames, more or less re-shaped by the waves. Unfortunately, the structure is nowhere well exposed, so that this hypothesis could not be tested.

In all the preceding cases, the gravel and sand are chiefly of materials derived from the Highlands.

Between Littleton and Boonton.—A mile north of Parsippany there is a gently-sloping, slightly-undulatory plain of sand and gravel, having an area of a quarter of a square mile. It has the lobate margin, steep front and re-entrant angles, characteristic of a glacial delta, *i. e.*, of a delta formed in standing water in immediate connection with the ice, the detritus being supplied by a glacier stream. The lobes of this delta rise abruptly thirty feet above the lower land to the south and west. Northward the plain passes into an irregular kame area, the site of which was occupied by the ice during the formation of the delta. To the south there are a number of large kames, which were probably formed before the ice had retreated to the kames north of the plain, and which, therefore, antedate the plain. The southern border of the plain seems to have grown out so as to encroach on the nearest of these kames. The general level of the plain is 396 feet. The ends of the lobes vary from 390 to 394 feet. From these figures the water-level would appear to have been about 394 or 395 feet. The kames south of the plain must, therefore, have all been submerged during the maximum lake stage. On some of them, traces of terraces at about 362 feet were observed, although they were not very definite.

Between Boonton and Montville.—Between Boonton and Montville, southeast of the canal, there is another glacial delta having an average width of three-eighths to one-half a mile, and a length of two miles. The surface is gently undulatory but perhaps not more so than is possible for a plain built in immediate connection with the ice front by a number of streams of varying velocities and volumes. The ice, too, may have co-operated, at least passively. The height of the outer margin of the plain at the top of the steep frontal slope varies between 381 feet and 399 feet, with variations of ten or twelve feet within thirty rods or less. In general, however, there is a rise of the margin towards the northeast. The general level of the plain is less than 400 feet, and the water-level, so nearly as it can now be determined, was at a level which is now about 394 or 395 feet at the Boonton end, and probably a little less than 399 feet at the Montville end. Towards the upper limits of the plain, near the canal, bowlders become more numerous and the surface is more irregular. Patches of till are also present, apparently indicating that the ice lay on the higher ground to the northwest during the formation of this delta plain. If this were the case, the general slope of the surface of the plain would be away from the ice towards the lake, and the internal structure should have a lakeward dip.

A single small sand and gravel pit was found on the Boonton plain, which showed that the beds at that point dipped northward, nearly opposite to the direction which would have been expected, if the plain was built from the northwest as supposed. But it is not safe to assume that this is the normal dip for all the beds, or indeed that it is the usual direction of dip. Particularly is this true since other features of the plain, for example, its surface slope and its lobate margin, and the unmistakable structure of neighboring plains, all agree in pointing to the conclusion that the ice lay on the high land to the northwest, and that the plains were built from the edge of the ice outward into the lake. The difficulty presented by the direction of the dip at the observed exposure may be met hypothetically as follows: If the plain was built around and over a number of pre-existent kames, its surface might be more or less hummocky provided the kames were not completely buried. In this case the internal structure of the plain might be more or less confused and discordant, as the material was washed irregularly into the depressions between the kames. Besides this, the beds of a kame might dip steeply in a direction opposite to the general dip of the beds of the delta plain proper, and a single small excavation might reveal only the kame beds. From such an exposure it might seem that the plain had been built towards the highland, after the manner of a terrace formed in the angle between the side of a valley and stagnant ice occupying the low ground, even though this was not the fact. If this were the case, the general dip of the beds would be towards the original hillside, if the material was derived from the melting ice.

The lobate front of the Boonton delta plain is well developed, the projecting lobes being sharply defined, falling off steeply fifty to seventy feet. The re-entrant angles also are clearly marked. Post-lacustrine erosion has in some cases undoubtedly increased their distinctness, but at many points they seem to preserve essentially their primitive forms. Along much of the front of this delta plain, there is a lower terrace, the height of which is about 320 feet (hand-level). At various other points along the lake margin, a series of terraces about seventy feet below the maximum shore line have been observed. These are thought to have been developed during the time when the level of the water in the lake was about seventy feet lower than at epochs preceding and succeeding.[1]

Northeast of Montville.—Just north of Montville there is a good example of a glacial delta. It is represented in contour in Figure B, Plate XXXIV. Its area is about a quarter of a square mile. Its surface is nearly flat save for an occasional shallow, saucer-like depression, and a gentle slope from north to south. Its distinctly-marked lobes rise seventy to ninety feet above the irregular kame areas toward the south. The D., L. & W. railway skirts its southern edge at the foot of the lobes, cutting directly across the end of the southernmost projection. The upper fifty feet of this section shows cross-bedded sand and gravel dipping towards the end (south) and sides of the lobe. This exposure is so large that there is no hesitation felt in asserting that this lobe, and the delta of which it was a part, were built from the north. Beneath this fifty feet of gravel is one to six feet of clay and fine sand. The laminæ of the clay are thin, one-eighth to one-sixteenth of an inch in thickness, and separated by thin, sandy partings. As seen in section, the clay and sand layers are horizontal, but they may have a slight southward dip. To all appearances, the clay is exactly similar to that found at numerous low places in the lake basin, and regarded as undoubtedly lacustrine. Towards the sides of the lobe, the clay layer is succeeded by coarse sand and gravel stratified parallel to the side slope of the present surface. Beneath the clay there is more sand and gravel, the fine sand being stratified horizontally, the coarse materials irregularly bedded, as in a kame. The coarse, irregularly-bedded gravels probably represent a kame,

---

[1] Report of 1893, p. 318.

around and over which were deposited the finer materials supplied by the glacial drainage which entered the lake half or three-quarters of a mile to the north. In time, the margin of the lake was so filled up by the coarser materials deposited nearer shore, that the streams came to drop their coarse material farther out, on the top of the fine deposits, made at an earlier time. Since there are no stratified deposits on the slope of the hill north of the delta plain, and since the slope of this hill shows no signs of river channels cut in the till, it is concluded that the streams which built this delta must have been short, and that the edge of the ice must have been very near the head of the plain.

Fig. 76.

The Montville glacial delta. Drawn from a photograph.

The heights of the margins of the different lobes vary from 388 to 395 feet, and the plain ascends gradually to a height little above 400 feet. The water-level seems to have been about 397 or 398 feet. On one of the lobes there is a faint indication of a terrace at about 325 feet, but no corresponding signs were found on the others.

Across the road just west of the northern end of this plain, there is a small lobe whose height corresponds very closely with that of the larger plain. This may properly be considered as a part of the larger plain, isolated in construction, and separated still more by erosion. Figure 76 is a sketch of this delta drawn from a photograph taken from a hill three-quarters of a mile to the southeast.

2 Half a mile northeast of the Montville delta is a small and not very well-defined terrace, which may have been built in standing water. It is more or less kame-like in places, and its origin is not certain. If it is to be referred to the lake, which may be fairly questioned, it seems to indicate a stand of the water at about 370 to 380 feet. There is also a faint indication of a terrace on the northeastern side of the Montville delta, at about the same level.

3. With the above exceptions there are no traces of shore lines in the first two miles northeast of the Montville delta, but at the three road corners a mile and three-quarters north of Whitehall, there is a small and well-formed glacial delta, represented in contour by Figure A, Plate XXXIV. This may be called the Jacksonville delta, from its proximity to the Jacksonville schoolhouse. In some respects this delta is the most significant in the lake basin. The top has very little slope until the brow of the lobes is reached, where there is a sudden change, and on the south an abrupt fall of fifty feet. Northward, towards the head, the surface becomes slightly undulatory, and at length breaks up into low kames north of the sink represented in the figure. The northern margin of the delta plain is marked by wide re-entrants, between which are narrow, cusp-like lobes of gravel and sand. The slopes are kame-like and bowlder-strewn. The limit of the bowlders towards the front of the delta is nearly coincident with the limit of the undulations of the surface, although an occasional bowlder is found on the plain proper. The topography of the head of the delta makes it clear that the ice stood at this point while the delta was being formed, and that when the ice melted, the head of the delta was left unsupported, and the sand and gravel slipped and settled down irregularly.

It is only for a narrow strip on the northwest side that the delta abuts against higher ground. Directly south of the delta front are a number of kames which just escaped burial beneath the advancing delta.

The heights of the crests of the different lobes are 408, 407, 406 and 398 feet, the lowest lobe being as clearly and sharply defined as the higher ones. The general level of the plain is about 410 feet, and the height of water must have been between 408 and 410 feet. No lower terraces were found on the slopes of this plain nor on the slopes of the neighboring kames.

4. A mile southwest of the intersection of the N. Y. & G. L. railway with the N. Y., S. & W., near Pompton, there is a striking sand and gravel terrace built against the steep slope of the highlands. It is traceable for nearly a mile. Its height is between 335 and 340 feet (hand-level), and it rises by steep slope over 100 feet above the level plain to the east. The terrace varies in width from 100 to 150 yards. The face of this terrace is in part lobate, after the manner of the front of a glacial delta. There is, however, some question as to whether this terrace is referable to Lake Passaic. It possesses certain features which make it seem probable that it was formed in the angle between the Highlands and stagnant ice occupying the valley, the material being supplied by the ice. So far as could be determined with a hand-level, its surface, at least in part, slopes gently towards the highlands, whereas, if it had been built out into a lake from the land, the surface slope should be in the other direction. Further than this, the topography of its eastern face strongly suggests, in places, the slipping and settling which would occur by the melting of a supporting wall of ice. Unfortunately, the internal structure is nowhere exposed, and it seems impossible to decide definitely between the two possibilities of origin. The height, 335 to 340 feet, is not very different from that of the faint lower terraces near Boonton and Montville.

5. Half a mile southwest of this terrace, there is a large, isolated kame of coarse sand, gravel and bowlders. On the east side, about forty feet below the summit, at an elevation of about 340 feet, is a narrow, wave-cut (?) bench, which at the south end of the hill passes into a short, narrow, flat-topped, steep-sided, spit-like ridge. The fact that this bench and spit are probably due to wave action would seem to make it probable that the terraces nearer to Pompton are also to be connected with the lake.

North of Pompton no traces of shore lines were observed, nor were any seen upon the trap hills on the east side of the Pompton plains. This was to be expected, since by the time the ice had melted back as far as Pompton, the outlet at Paterson was probably open.

The gravel deposited along the shores of Lake Passaic in all these situations is chiefly of gneissic origin.

On and near Second mountain.—Shore features are not so well developed on the eastern shore of Lake Passaic as on the western, but there are enough to make it possible to fix the position of the shore line with some accuracy.

1. At Upper Preakness is the largest and most typical glacial delta plain found within the lake area. Its surface is nearly flat. Its margin is strongly lobate, falling off abruptly fifty to fifty-five feet. Its area is about a square mile. Its altitude at its front is from 330 to 335 feet, from which elevation its surface rises gradually for nearly a mile, to 360 feet. To the northwest, the plain abuts against a strongly-marked kame area, the knolls of which rise to 420 feet. On the northeastern side, the plain falls off abruptly eighty feet, to a swamp. The margin here presents, to a slight degree, the steep and billowy appearance characteristic of deposits built against an irregular ice front. The material of which the plain is built varies from fine sand to coarse gravel and cobbles. Bowlders are uncommon, or altogether wanting.

Just north of this delta plain is a moraine-like kame belt, half a mile in width. The hillocks are of coarse material, and in general thickly strewn with bowlders. While the Upper Preakness delta was being built by glacial streams which flowed into a lake whose waters stood at a height of between 335 and 340 feet, the kame belt seems to have been forming just beneath and at the irregular margin of the ice. A large ice mass perhaps occupied the area of the swamp just north of the plain.

2. North of the kame belt is another but more irregular plain of sand and gravel. While it was probably not fashioned entirely beneath water, and perhaps not principally, its surface still seems to have been more or less modified by the action of standing water. But this is not beyond question. To have extended over it, Lake Passaic must have had an elevation of about 412 feet. The surface of this plain is not strewn with bowlders, and in this respect it is in marked contrast with the half-buried moraine-like

kames which, near its southern margin, rise above its surface. The evenness of the surface of the plain is further broken by numerous sinks and hollows, which may find a partial explanation in the unequal settling of the sand and gravel, due to the melting of blocks of ice incorporated in the sand and gravel of the plain during their deposition. The height of this plain accords with the height of the Jacksonville delta, while that of the Upper Preakness plain corresponds to that of the terraces near Pompton, and the lower benches near Boonton and Montville. The relationship of the 412-foot plain to the moraine-like kame area on its outer margin, is such as to strongly suggest that it was formed after the lower plain at Upper Preakness.

3. On the slope of Second mountain, one and a half miles west of Haledon, there are terraces at two levels, the upper marking a water stage of about 405 feet, and the lower, one of about 340 feet. In places the lobate delta margin is well developed, falling off steeply thirty to forty feet. These terrace plains are closely associated with kames, some of which rise steeply above the surface of the plain, while others are partially buried near the outer part of the plain. The surface of the kames is marked by many bowlders, whereas they are rare on the surface of the terraces. The terraces are composed of sand and fine gravel. At this point there seems to have been a kame area, probably formed beneath the ice or at its immediate border, and afterwards partly buried by the sand and gravel of a glacial delta, formed when the ice had retreated a short distance from the kames. Both here and above Upper Preakness, the kames have the morainic habit.

Traces of the higher plain were noted between the kames farther north toward the higher plain north of Upper Preakness, but they are not distinct.

4. There are no shore lines along the trap ridge between the terraces west of Haledon, and Caldwell, a distance of seven miles, unless a small, spit-like form half a mile north of Cedar Grove, having an elevation of 375 feet, is to be regarded as such. In the vicinity of Caldwell there is a somewhat extensive sand and gravel plain, whose evenness and regularity are more or less interrupted by kames and ravines. Those kame hillocks whose summits are of about the same height as the plain are somewhat

flattened, as if more or less truncated by the waves. The plain is well developed near the school-house and cemetery of Caldwell, where its height is 385 to 387 feet. It rises towards the east being about 410 feet at the Presbyterian church, half a mile east by south of the school-house. This plain indicates a lake-level of 385 to 390 feet.

In front (northwest) of the school-house and cemetery, the higher terrace falls off somewhat abruptly to a lower one, whose average height is about 363 feet, and whose width is from 150 to 200 yards. Half a mile north by west of the church, this lower terrace is better developed, its outer edge being about 358 feet in altitude, and its upper margin 369 feet. Above, there is an indistinct bench at an elevation of about 400 feet. In front of the school-house, the outer margin of the lower terrace is more or less delta-like, and falls off steeply forty or fifty feet.

The higher plain (about 393 feet) about Essex Fells, a mile southwest of Caldwell, is a continuation of the upper part of the school-house level, while the poorly-defined level west of the depot at Essex Fells is about 360 feet high, and appears to correspond to the lower terrace at the school-house. Numerous pits have been opened in the kames about Caldwell, but there are no large exposures showing the structure of the plain surrounding the kames. The thickness of the stratified gravel is very great. A well near the school-house was sunk 120 feet, and one near Essex Fells station 145 feet, neither of them reaching bed rock.

5. A mile south of Roseland a small terrace was noted on the slope of Second mountain. Its height is about 370 feet (hand-level), and it may be wave-built in origin, but no positive assertion can be made to this effect. At one or two other places between Caldwell and Summit, faint traces of what might be wave-built forms have been seen.

On islands in the lake.—1. Near the northern end of the trap hill west of Livingston, which stood as an island in the lake, there is a small deposit of gravel, largely of trap, poorly water-worn and strongly resembling the trap gravel beds of the extra-morainic portion of the basin, save that there is a larger percentage of foreign pebbles. This deposit, which, where exposed, does not exceed five feet in thickness, lies between two hills of trap, incoherent drift, while in the latter, except for the thin coating of residuary material, they beat upon solid rock. Deltas are the most conspicuous intra-morainic shore features. For the formation of deltas outside the moraine there was little opportunity. The largest deltas within the moraine may well have required far less time for their building, than was required for the accumulation of the gravel beds along the trap ridges.

Stratified Drift in the Upper Passaic Basin not Associated with the Shores of Lake Passaic.

The stratified drift of this area was deposited partly while the basin was occupied by ice, partly while it was occupied by the waters of Lake Passaic after the ice had receded, and partly since the draining of the lake. A part of the drift of this general area has already been referred to in connection with the valleys tributary to the Passaic from the north.

In the valley of Preakness creek.—The deltas in this valley have been referred to (p. 653). With them, at slightly higher levels, are associated kames and kame-moraines.

South of the main delta at Upper Preakness, a gravel plain, the surface of which is somewhat broken by undulations, extends south to the Passaic. Its elevation just below the Upper Preakness delta is 260 to 270 feet. In two and a quarter miles it declines to about 190 feet, though swells in the plain rise above this level. Just south of the delta, the material of the plain is gravel, the pebbles of which are three inches or so (average) in diameter, while to the south, the surface material is largely sand. The plain has not a continuous aggradation slope. Some of its surface irregularities are the result of deposits made while the ice occupied the valley, and not buried later by the deposits of lake or river. The lower part of the plain, from Mountain View to Little Falls, is underlain by clay. This was deposited in Lake Passaic at a time when the edge of the ice lay north of the clay, but before the Paterson outlet was opened.

On the flats about Great Piece and Troy meadows, and Hatfield swamp.—Most of the stratified drift in this part of the Passaic basin consists of fine gravel and sand, with which are associated some loam and clay. Most of it lies but little above the level of the Great Piece meadows. The stratified drift of the Passaic valley is here continuous with that of the lower part of the Rockaway valley. Above the flat of sand and fine gravel are kames of coarser material, rising to a maximum height of 30 feet above their surroundings.

At Pine Brook, the upper level of the continuous body of stratified drift has an elevation of about 190 feet, and between that point and Singac (Little Falls), the decline is only about ten feet. The topography is often gently undulatory, with a relief rarely reaching ten feet. The depth of the stratified drift is not known, but shallow excavations at various points show that it frequently exceeds fifteen and twenty feet. Above the general level of the fine sand there are, as at Franklin, occasional areas of compact gravel, which differ in character, and probably in time and mode of origin, from the stratified drift at lower levels.

The stratified drift north of the river at Little Falls is thin, frequently less than ten feet thick, and sometimes rests on the trap rock with no till between. The meadows, Great Piece, Troy and Hatfield, are marshy areas, the surface material of which is primarily organic. With the peat and humus there is some alluvium, so mingled with the organic matter that the two are inseparable. What phase of drift lies beneath the surface peat and alluvium, is not generally known. Stratified drift borders the meadows in some places, and till in others, and the substratum of the flats is doubtless partly till and partly stratified drift. Shallow bodies of water stood over these flats after Lake Passaic was drained, and in them there were probably shallow deposits of silt or clay. Such deposits are known to underlie the organic matter of the meadows locally, and they may be general. Above the lowlands of the Upper Passaic basin there is a good deal of stratified drift disposed partly as kames, partly as eskers, and partly in ill-defined patches which fall into none of the distinct categories of stratified drift.

The Kames of the Upper Passaic Basin.

The Clinton-Fairfield kames.—There are five kames in this group. Two, and perhaps three, of them appear to be older than the gravels and sands of the surrounding plain, by which they are partly buried.

A quarter of a mile southeast of Clinton (the 208-foot hill of the topographic map) there is a kame which, though but twenty to thirty feet above its surroundings, is somewhat conspicuous. It has a length of about a fourth of a mile, and a width of about two-thirds its length. It is composed of gravel and sand, but bowlders are present on the surface.

The 185-foot hill southwest of the above has somewhat the form of a kame, but is ill-defined.

A mile or less northeast of the above is another kame, or kame area, the hillocks of which have a maximum height of twenty to twenty-five feet. The area has a length of half a mile, and a width half as great. Bowlders occur on the surface of the kames, which are composed chiefly of gravel.

Near the Fairfield church there is a small area of weak kame topography, with a relief of less than twenty feet. Its distinctly kame-like parts are two knolls, the materials of which are sand and coarse gravel, in contrast with the finer materials of their surroundings.

The hill about three-fourths of a mile due east of the Fairfield church, having a summit elevation of 187 feet, and rising about fifteen to twenty feet above its surroundings, is also a kame. It is nearly circular, with a diameter of about a fourth of a mile. The topography is undulatory, with slight relief.

Three-fourths of a mile northeast of Fairfield church, a gravel knoll reaches an elevation of 180 to 190 feet. It is not very sharply differentiated from its surroundings, and is but a poorly defined kame.

The Westville-Franklin kames.—Two small kames occur near Westville. The easternmost, a little east of Westville, has an elevation of 250 feet, and is ten to twenty feet above its surroundings. It has a length of little more than one-eighth mile and a width one-half as great. The other is forty feet lower on the slope, and is about half as large as the first. Fifteen feet of stratified gravel and sand were reported here.

West of Franklin there are a number of hillocks which are kames, or which closely simulate them. The most southerly is a low gravel knoll a little north of Pine Brook, and just west of the Westville-Franklin wagon-road. It is bordered on the east by till, and elsewhere by the fine stratified material of the Passaic plain.

Northwest of Franklin there are three hillocks rising above their plane surroundings. While they are believed to be chiefly of stratified drift, one of them, at least, is veneered with till. The easternmost, just west of Franklin, is about a fourth of a mile long and one-half as wide, and fifteen to twenty-five feet high. Its surface, at least locally, is till-coated. Northwest of it is a very small kame, and west of it, less than a mile from Franklin, on the Clifton road, is the largest of them all. Its material is gravel, the upper portion unstratified where exposures show its structure.

Kames on the slope northeast of Franklin.—There are four gravel patches on the east side of the valley northeast of Franklin, which have a kame-like habit, though hardly normal kames. The southernmost is rather more than a mile northeast of Franklin, on the east side of the brook leading down to Long meadow. The gravel is disposed in the form of a low, flat-topped ridge projecting out from the hillside. No exposures occur in it, but it appears to be of gravel, largely trappean.

About an eighth of a mile north of the last, there is a smaller gravel ridge about ten feet high, in similar relations, but without the flat top. Its form is more kame-like. Its surface is bowlder-strewn, but indicates that it is composed of gravel and sand.

A fourth of a mile north of the above is a kame twenty feet high. Its longer diameter is one-eighth of a mile, and its width is half its length. Its surface is likewise bowlder-strewn, but otherwise it is composed of gravel and sand.

A mile northeast of the last, and less than a mile from the Passaic at the mouth of Deepavaal brook, is another similar, though larger area of gravel. It reaches a maximum elevation of about 210 feet, and has a length of nearly a fourth of a mile, and a width about half as great. Its topography is undulatory, with slight relief. More than half the stony material is red sandstone and shale, but trap, gneiss, and conglomerate, etc., are all present.

About Caldwell and Livingston.—About Caldwell there are considerable bodies of stratified drift which were deposited along the shore of Lake Passaic. Along with the shore gravels are some kames, notably half a mile southwest of the village.

Kames also occur about Livingston, especially just east of the village, where marked depressions accompany the hillocks, the combination giving the topography a morainic aspect. There is some intermingling of unstratified drift with the stratified, as is common when the topography assumes a morainic phase.

Kames in the vicinity of Hanover.—There are a number of kames, or kame-like hillocks, in the body of stratified drift between Hanover and Hanover Neck. They differ from the sand and gravel with which they are associated only in that they are hillocks. The 287 and the 264 foot hills (see topographic map) west of the road between Hanover and Swinefield Bridge, are the most conspicuous of the kames, but there are a number of smaller ones in the vicinity.

Still other kames occur north of Chatham, and just south of the meadows bordering the Passaic.

Kames about the Troy meadows.—Kame areas of peculiar development and relations have considerable extent in the valley of the Rockaway river, in and north of the Troy meadows. Similar kames occur outside the moraine, about Green Village and beyond.

In the Rockaway valley, the kames occupy the bottom of the valley even down to the present flood plain of the river. Since they were made, the river seems not to have lowered its channel by any considerable amount. The Rockaway valley kame area begins just east of the point where the river turns to the south, two miles northeast of Old Boonton. Its development is here weak. The kame-like character is better shown a little farther south, along the road leading in a westerly direction from Horse Neck bridge. The hillocks are confined to a belt about half a mile wide on the east side of the river. West of the Horse Neck bridge, the kame-like hillocks have a tendency to elongation in a north-south direction. Where the river bears to the east, northwest of Pine Brook, the kame-belt preserves its north-south course, and appears on the west side of the river. The topography is here striking. While the hillocks are not high, or the intervening hollows deep, both are clearly defined and follow each other in quick succession. The depressions are frequently occupied by ponds or peat-bogs. Throughout the area, the kames are, on the whole, small. Many of them are mere mounds, no more than five feet or ten feet in height. The depressions are, locally, as striking as the hillocks. In constitution, the surface material at least, is predominantly sand. With it is associated fine gravel, the pebbles rarely being an inch in diameter, but they are frequently more than half that size, too large to be referable to the wind. Bowlders are, for the most part, wanting, as are also cobble stones.

Northeast of Pine Brook, on the southeast border of the Great Piece meadows between Clinton and Fairfield, the surface presents, in subdued form, many of the same characteristics as those of the area just described; but the depressions are here quite as marked as the hillocks. Here, too, fine sand predominates, but small pebbles are occasionally found. The undulations of the surface are, perhaps, too gentle to allow the area to be characterized as a kame area, but contrasted with the area along the Rockaway, its differences are of degree and not of kind. In both regions the areas under consideration are low, scarcely above the river level, and they are in such close proximity as to make their mention in the same connection seem proper.

No satisfactory explanation of these remarkable kame areas has suggested itself. All of them are along low drainage lines, and manifestly connected with glacial drainage, but the exact mode of their origin seems to be somewhat different from that of typical kames. Perhaps their relationship is with pitted plains rather than with normal kames. This seems to be especially true of the kame area southwest of Madison.

The absence of strictly glacier-deposited material from the surface parts of the kame area of the Rockaway valley seems to indicate that active glacier ice had entirely withdrawn from the valley at this point before the kames were made. The fact that they were neither worn away nor buried seems to indicate that no great body of glacial waters poured through the valley subsequent to their formation, since the passage of a flooded stream would have accomplished either one result or the other. On the other hand, the explanation of their topography seems to require at least the passive assistance of ice, though perhaps not of strictly glacier ice.

The Montville kames.—East of Montville and south of the D., L. & W. railway is a well-developed area of kames. The more or less separate kames are high and conspicuous. They are composed of gravel and sand, well exposed in numerous pits, but bowlders are not wanting. Much of the gravel is well rounded. These kames lie just north of the Rockaway valley kame area, and may, perhaps, be looked upon as the northern terminus of the same, or as their head.

Near Whitehall.—The 243-foot hill (see topographic map) northwest of the railroad station at Whitehall has smooth contours, and is elongated in a northwest-southeast direction. It is about thirty feet above its surroundings. No good exposures occur in it, and the surface material is heavy loam. It is, however, said to be composed of gravel, and belongs to the kame category.

The 286-foot hill just east of the above is an elongated crescent-shaped kame, rising up promptly about seventy-five feet above its surroundings. The hill just south of it is a part of the same kame group.

Associated with the kames mentioned above, there is gravel and sand with a generally level topography but with some undulations. It is considerably above the level of the gravel plain of the Pompton river, and is probably connected with the kames, rather than with the river plain, in origin.

Eskers.

There are two eskers in the basin of the Upper Passaic, one near Afton and one near West Livingston.

West Livingston esker.—The West Livingston esker lies a little east of the village. It has a length of rather more than two miles, and a northeast-southwest course. A low gravel and sand hill in the midst of a marsh about three and a half miles southwest of Livingston, and a short distance west of Washington Place, may, perhaps, be looked upon as its extreme southern end

(Kümmel). It is interrupted by the alluvial plain to the northeast toward Cheapside, but is continued beyond as a low gravel ridge, breaking up into two rather sharp knolls at Cheapside. From Cheapside to West Livingston, the esker continues as a distinct winding ridge, but with no sharp curves. No exposures occur, but the surface indicates the sand and gravel composition of the ridge. About half way between Cheapside and West Livingston the crest of the ridge is marked by depressions. Northeast of West Livingston the ridge becomes more prominent, and where it crosses the road between Livingston and West Livingston, a half mile from the latter place, it is well defined, being twenty feet in height and composed of coarse gravel. Farther north, the ridge becomes less prominent, and finally ends in a sharp knoll fifteen or twenty feet in height. From this termination a small area of sand stretches to the northeast. Between Cheapside and West Livingston, the esker is bordered on the west by a narrow area of gravel, the topography of which is somewhat undulatory. Its height varies from a few feet (four or five) to something more than twenty.

The Afton esker.—A much longer and more massive esker, though much interrupted in its course, and often less clearly defined, runs through Afton. Its southern end is one and a half miles northeast of Madison. For a mile or so it lies about one-third of a mile east of the Madison-Afton road. Pursuing a north-northeast course, it crosses the two roads running southeastward from Afton, and, holding the same general direction, it lies just east of the road running from Afton to Hanover. After a slight interruption north of the church at Hanover, it continues three-fourths of a mile farther north. The total length of the esker is about three and one-half miles. There are ten gravel and sand pits along its course in this distance, and the gravel and sand associated with the esker have often something of the kame disposition. Nowhere does the esker have distinct branches which persist for more than a few rods, though at some points seeming branches break up into kame-like hillocks. Its crest is uneven, often rising into somewhat sharply-marked hillocks. But ever and anon it develops the narrow, ridge-like character which is so characteristic of the type with which it is here classed.

Other Areas of Stratified Drift.

Besides the shore gravels of Lake Passaic, the kames and the eskers, there is not a little stratified drift in the basin of the Upper Passaic, which is in ill-defined patches, or in areas without distinctive topography. A detailed description of such areas would be unprofitable. The stratified drift is often so closely associated with unstratified as not to be readily separable.

One considerable belt of stratified drift, or one considerable belt in which stratified drift abounds, extends from Madison to Hanover Neck. It lies on both sides of the Afton esker, and extends beyond its ends. A lesser belt lies between West Livingston and Swinefield Bridge. Still another is found about Monroe, east of Morristown, and others between Franklin and Hatfield swamp, and between Clinton and Fairfield, southeast of Great Piece meadows.

In some of these places the topography is plane; in others, undulatory, and in still others it is not notably different from the topography of the ground moraine. Stratified drift not of kame phase is also associated with most of the kames mentioned on the preceding pages.

ALLUVIAL PLAIN OF THE UPPER PASSAIC.

In the basin of the Upper Passaic, the alluvial plain is not separated from the swamps and meadows. Between the moraine and Little Falls, the post-glacial erosion has been practically nothing, and the work of the streams has consisted chiefly in adding a small amount of alluvium to the organic matter accumulated on the lowlands adjacent to it. The greatest thickness of the peaty soil known along this part of the river is twenty-seven feet.

STRATIFIED DRIFT BETWEEN THE MORAINE AND THE SPRINGFIELD-UNION-WAVERLY KAME BELT.

About Perth Amboy.—In the south part of Perth Amboy, next the bay, there is a little stratified drift, chiefly gravel, which should be separated from the moraine on which the city is built. The stratified drift is chiefly below a level of thirty feet. Other small patches of stratified drift or wind-blown sand occur north of Perth Amboy, opposite Arthur kill, and south of the mouth of Woodbridge creek.

About Woodbridge.—There is some stratified drift on the lowland on either side of Heard's creek, in Woodbridge and below. Its limits are ill-defined. The hill (ninety-two feet) just south of Woodbridge is in part covered with gravel, though the hill is not wholly, probably not chiefly, composed of it. Other small areas of stratified drift lie west and southwest of Woodbridge.

About Star Landing.—At Star Landing and Island View there is some stratified drift, mostly below an altitude of twenty feet. It is partly covered with sand of eolian origin.

Houtenville and Iselin.—There is some stratified drift in the valley of the South Branch of the Rahway river, extending from a point half a mile or more above Iselin to a point somewhat below Houtenville, and mainly east of the railway. Throughout much of the area the topography is rather flat, but there are places, notably southeast of Iselin, where it is somewhat undulatory and kame-like. The materials are gravel and sand. Exposures are not numerous, though a railroad cut south of Houtenville shows stratified gravel, mainly of Triassic material. From wells, considerable depths (twenty-two feet) of fine sand are reported.

About Rahway.—The surface of the till about Rahway is often so sandy, that without good exposures it is difficult to distinguish areas of till from areas of stratified drift. The topography is not such as to relieve the difficulty of discrimination, for the surface is, in general, so flat as to resemble the surface of stratified drift, even where the material is till.

In Rahway there are two kames, the fifty-five foot hill in the northwestern part of the city, and the forty-two foot hill in the southwestern part. There is a third area of stratified drift of undulatory topography a quarter of a mile east of the Scott Avenue station.

The only notable feature of these kames is the fact that one of them, the highest, has a layer of till, including bowlders, over its surface. Below this superficial coating, stratified gravel and sand make up the body of the hill.

Two or three miles west of Rahway, there are two hills, the crests of which have elevations of 104 feet and 187 feet respectively, though they are little more than distinct knolls above their surroundings. Their surfaces are not decisive as to their constitution, but they are said to be of gravel and sand. Their reference to stratified drift is open to question.

About Willow Grove.—Near Willow Grove, stratified drift covers an area of about two square miles. It is chiefly about the head waters of the brooks south of Westfield, and along the northeast border of Ash swamp. Its topography is in no way distinctive, and its limits are ill-defined. A kame occurs at the west side of the swamp, together with an ill-defined patch of drift. Still another small kame ten to twenty feet high is found above Willow Grove pond.

Cranford and Elizabeth.—There is a small kame a mile and a half northwest of Cranford, an irregular and ill-defined patch of gravel at El Mora just west of Elizabeth, and other small areas of stratified drift east of North Elizabeth, and still farther east, at Great Island, in the tide marsh. Stratified drift also borders the left bank of the Elizabeth river through the city, and out to Elizabethport.

THE WAVERLY-UNION-SPRINGFIELD KAME-MORAINE BELT.

There is a rather remarkable belt of stratified drift, with which some till is associated, extending from Waverly, westward through Salem, to New Orange. Thence one branch of it extends westward to Branch Mills, and the other northwest to Springfield and Millburn. The Branch Mills division extends to the northward projection of the moraine at Westfield. The limits of the belt are often ill-defined.

One of the most notable features of the belt is the pronounced kames, which are so aggregated as to give the general effect of a terminal moraine. This is especially true of the region southwest of Union (north of New Orange) and, less conspicuously, of the whole area along the West Branch of the Elizabeth river long and a quarter of a mile wide, is the most marked depression in the surface, but numerous minor depressions to the southwest are equally striking. To the main marsh at tide level, the surface of the stratified drift at the north descends with a steep slope, fifty feet in height.

South of the marsh, the rise is less abrupt, and the maximum altitude is less, forty to forty-seven feet. From the maximum elevation near the marsh, the surface slopes gently southeastward to tide level, after the fashion of an outwash apron. South of the marsh west of Waverly, sharp sinks fifteen to twenty feet deep occur, while at the west end of the marsh, one-third of a mile east of Lyons Farms, the gravel rises abruptly sixty feet from tide level, and constitutes a plain which rises northward to seventy feet. Its surface is somewhat pitted. West of the marsh, the surface is notably pitted, with abrupt sinks thirty and forty feet deep. From the L. V. railway, the level of which is below the level of the pitted plain, the appearance of the topography is, in places, morainic; but from the level of the plain, it is seen that the undulations are due to depressions rather than to hills.

The material of the northern portion of the plain is coarse gravel, with some small bowlders. The gravel decreases in coarseness southward, as the surface of the plain descends, and grades into sand before Elizabeth is reached. The L. V. railway cuts furnish some good exposures, generally of coarse gravel, showing little stratification at some points.

West of the Elizabeth river, the stratified drift takes the form of kames in some places, and of plains in others. It is divided into a north and south part by the valley of the West Branch of the Elizabeth river, along which there are depressions comparable to those at Waverly. These depressions were probably occupied by masses of ice while the surrounding gravel was being deposited. The altitude of the northern margin of the stratified drift here rises to about 100 feet, and has the form of a plain, with a steep front to the northeast next to the valley. In the plain, the layers of gravel dip at a high angle toward the southwest, as shown by some gravel pits on the east side. To the southeast, the gravel is markedly undulatory, kames rising to heights of 124 and 132 feet. Kames are still more conspicuous farther west along both sides of the West Branch.

The origin of the plain presents serious difficulties, unless the region was submerged as the ice retreated. The high dip of the strata exposed suggests deposition in a body of standing water, but no body of standing water above sea level could well have been held here (see p. 508). The kames just south of the plain show no evidence of wave-cutting, and the presence of what seems to be a well-developed overwash plain at a lower level, puts difficulties in the way of the submergence hypothesis. The steep northeast side of the plain may have been developed by the deposition of gravel against ice which lay on this side of the plain. The fact that the plain is highest to the northeast, next to the abrupt fall-off, is consistent with this interpretation. The steep descent from the plain to the swamp of the Elizabeth river is probably the result of the melting of the ice against which the gravel was deposited. Its melting left the slope steep in some places and undulatory in others. If the ice which occupied this depression extended southward across the Elizabeth river, a pond might have been formed where the plain now is, at a level of 100 feet or thereabouts.

From Salem nearly to the Rahway river, the larger part of the stratified drift is made up of kames, or of kame-like aggregations. Plain topography prevails, however, a mile south of Union, and again north of Cranford, near the Rahway. In the former area, an elongate kame with two summits rises above the plain. The material of the plain is generally sand or gravel, but so compact that its surface suggests till, and in some shallow exposures till-like material was noted. Nevertheless, the topography and such other data as are available indicate that the material of the plain is stratified. At one point on the plain (fork of road three-fourths of a mile south of Union) the depth of the gravel and sand is thirty-one feet.

The kames along the West Branch of the Elizabeth river a mile northwest of Salem, including the 124 and 132-foot hills of the topographic map, are conspicuous. Their topography is rough, with hillocks and hollows of considerable relief. The topography of the kame area south of the stream, a mile west of Salem, is less pronounced, and grades off to planeness to the south. The material on the north side of the stream is coarser and looser than that on the south. About Salem, the gravel is locally so mixed with loam as to give its surface a till-like appearance, while near by, the material is clean, rounded gravel.

Southwest of Union, a marsh about a mile long and a fourth of a mile wide lies within the belt of stratified drift. The slopes to the marsh are sometimes abrupt, and sometimes gentle and undulatory. South of the marsh, the topography is strongly undulatory, and at some points distinctly morainic. Outside the marsh along the stream, are other lesser but equally steep-sided depressions of which the "ship hole" is the most notable. The bottom of this hole is at about the level of the marsh along the stream. Probably both the stream marsh and the lesser depressions to the south were occupied by ice blocks while the gravel was being deposited about them.

About the west end of the swamp occur the most conspicuous kames of the belt, and among the most notable of the State (Fig. 77). From the surrounding plain at about 100 feet, they rise up abruptly forty, fifty, sixty and even eighty feet. The topography is well shown by the topographic map, although the minor sinks and swells are not brought out by ten-foot contours. The material of the hills varies from coarse gravel to fine sand. Frequently there is surface coating two to eight feet in depth, of material which is till-like.

Esker ridges.—On the north side of the marsh, southwest of Union, near the west end of the kame area, there is an esker-like ridge of gravel in the kame belt. The ridge is elongate in a northeast-southwest direction. Its length is something more than half a mile, and its height varies from twenty to forty feet. Its material is loose gravel, and bowlders lie on the surface. Its structure is nowhere well exposed. If the kame belt represents the direction of the ice front, the ridge is not very nearly parallel to the direction of ice movement.

This ridge is nearly parallel to another short esker which has a general east-west course in the forest between Milltown and Connecticut Farms. This ridge is low, but well defined, and has the windings characteristic of such ridges. Traced from east to west, it commences about one mile west of Union (Connecticut

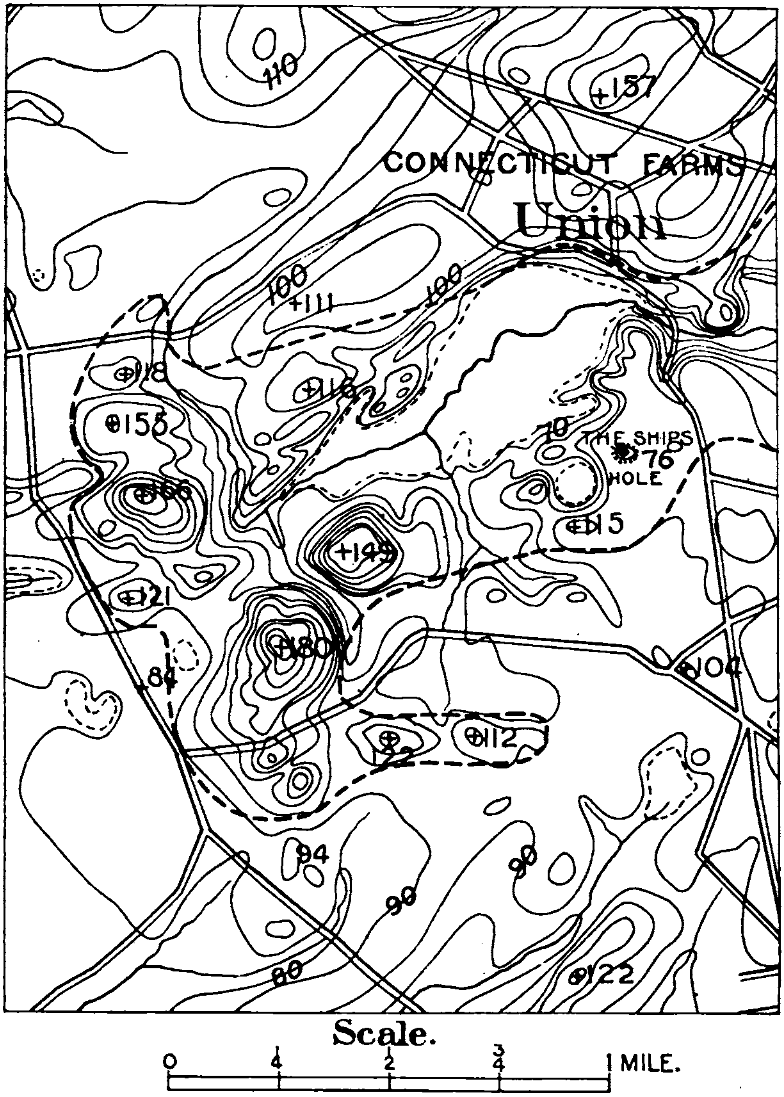


Fig. 77.

Kames near Union. The heavy broken line encloses the kame area.

Farms). Here it rises up from rather flat surroundings in the form of a low, but well-defined ridge. It has a winding course, running westward for about one-third of a mile, with a height of about ten feet. It is here interrupted, but is continued a little farther west as a distinct ridge twelve to twenty feet in height, and about a hundred feet in width. In a general way, its height is greater where its width is less, and *vice versa*. Toward its western end, the esker becomes notably sinuous. After a course of about a mile, it is lost in the gently-undulatory gravel plain. The material of which it is composed varies from coarse gravel to fine sand. The western end has an abundant scattering of bowlders and cobbles of considerable variety. Nowhere does this esker cross any highway, nor is it anywhere distinctly seen from any road.

West of New Orange.—Conspicuous kames do not occur west of the northwest-southeast road, a mile and a half southwest of Union. From that road, a slightly undulatory gravel plain, covered with clay and loam, slopes off to the Rahway river.

North of Cranford, the plain is so heavily coated with loam that little is known of its constitution. Near New Orange, however, the loam coating is less heavy, and shallow exposures show that the gravel decreases in coarseness southward from the prominent kames. This decrease in coarseness, together with the slope of the plain, suggests its deposition in front of the ice after the fashion of an overwash plain, when the ice edge had a northwest-southeast direction. Areas of undulatory topography between the Springfield kames, and the kames north of New Orange, strengthen this suggestion.

At Springfield, kames reappear. In the southeastern part of the village, there is a circular kame some thirty feet above the gently broken plain. In the north part of the village, there are a number of sharp kames twenty to thirty-two feet in height. The gravel plain of the Rahway becomes more undulatory as the kames are approached, and there is no sharp line of demarkation between them. Some of the kames are composed of coarse gravel, and others largely of sand, so far as exposures show. In some places, some till seems to be associated with the stratified drift.

From the moraine at Millburn, down to these kames (about a mile), a gravel plain descends after the fashion of an overwash plain. It commences a few hundred yards north and west of the Millburn station at an elevation of 160 feet, and, descending rapidly southeastward, reaches the kames north of Springfield as a gently sloping plain. Beyond this point, the plain cannot be traced. It is probable that the kames are older than the plain to the north, and that the materials of the latter were deposited after the edge of the ice had retreated from the kames. Deposition at the later stage aggraded the surroundings of the kames, but did not bury them.

There is some gravel west of Springfield, and south of Short Hills, along the inner border of the moraine. It is continuous with the undulatory plain about Springfield, and is but indistinctly separated from the moraine against which it lies. The moraine itself contains a considerable proportion of gravel and sand.

Branch Mills kame area.—Northeast of Branch Mills, and north of the marsh above the junction of the Normahiggin brook with the Rahway river, there is a group of kames. Seen from the south they are prominent, but from the north, much less so. They grade off to north and east into till without sharp lines of demarkation, and to the west into stratified drift, with a plane or nearly plane topography. To the south, there is a gravel plain which becomes somewhat undulatory near the junction of the Normahiggin brook and the Rahway river. Stratified drift lies along the Normahiggin brook above Branch Mills, and expands into a considerable area along the inner face of the moraine northwest of the Mills.

NORTH OF THE WAVERLY-UNION-SPRINGFIELD KAME BELT AND WEST OF THE PASSAIC.

Rahway valley.—In the valley of the Rahway, above Millburn, stratified drift is nearly continuous from the moraine to Pleasantdale. It has the form of kames, kame terraces, and normal terraces, and there are some ridges which may be regarded as poorly developed eskers. East of Brookside road, and south of South Orange avenue, somewhat more than a mile above Millburn, there is stratified drift, indistinctly separated from till. Its upper limit is at 320 to 340 feet. It is disposed as a rude terrace on which, a mile and a half south of the Orange reservoir, there is an ill-defined esker. It lies east of Brookside avenue, and west of the river. There is another shorter esker-like ridge a quarter to a half mile south of the Orange reservoir, on the east side of the stream.

At the south end of the Orange reservoir, there are gravel hillocks of the kame type. About the reservoir there is little stratified drift, but a mile to the north gravel reappears. It occurs up to an altitude of 380 feet, and is disposed as a terrace. The surface gravel is coarse, with some bowlders. A mile above the reservoir, the gravel constitutes kames on the west side of the river, while on the east side it is continued northward as a terrace, the surface of which occasionally manifests a kame tendency. Just south of Pleasantdale, the kame tendency becomes pronounced. At this point the continuity of stratified drift in the valley is interrupted.

The gravel in the valley of the Rahway increases in elevation continuously from Millburn northward to the kame area one and one-fourth miles north of the Orange reservoir. From that point to Pleasantdale, its upper level (about 400 feet) is little changed.

Between Pleasantdale and Millburn, the gravel in the valley nowhere constitutes a well-defined aggradation plain. In coarseness it does not present continuous gradation from north to south, as would be the case if the terraces were developed from a continuous valley plain made while the edge of the ice stood in one position. Neither does it present the series of gradations which would have been expected had the gravels been deposited below successive halting places of the ice.

From Springfield, stratified drift is continuous in the valley of the East Branch of the Rahway, to its source. The kame tendency, so pronounced about Springfield, extends up the valley some distance above that place. The material of the lower levels is largely sand, which is perhaps contemporaneous with the material of the same sort about Springfield and below. Some of the fine material of the lower levels about Springfield probably came down this valley, after the kames were deposited. South of

Maplewood, the upper limit of the stratified drift is ill-defined, both topographically and otherwise. The surface often has the topography of a weak terminal moraine, and the material is in correspondence; that is, stratified and unstratified drift are not distinctly separated.

Just above Maplewood, there are a few small kame-like aggregations of gravel. Otherwise, from Maplewood to West Orange there is little stratified drift in the valley except near its bottom, where it occupies the lowland a few feet above the alluvial plain. The surface is now flat and now undulatory, with a tendency to the development of low swells elongate in the direction of the valley.

The gravels of the valleys are chiefly well rounded, and primarily of Triassic sandstone. Above the low-lying gravels of the valley, the lower slopes show, at numerous points, some suggestion of stratified drift.

At Orange Valley, the stratified drift is fifteen to eighteen feet thick, and rests on rock. At West Orange, just northwest of the station, there is a distinct kame. The stratified drift of the East Branch of the Rahway here becomes continuous with that of the valley of Second river.

At the head of the East Branch, the stratified drift has an elevation of about 190 feet. Its surface declines to about 120 feet at Maplewood, and to ninety feet at Springfield. There is little in the valley to indicate successive halting places of the ice, though the tendency to kames above Maplewood may be such a suggestion.

Kames inside the Waverly-Union belt.—Inside the Waverly-Union kame belt, and outside the valleys already noted, there are five small kames and one kame area. Three of the kames lie between Lyons Farms and Newark. All are small and without exposures. Two lie half a mile north and northwest of Union, on the north slope of the till area at Union. Small areas of morainic topography, involving some stratified drift, lie a mile north, and a mile and a half northeast of Union. Within these areas are individual hillocks which are kames.

CHAPTER XIII.

STRATIFIED DRIFT OF LATE GLACIAL AGE SOUTH OF THE MORAINE.

CONTENTS.

The stratified drift north of the moraine described in the preceding pages was largely deposited by water flowing from the ice while the ice was retreating. It remains to give account of the gravel and sand which were carried beyond the moraine, chiefly by the waters which flowed from the ice while it occupied its most advanced position. Such drift is found chiefly in two classes of situations: First, in the valleys which lead southward from the moraine, and second, on low plane areas adjacent to the moraine. In the former position, valley trains were developed (p. 124); in the latter, outwash (overwash) plains (p. 128), or, where lakes existed, *delta or subaqueous overwash (outwash)* plains (p. 130).

of debris above the moraine. When the ice had receded so far that the river below the moraine was no longer burdened with debris, it set to work to carry away the material which it had left on the flood plain when it was overloaded. In this task it has since been engaged. In its accomplishment, the river was perhaps aided by a gradual uplift of the upper portion of its drainage basin, as the ice receded. If such elevation took place, it accelerated the velocity of the stream and increased its erosive power. It is estimated to have removed between two-thirds and three-fourths of the material deposited in the valley below the moraine during the last glacial epoch.

When, in the progress of degradation, the river had lowered its channel to such an extent that its waters no longer covered the glacial flood plain, such parts of the latter as remained became terraces. Where the stream's course chanced to be on one margin of its plain at the time it was changed from a depositing to an eroding stream, a part of the old flood plain remained as a terrace on the opposite side of the valley (Fig. 79). Where the

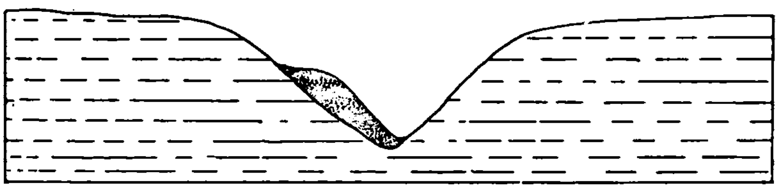


Fig. 79.

Showing a gravel terrace on one side of the valley only.

stream's course chanced to be remote from either margin of its glacial plain, remnants of the flood plain remained, for a time at least, on both sides of the new channel, as bordering terraces (Fig. 10). Thus at Hutchinson's, just north of Riegelsville, a mile south of Holland Station, and at several points between Tumble and Trenton, the terrace has been removed from the left bank of the river, while it still remains on the Pennsylvania side. Remnants of the terrace remain with equal frequency on the New Jersey side of the river where they are wanting on the opposite side. This is true at Hutchinson's, Carpentersville, Milford, Tumble and Byram, as well as at other points. In other situations, gravel still remains on both sides of the valley, as at Trenton.

Where the preglacial valley was narrow, and where the gravel plain was therefore narrow, all or nearly all the gravel has been removed. This has happened at several points, as at Phillipsburg, one and a half miles south of Carpentersville, and three-fourths of a mile south of Kingwood station. Where the valley was wider, the gravel and sand have not generally been altogether removed. It frequently happens that traces of the gravel remain scattered over the valley slopes, even where there is no recognizable part of the old plain. In such cases, the upper limit of scattering pebbles of glacial age often indicates the height of the old plain.

The terraces of the Delaware are rather insignificant topographic features when compared with the Delaware valley as a whole. This is especially true of the upper part of the valley originally affected by the valley train. In the vicinity of Trenton, the terraces are less inconspicuous by reason of the slight relief of their surroundings. But small as the terraces are in comparison with their surroundings, they are the most conspicuous topographic features of the valley, often constituting, as they do, broad flat benches or plains on which are built most of the towns along the Delaware between Trenton and Belvidere.

The terrace remnants of the old valley train of the Delaware afford ample data for the reconstruction of the old valley plain. By connecting their surfaces with one another, it is possible to see what the slope of the valley train would be, if it were restored, but this does not necessarily show what the slope was when it was formed, since subsequent deformation may have changed the relative levels of different parts.

The altitude of the terraces.—The altitude of the valley trains of the Delaware near its northern terminus, just below the moraine south of Belvidere, is about 300 feet, and at Trenton about sixty feet. The distance between these points is about sixty miles. A regular decline would therefore give an average fall of about four feet to the mile. The decline is, however, much more rapid near the moraine than farther south. Measurements by Mr. Atkinson give 300 feet for the altitude of the terrace at Roxburg station, about two miles below the moraine, and 230 feet for the corresponding terrace at Phillipsburg, ten miles farther down the valley. This gives an average decline of seven feet per mile between these points. Between Phillipsburg and Holland station, a distance of about twelve and a half miles by the course of the valley, the surface of the terrace declines from 230 feet to about 175 feet, or about four and a half feet per mile. Between Holland station and a point fourteen miles below, near Byram, the surface of the terrace declines from 175 feet to 120 feet, or rather more than three feet per mile. From the last point to Trenton, a distance of about twenty-two miles, its decline is about sixty feet, or about two and three-fourths feet per mile.

If the terrace remnants of the old plain be measured in terms of their elevation above the river, instead of in terms of elevation above the sea, instructive results appear. Between Roxburg and the upper part of Phillipsburg, the river has a fall of fifty feet, while the gravel plain declines seventy feet. The terrace at Roxburg (ninety-five feet above the river) is therefore about twenty feet higher than that at Phillipsburg (seventy-five feet), as compared with the river. In other words, the terrace declines two feet per mile faster than the river. Between Phillipsburg and Holland station, the river falls thirty-five feet, while the terrace declines fifty-five feet. The terrace at the former place (seventy-five feet above the river) is therefore about twenty feet higher than that at Holland station (fifty-five feet), as compared with the river. The terrace here declines about one and three-fifths feet per mile faster than the river. Between Holland station and Byram, the river has a fall of about fifty feet, while the terrace declines about fifty-five feet, leaving the terrace five feet higher at the former point than at the latter, as compared with the river. Between Byram and Trenton the river falls about sixty feet, while the terrace declines about the same amount. Hence between these two points the river and the terrace sustain essentially the same relations to each other, in point of altitude. Between Belvidere and Trenton, the river has about forty-five feet less fall than it had when the valley train was completed, if there has since been no subsequent differential change of level.

Southward limit of the Trenton (fluvio-gracial) gravel.—On the New Jersey side of the river, the Trenton gravel, as this terrace material has been called, is not distinctly traceable below the southward bend of Crosswick's creek, about three miles below Trenton. Below this point, traces of the same sort of gravel are seen at various points, but they are for the most part meagre. At many points, occasional pebbles of fluvio-glacial origin are found mingled with much larger quantities of gravel derived from the older formations of the Coastal plain. These gravels of Coastal plain origin were worked over, mingled with the glacial gravel, and deposited anew in the valley during or since the last glacial epoch.

South of Trenton, gravel of glacial origin has been recognized, chiefly by Mr. Knapp, three-fourths of a mile west of Kinkora, on the west bank of the creek, at an elevation of about thirty feet; in the west part of Florence, and at various points between Florence and Burlington, at elevations of thirty feet or less; doubtfully at various points between Burlington and Palmyra, and even as far south as Camden. In most of these places the material of glacial origin is very subordinate to that of local origin. At some of them, the evidence that what appears to be Trenton (glacial) gravel is really such, is not altogether satisfactory.

On the Pennsylvania side of the river, the Trenton gravel is found farther south, although its limits are by no means clearly defined[1]. It is exposed at various points along the line of the Pennsylvania road for a distance of five miles below Morrisville, and extends back from the river a little below Fallsington for a distance of fully four miles. Two and three-fourths miles southwest of Fallsington, it is said to be sixteen feet deep, and to rest on a sharply-defined surface of stiff clay. The gravel is here composed in part of material of local origin, mixed with much of glacial origin, which came down the Delaware.

Beyond Mill creek, the limits of the fluvio-glacial (Trenton) gravel are ill-defined. This gravel may be recognized on Turkey hill, three or four miles southwest of Trenton up to an altitude

[1] The following statements relative to the gravels on the Pennsylvania side of the river are based largely on the work of Mr. A. R. Whitson.

of about fifty feet, though the body of the hill is of other and older material (Cretaceous capped with Pensauken). About Bristol, the Trenton gravel may be seen on the river bank at various points, and also a mile and a half to two miles south by west of the city, at an altitude of about thirty feet. Traces of glacial gravel are again found half a mile from the river at Dunk's ferry, at an elevation of less than twenty feet. From this point to Tacony, doubtful traces of it may be seen at several points, and even in Philadelphia, pebbles have been seen in various excavations, which appear to be referable to the glacial Delaware.

On this side of the river, as on the other, such elements of the sand and gravel below Trenton as appear to have come down the Delaware are generally overshadowed by materials of other sorts, and their identification is sometimes a matter of uncertainty, especially where exposures are poor.

The islands in the river appear to be made up largely of Trenton gravel material. This material is, however, largely sand instead of gravel. Burlington island has more gravel than the others. How far these low-lying Trenton gravels may be in secondary position, and, therefore, of post-glacial deposition, is not known. It is evident, both from their constitution and disposition, that the gravels of the Delaware valley south of Chambersburg are somewhat different in character from those above, and that they have had a somewhat different history. It is not altogether clear how far this gravel is fluviatile, and how far estuarine (ice perhaps aiding in its transportation); how far it is glacial in age, and how far post-glacial.

While the fluvio-glacial gravels of the Delaware valley have little development below Trenton, the low terrace plains of this part of the valley are the time equivalent of the glacial terraces of greater elevation to the north. They will be referred to on a later page.

Human relics in the Trenton gravels.[1]—Much has been said and written of human relics in the gravels at Trenton. There is no doubt but that relics of one sort and another have been found

[1] For discussion of this subject, see Holmes, Journal of Geology, Vol. I, 1893, p. 15.

on the surface of these gravels, and even beneath the surface, to the depth of some two to four feet. But none of these relics are now thought to possess great significance relative to the antiquity of man. All the relics yet found are probably the relics of Indians, and there is no warrant for supposing them to be of great antiquity. Some of them are in wind-blown sand and loam, and some of them in the surface parts of secondary terraces and flood plains of relatively recent origin. In no case have they been found in such relations as to demonstrate the occupancy of the valley by man while the stream was discharging the waters of the melting ice.[1]

LOCAL DETAILS.

The Outwash Plain at Belvidere.

The moraine in the Delaware valley is ill-defined (p. 249). Most of the drift where it ought to be, is stratified, and much of it

[1]Since the above was written, the results of investigations later than Mr. Holmes' discussion have been made public. Numerous artificially chipped stones have been found on the Lalor farm south of Trenton, on the terrace bluff overlooking the river, in a yellow clayey loam three to four feet thick. This loam rests upon coarse gravel and sand. The evidence that the chipped stones were found in undisturbed positions seems indisputable, so that the question here turns upon the age of this deposit. There is no question but that the underlying gravel and sand is of Trenton age, *i. e.*, contemporaneous with the terminal moraine at Belvidere. The age of the clayey loam, however, is not so satisfactorily established. By some it is believed to represent the closing stages of the deposition of the Delaware valley train, following immediately after the gravel and sand. Other geologists have inclined to the belief that it is an eolian deposit, and hence, may be much later than the Trenton gravel. Members of the Survey Staff, after careful study of all the deposits of the Delaware valley, and of other valleys of the State, do not believe that the glacial age of the loam is beyond question.

A fragment of a bone, pronounced to be a portion of a human femur, is reported to have been found in a sand-bed beneath four feet of gravel in an excavation at South Trenton. The surface here is somewhat lower than the highest level to which the gravel was deposited in this vicinity, but it is not clearly a secondary terrace. The bone had fallen from its place when first seen but two smaller splinters are said to have been found *in situ* in the sand. This relic is of greater interest than those in the surface loam inasmuch as there is no question as to the age of the gravel and sand, if they are a part of the upper terrace. H. B. K.

is disposed as a plain, showing that drainage was vigorous in the valley while the moraine at other points was forming. Between Belvidere and Oxford Church, and thence to the head of Buckhorn creek, the drift is spread out in the form of an outwash plain. South of Belvidere, gravel and sand cover most of the surface below an elevation of 320 feet, and are banked up against the bluff below Oxford Church to an elevation of 340 to 350 feet. This plain of stratified drift has been referred to in Chapter IX.

About two miles below Belvidere the plain narrows notably near the head of Buckhorn creek, and in the valley of this creek is the more conspicuous valley train leading off to the south. As far south as Roxburg, the corresponding material originally deposited in the immediate valley of the Delaware has been removed by erosion.

Terraces.

About Hutchinson's.—Between Roxburg station and Hutchinson's the railway follows a low terrace, east of which the surface rises abruptly forty to fifty feet. At this level there is a well-defined terrace, which at Hutchinson's is seventy to eighty feet above the river. The terrace at this point is common to the valleys of both the Delaware and the Buckhorn. Up the valley of the Buckhorn, the terrace is continuous until it expands as the overwash plain below the moraine, some two miles above the village of Roxburg. The stratified drift in the Buckhorn valley is still much as it was left by the glacial waters, for the creek has done relatively little in the way of re-excavating its valley since it was aggraded in glacial times. The explanation of the ineffective work of the creek is found in the coarseness of the material, most of which is beyond the competency of the stream. The continuity of the terrace in the Delaware valley above the Buckhorn is interrupted by jutting points of rock, and by local drainage channels which have been eroded in the terrace. Above the Roxburg station, very little of the original valley train remains on the New Jersey side of the river. On the other side, much more of the original valley train still remains for some miles below the moraine.

The material of the high terrace is well exposed at Hutchinson's, where its constituents are seen to be sand, gravel and cobbles, well stratified. Some of the layers are cemented by lime carbonate into a moderately firm conglomerate. One of the constituents of the gravel is limestone. The percolating waters dissolve the lime carbonate, and on evaporating, leave the mineral matter as a coating about the pebbles and cobbles which are thus bound together at their points of contact. The lime carbonate rarely fills the interstices between them.

Fig. 80 represents a cross-section of the valley between Hutchinson's and Roxburg station. The larger valley, as seen in this diagram, is about 500 feet deep, and four miles wide. The Delaware now flows in the gorge at D, while Buckhorn creek occupies the lesser valley to the east. The section shows two small terraces

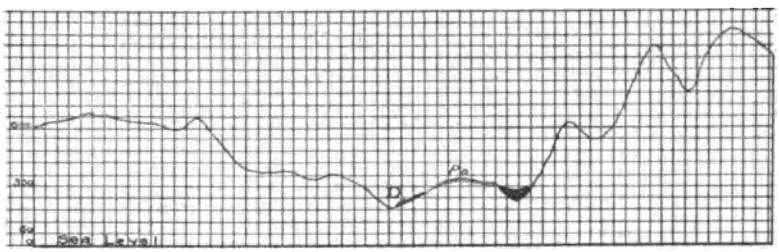


Fig. 80.

Cross-section of the Delaware valley near Roxburg. Terraces of glacial gravels shaded black. Old drift is shown at Pn between the Delaware and the Buckhorn.

(colored black) of fluvio-glacial drift in the main valley. The higher represents the original aggradation level. At the end of the glacial epoch, gravel filled the valley to its level. The lower terrace on which the railway runs is the remnant of a flood plain developed by the stream in post-glacial time. It is therefort a *secondary* terrace. The section also shows the relatively slight erosion which the valley of the Buckhorn has suffered since the glacial gravel was deposited.

On the low rock divide between the Delaware and the Buckhorn, there is a small amount of drift, Pn, which antedates the last glacial epoch. This earlier drift will be described in the next chapter.

At Martin's Creek station.—From the map shown in Fig. 81, it will be seen that for two miles below Hutchinson's the course of the Delaware is north of west, and that at Martin's Creek station, it again turns southward. Between Hutchinson's and Mar-

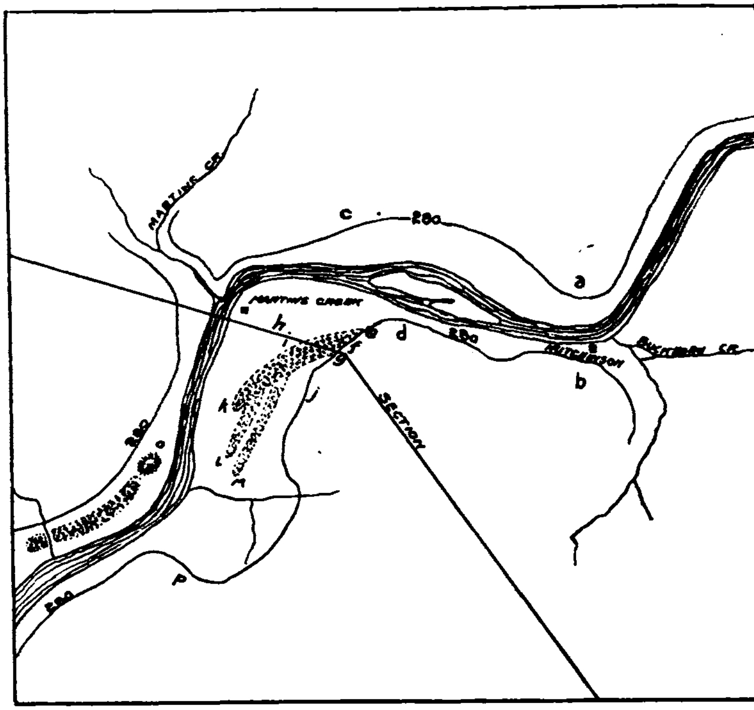


Fig. 81.

Sketch map of a section of the Delaware valley. The lines on either side of the river are the 280-foot contours. Glacial gravels originally filled the valley about to this level. The shaded areas are terrace bars. Scale, about one inch per mile.

tin's Creek station, little of the original valley train remains on the New Jersey side of the river, and at one point only is there a distinct lower or secondary terrace. A little above the Martin's Creek station, the high level terrace re-appears on the left bank of the stream (Fig. 81). Generally speaking, the terrace representing the original aggradation level, if present on one side of the stream, is absent on the other. Thus in Fig. 81, the high terrace above Hutchinson's ends at the Buckthorn, but a corresponding terrace occurs on the right bank of the stream between a and c. At the latter point it disappears on the Pennsylvania side, but its equivalent appears at e, and extends down stream to k. About opposite the point where it terminates, a corresponding terrace, appears on the opposite side below.

The sketch seems to suggest a relationship between the presence or absence of terraces and the course of the channel. Where there is a bend in the course of the stream, as at a, the stream

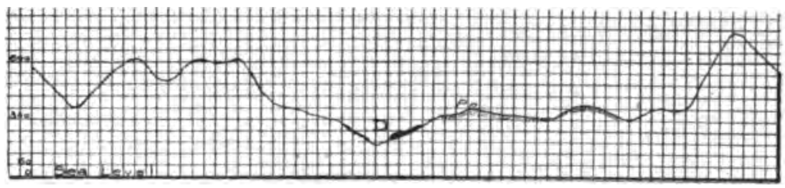


Fig. 82.

Section along the line marked in Fig. 81. The glacial terraces are black. Pn represents old drift.

holds its antecedent direction until it impinges on the opposite rock wall (at b). It is then given a new direction (in this case to the west), but it hugs the outer bank of the curve with such persistence, that all loose material is undermined and carried away, while the corresponding material on the opposite side (a to c) remains. Similarly the loose terrace material has been removed from c to o, while it remains from e to k.

This relation between the presence or absence of terraces and the course of the stream is of general application. It helps to show that the terraces are remnants of a once more extensive deposit, which have escaped erosion by reason of their advantageous position.

The high terrace at Martin's Creek station (e to k, Fig. 81) presents certain peculiarities which are repeated at other points in the valley. Its surface is not flat. Its most notable departure from flatness is a ridge of gravel represented by e k. In position, the ridge is roughly tangent to the valley wall at e. At the east side of its head, e, the gravel is banked against the rock. A little farther from its head, f, its upper surface becomes flat, and the flat widens with increasing distance from the valley wall. Still farther from its head, the flat assumes the form of a ridge by the development of a depression (beginning at g) between it and the valley wall. The slope of the ridge toward the valley wall is steeper and shorter than that toward the river. On the river side, the slope is not interrupted by any distinct and persistent bench above the level of the depot, some forty feet below the crest of the ridge.

At its head, the ridge is of coarse gravel, cobbles six inches in diameter being common. Its material becomes finer near its distal end, but everywhere it is coarser than the material behind it.

This ridge is believed to be constructional, not the result of degradation. Similar ridges occur in similar situations at other points down the valley, being sometimes ten to fifteen feet above the sags behind them. A similar ridge is shown in Fig. 81, on the opposite side of the river, where a boss of rock, o, projects above the terrace level. The terrace bar is below it.

South of the main terrace bar, f k, there are minor ridges, l and m, giving the surface a somewhat ridged or fluted appearance. The original aggradation surface here seems not to have been flat, and it is sometimes difficult to draw the line between the surface of original deposition, and the surface which has been since degraded.

Harmony station.—From Martin's Creek station to Harmony station, nothing of the original valley train remains, though there are low terraces of secondary origin both south of the high terrace at the former place, and north of that at the latter. The general relations of the high terrace—the remnant of the original valley train at Harmony station—are shown in Figs.

83 and 84. As in the localities mentioned above, the terrace is just below a bend in the stream, and the beginning of the terrace

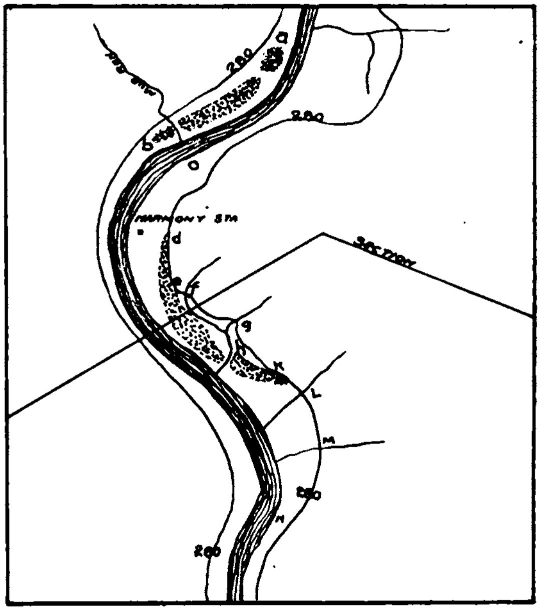


Fig. 83.

Sketch map of a portion of the Delaware valley showing the terrace bar at Harmony station. Scale about one inch per mile.

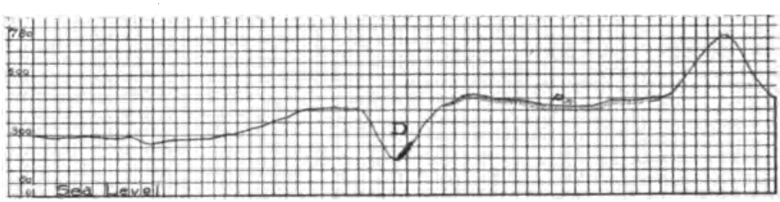


Fig. 84.

Cross-section of the valley along the line indicated in Fig. 83. The late glacial river terrace shown by the black, and the old drift by the shaded area Pn above.

on the New Jersey side corresponds essentially with the position of its disappearance on the opposite side.

The high terrace is accompanied by low terraces which present no exceptional features. There are sometimes two or more of them, but in all cases they represent successive flood plains developed in the process of degrading the original valley train.

Beginning at d, Fig. 83, is a terrace sixty-four feet above the river, and at this point about two rods wide. Its surface slopes toward the stream. To the south, the terrace rises, until at e it reaches its maximum elevation of about eighty feet above the river. Its surface meanwhile has become wider and flatter, and a slight depression has appeared between it and the bluff. Below e, the terrace assumes the form of a flat-topped ridge, which form it maintains to h, where a creek has cut through it. The interrupted ridge is resumed below the creek and continues to k, where another slight break, four to six feet deep, occurs. Beyond the break, the equivalent of the ridge is continued to the upland. From d to k the terrace has the form of a ridge, which leaves the valley bluff, tangent fashion, at e, and recurves to the bluff at k, enclosing a depression between itself and the upland.

The depression between the ridge and the upland is partly constructional, and partly the result of subsequent erosion. The drainage line below f is occupied by water during wet seasons only. Its course above g was determined by the constructional depression. The course of g, after reaching the terrace, also points to the existence of a depression back of the terrace ridge. This stream probably originally crossed the ridge at k, but was later diverted by a tributary, working back from the river at h.

The material of the ridge is exposed at h, where it is seen to be well stratified sand, gravel and cobbles. The surface is well covered with cobbles, except where they have been removed by human agency.

Comparing this terrace ridge with that at Martin's Creek station, the two seem to have several points in common. Both stand in the same relation to valley curves; both are themselves curved, though one recurves to the upland, while the other does not; both slope from the up-stream end to the down-stream end, the point of maximum elevation being near, but not at the upper end; both have depressions behind them, and both consist of the same sort of material, grading from coarse to fine in the same manner.

At Phillipsburg.—Between Harmony station and Phillipsburg, the high terrace does not appear on the New Jersey side of the river. In this part of its course, the stream flows at the immediate base of the high rock wall which limits the valley. Near Phillipsburg, remnants of the old valley train appear both above the city and in its lower part.

About one and a half miles north of Phillipsburg, the river

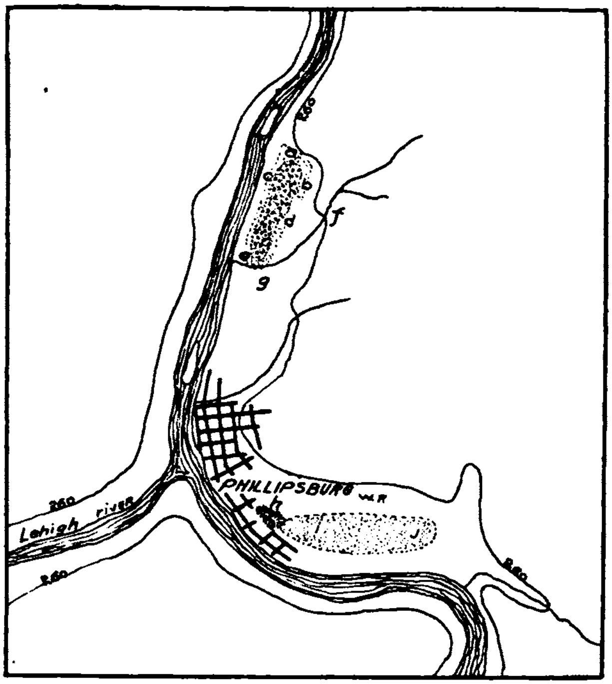


Fig. 85.

Sketch map of a section of the Delaware valley in the vicinity of Phillipsburg. Scale, about one inch per mile.

issues from the narrow gorge which constitutes its valley from Marble mountain (a, Fig. 85). Such glacial gravels as once existed in this gorge have been removed. Immediately below the gorge, the valley broadens suddenly, so that the mountain above juts out into the valley. In the lee of this projecting headland, there is a remnant of the original valley train, shown in Fig. 85. The surface of the terrace is marked by a ridge, a terrace bar, a e, which has a length of 120 rods. Its maximum elevation is a little below its upper end, and from this point it slopes down stream, declining about ten feet in 100 rods. Its maximum width is about thirty-six rods. Between the southern end of the terrace bar and the valley wall, there is a depression which has a maximum depth of twenty-two feet below the crest of the ridge. A part of this depression is due to erosion. North of d, where no stream occupies the depression, it is but four or five feet deep. The material of the ridge decreases in coarseness from north to south, but the coarsest of its material is notably finer than that of the ridge below Harmony station.

Below the high terrace just mentioned, there is a lower one, of secondary origin, forty feet or so above the river. Its surface, like the surfaces of most of the secondary terraces, is of sandy loam. Beneath the surface, sand predominates over gravel, so far as exposures indicate the constitution of the terrace.

In the lower part of the city of Phillipsburg, a boss of rock rises abruptly above the terrace level, and nearly 200 feet above the river. About its base, on all sides, remnants of fluvio-glacial gravels are found; but on the southeast, or down-stream side, the terrace is best developed. Its form is that of a flat, broad ridge, the margins of which are not sharply defined, but blend into the general terrace level. The point of maximum elevation, somewhat below the boss of rock, is about eighty feet above the river. As in the preceding cases, the material becomes notably finer from north to south, until, in the vicinity of j, considerable pits are found where sand for mason work is obtained. In these pits the gravel is very subordinate to sand.

The terrace ridge in the lower part of Phillipsburg (Fig. 85) stands in the same relation to the rock boss above, as that above Mud run (between a and b, Fig. 83). That in Phillipsburg is low, broad and short, as compared with that above Mud run.

At W. F., the site of the Warren foundry, excavations are to be found in drift which antedates the last glacial epoch. These excavations and those in the last glacial terrace afford opportunity for a comparison of the older and younger drift of the region.

Near Carpentersville.—For a distance below Phillipsburg, there are no remnants of the original valley train, but a mile or so above Carpentersville there is a terrace which, like those above, lies on the concave side of the river curve (Fig. 86). Like the preceding, too, the surface of this terrace is ridged. The highest part of the ridge is a little below its head, and a depression lies be-

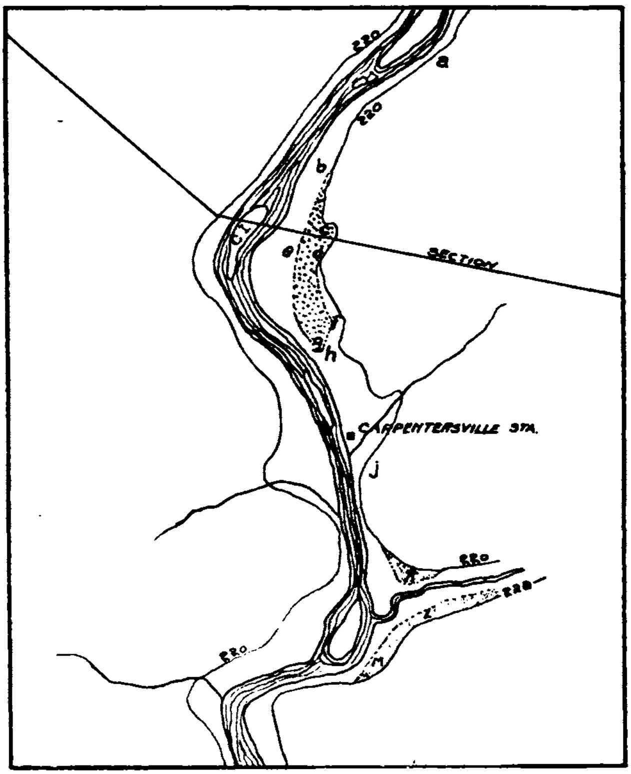


Fig. 86.

Sketch of a section of the Delaware valley showing the positions of high terraces near Carpentersville. Scale, about one inch per mile.

tween it and the valley bluff. The terminus of the ridge is abrupt, like the terminus of a spit. A gravel pit at its southern end shows it to be made up of well stratified gravel and sand, in which cross-bedding is pronounced. This, together with the presence of an occasional bowlder, points to vigorous drainage when the gravel was deposited.

A lower secondary terrace borders the higher, on the riverward side. Erosion has so modified its surface that a distinct terrace flat is not conspicuous, except at the south end of the higher terrace. The relations of these terraces to the valley are shown in Figure 87.

At the mouth of Pohatcong creek.—Near the junction of the Pohatcong creek with the Delaware (between k and m, Fig. 86), there are terrace remnants of the original valley train of the Delaware. These occur on both sides of the creek, that on the north being the higher. The west end of the terrace on the south side of the creek is chiefly of material brought down the Delaware, but the extension of the terrace up the Pohatcong is made up largely of debris brought down by that creek.

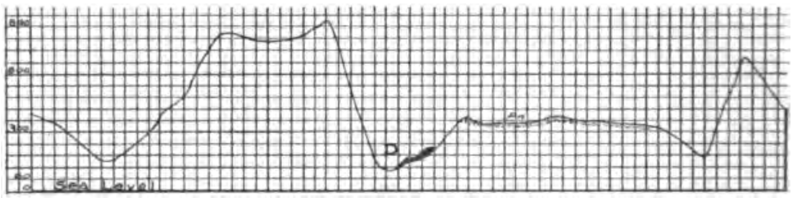


Fig. 87.

Cross-section of the Delaware above Carpentersville, along the line indicated in Fig. 86.

Below the Pohatcong, remnants of the glacial river plain are wanting as far south as Riegelsville, though narrow secondary terraces are present about half the way between these points.

At Riegelsville.—On the Pennsylvania side, just below the point where the river emerges from its gorge in Pohatcong mountain, the highland juts out into the valley, and below the headland is a terrace ridge similar to those described above. Its upper end is separated from the headland by a sag, and from the bluff to the west, by a trough-like depression. Both the trough behind the ridge and the sag between its head and the headland are constructional.

At the mouth of the Musconetcong.—Immediately below the junction of the Musconetcong river with the Delaware, there is a high-level terrace similar to those at the debouchure of the Pohatcong creek. The terrace here is well defined, is about forty-five feet above the river, and is accompanied by lower terraces of secondary origin. The low terraces, generally narrow, continue down the valley, interruptedly, to Holland station and beyond, and have their greatest development in the vicinity of that station.

About Holland station.—Midway between Monroe (Pa.) and Holland station, and opposite Kintnersville, there is a narrow terrace fifty feet or so above the river. It has a length of about 100 rods, and is separated from the valley wall behind it by a slight depression at its lower end. This terrace is notable for the preponderance of local or sub-local material, over that which was brought down the river. This local material is more angular than the glacial gravel, and so was probably contributed by some one or more of the local streams which join the Delaware near this point.

For a mile west of Holland station there is a narrow terrace on the side of the valley, forty-five to fifty-five feet above the river. Its terrace form is best developed just west of the creek northwest of the station. Gravel is subordinate to sand in the terrace at this point, so far as exposures show.

Above this terrace, there are remnants of gravel, generally in the form of scattered pebbles or in thin patches only. Occasionally the pebbles of the higher gravel simulate those of last glacial age, but in general they are sufficiently distinct to be readily recognized. They are probably river gravels which antedate the last glacial epoch.

A little east of Holland station there is a terrace which is probably a remnant of the original valley train, though somewhat below its normal level. Its surface may have been somewhat reduced by erosion.

Below the higher terrace there is a lower one, thirty feet or less above the river, for some distance above and below Holland station. It is composed chiefly of sand, and its surface has been somewhat modified by the wind and by local streams. Through the loamy sand which covers the surface of the terrace, occasional swells of gravel show themselves, in such relations as to suggest that they antedated the deposition of the surface sand, which partly buried them.

It should be noted that while the valley configuration in the vicinity of Holland station is similar to that about Martin's Creek and Harmony stations, there is no corresponding terrace ridge.

Change in the character of the valley.—Below Musconetcong mountain, the river emerges from the more resistant and older terranes into the Triassic, and the valley becomes notably wider.

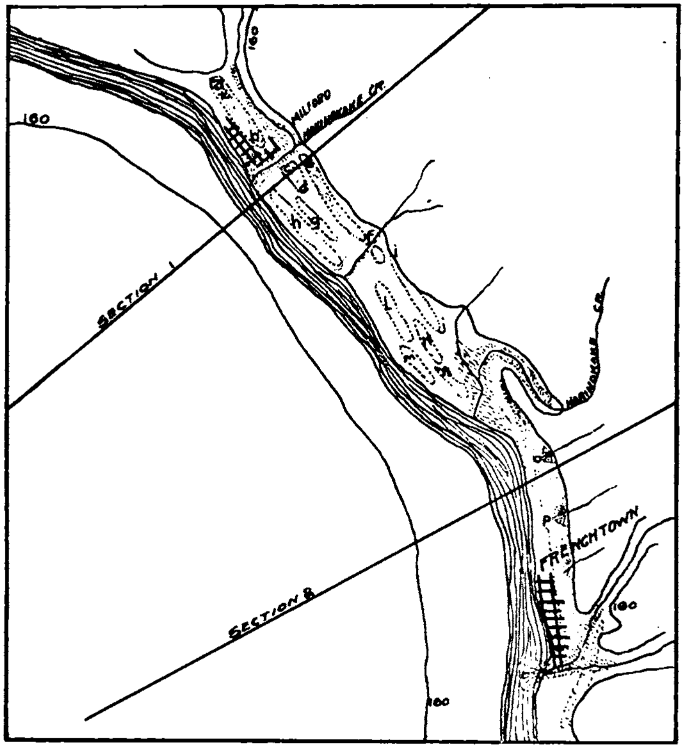


Fig. 88.

Sketch map of a section of the Delaware valley about Milford showing high terrace remnants (shaded) and the position of similar terrace bars at lower levels (no shaded). Scale, about one inch per mile.

Below this point, too, its width is more nearly uniform than above, since there is less disparity in the hardness of the rock in which it is cut. Through the Triassic belt, the course of the valley is more direct than farther north, and there is a notable absence of the short, sharp curves which are found north of

Musconetcong mountain. With these changes in the character of the valley, there are certain changes in the character of the glacial gravels.

At Milford.—Between Holland station and Milford, the fluvio-glacial gravels of the Delaware have been carried away by post-glacial erosion, but at Milford there is a remnant of the glacial river plain, lying partly north and partly south of Hakihokake creek (a, b, c, d, Fig. 88). The terrace is about forty-five feet above the river. It has something of the terrace bar form, being separated from the bluff by a depression which influenced the course of Hakihokake creek. The creek, in turn, has deepened the depression. Between the terrace ridge mentioned above and

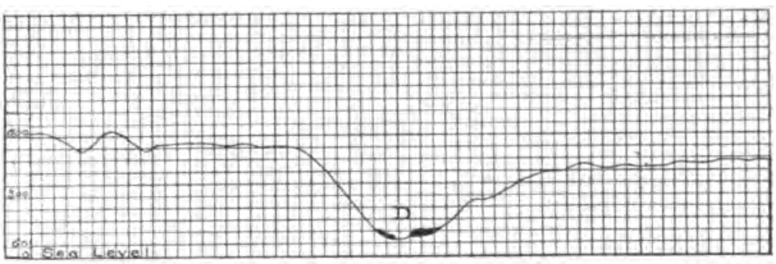


Fig. 89.

Shows the terrace of glacial gravel in the Delaware valley near Milford, along the line indicated in Fig. 88.

the bluff below Hakihokake creek is another similar ridge, which may be a part of the original aggradation plain of the valley. At a slightly lower level, there is a terrace, the surface of which is marked by feeble longitudinal ridges of secondary origin (j, k, l, m, n). The lower terrace constitutes the fertile flat between Milford and Frenchtown.

At Frenchtown.—At Frenchtown, and for a short distance above and below, the old river plain is represented by a flat-topped terrace lying against the shale wall of the valley. Its upper edge attains an elevation of about 150 feet, or about fifty feet above the river. The continuity of the terrace is interrupted by the valley of Nishisakawick creek. The higher terrace is accompanied by a lower, secondary terrace. The higher parts of Frenchtown are built on the upper terrace, and the lower parts on the secondary terrace. The section shown in Figure 90 shows the relations just above Frenchtown, where the lower terrace is not developed in New Jersey. The glacial gravel here is but a cap on the shale bench. Alluvial fans of shale gravel have been built on the terrace where the tributary streams issue from their upland valleys (Fig. 88). Terraces have more extensive development on the Pennsylvania side of the river in this vicinity, than on the New Jersey side.

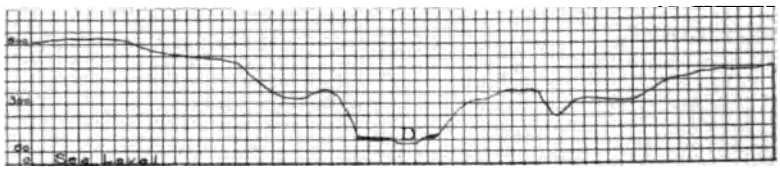


Fig. 90.

Section across the Delaware valley just above Frenchtown showing the position of the glacial gravels, along the line marked in Fig. 88.

Between Frenchtown and Byram.—Between Milford and a point two miles below Frenchtown the walls of the valley are of relatively soft red shale. The valley is flat and wide, and the fall of the stream slight. Two miles or so below Frenchtown, beds of hard black shale make their appearance in the walls of the valley, and farther down, trap occurs. Where these harder formations appear, the valley is constricted to about one-third its width at Frenchtown, and the stream is characterized by rapids where it crosses the harder strata.

With the narrowed valley goes a decrease in the development of the terraces, and remnants of the original plain are found only in protected situations, such as on the downstream sides of projecting headlands. In this part of the valley, terrace remnants occur at the mouth of Copper creek, at a point one and a half miles north of Kingwood station, and at Tumble. In addition to the terraces, traces of the material of the old plain are found on the lower slope of the valley at numerous points.

The terrace remnants of the glacial river plain near the mouth of Copper creek are small and isolated. Just above the creek there is a terrace forty-five feet above the river, and a few feet higher there is a slight bench of gravel which antedates the last glacial epoch. Below Copper creek, there are likewise narrow terrace benches, and traces of glacial gravel down to a point opposite the middle of Stover's Island. In a terrace near the mouth of Copper creek, there is some fine sand, now buried by local debris from the bluff above, which is very like the molding sand common in the valley farther south.

This is the most northern point where this type of sand was observed, and it is perhaps significant that it occurs here at the level of the glacial terrace.

Below Kingwood station, traces of glacial gravel are found up to the level of the original valley train, but no distinct terrace is found as far south as Tumble. Just above Tumble, the stream bends to the east, and just below the bend is a narrow terrace forty feet above the stream. Its surface is now partly covered with debris from the valley walls above, but beneath the surface the glacial gravel is found. The gravel here evens up an uneven surface of shale.

Between Tumble and Byram, thirteen little tributaries, varying in length from a fraction of a mile to three miles, join the Delaware. Their courses are generally at the contact of black shale layers, with red. Most of them illustrate the principle of monoclinal shifting, the channels of the streams being shifted down dip, that is, to the northwest. All these streams have built alluvial fans where they debouche into the Delaware valley.

Near Byram.—Just below Byram, the river turns eastward and the valley widens notably. In the concave side of the bend is found a terrace remnant of the original valley plain. Secondary terraces have much more extensive development, and are continuous from a point just below Byram to Hendricks Island, and have but little interruption to Lambertville.

Just below Byram, there are several notable terraces. The third above the river is regarded as marking the original level of the glacial valley plain at this point. Its maximum height is more than fifty feet above the river. Lower secondary terraces occur at about forty to forty-five feet above the river (low water) and at lower levels.

Above the terrace remnant which is regarded as marking the level of the original plain, there is gravel which antedates the last glacial epoch, rising to a height of nearly seventy feet above the river.

Raven Rock.—Above Raven Rock there are traces of glacial gravel on the slopes of the valley, though no terrace remains. Bulls Island and the corresponding plain south of Raven Rock

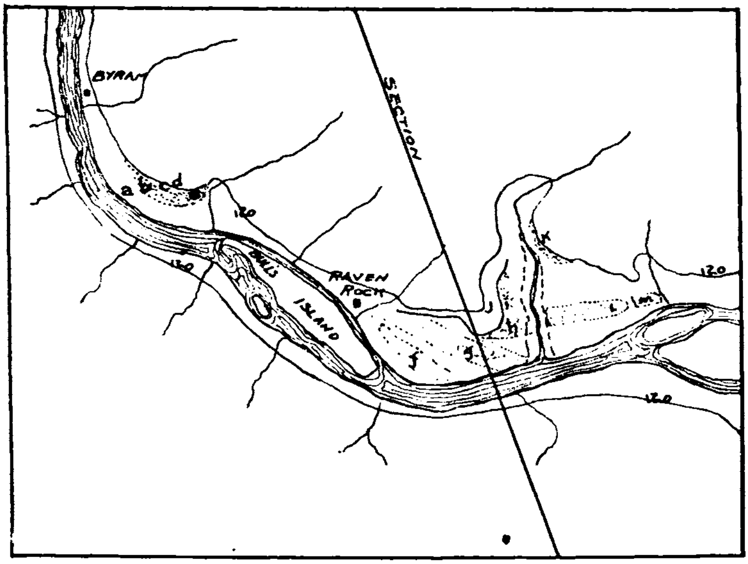


Fig. 91.

Sketch map of a section of the Delaware valley near Byram and Raven Rock, showing the position of remnants of the valley train. Scale, about one inch per mile.

represent a secondary terrace level, the surface of which is somewhat ridged like the surfaces of most of the lower terraces.

Below Raven Rock, near the mouth of Lockatong creek, are terrace remnants at, or near, the level of the original valley plain. They range from a little less than forty to nearly fifty feet in height. They extend a short distance up the valley of the Lockatong, and in this direction are composed largely of local material. Occasionally pebbles of glacial gravels are found on the slopes a few feet above the terraces.

Old drift at Raven Rock.—Well above the terrace of last glacial age, at Raven Rock, there is a bed of older gravel at the elevation of about 100 feet (Pn, Fig. 92). This gravel does not itself constitute a terrace, but caps a rude bench of rock. The material of this higher gravel is more heterogeneous, physically, than that of the younger terrace below. Bowlders two or three feet in diameter are common, and there are a few five or six feet in diameter. A brown-red loam, very different from the loam of the lower terraces is associated with the older gravels, giving them a heavier soil. This high level gravel is locally as much as six feet at least in depth. It differs from the younger gravel below in its greater weathering, in the absence of limestone, of fresh granitic material, and of the bright, fresh-looking blue-black discs of shale and sandstone characteristic of the late glacial gravels below. The older gravel contains a considerable variety of sandstone, quartzite, chert, etc., but weathering has given to all varieties of pebbles a similar surface aspect, so that their real nature is not easily recognized.

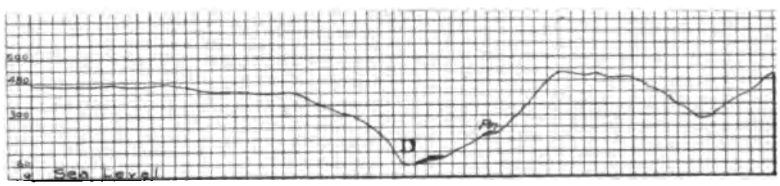


Fig. 92.

Cross-section of the valley of the Delaware, along the line indicated in Fig. 91. Shows the valley train of the Delaware, the black area near the bottom of the valley, and the old drift, Pn, on the slope above.

Gravel older than the last glacial gravel, has been referred to at several points in the preceding pages. They occur at Hutchinson's, Martin's Creek and Holland stations, at Carpentersville, Phillipsburg, etc.; but at these places, similar materials extend back over the uplands, and are not confined to any particular level near the stream. At Raven Rock, on the other hand, the older material does not run back over the uplands, but is confined to the valley. It will be seen later that the ice of an early glacial epoch came as far south as Riegelsville, and the old drift found here at Raven Rock is perhaps a remnant of the valley train of this early ice sheet.

Between Raven Rock and Lambertville.—Except near the debouchure of Lockatong creek, remnants of the original valley plain are absent on the New Jersey side of the river between

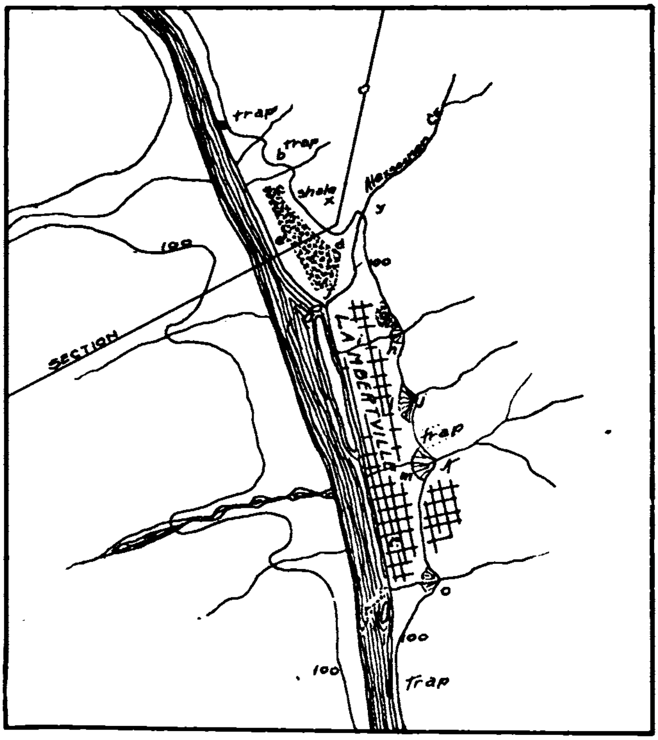


Fig. 93.

Sketch of the Delaware valley near Lambertville showing the glacial (the shaded area) just above.

Raven Rock and Lambertville, though terraces of glacial gravel are found on the valley slopes up to the level to which the valley was once filled. Lower terraces of secondary origin are however not wanting between the points mentioned. Within this stretch, the lower terrace is best developed at Stockton, which is built chiefly on the secondary terrace about thirty feet above the river.

On the slope above the terrace, there is gravel weathered out from the arkose conglomerate beds which outcrop in this vicinity. This gravel is to be distinguished both from the late glacial gravel, and from the old drift.

About Lambertville.—The glacial gravels about Lambertville attain an elevation of about 100 feet. A mile and less above Lambertville, the walls of the valley are of trap rock, and the valley is narrow. Where the stream passes from the trap to the shale, the valley widens so that the portion below 100 feet is about three times as wide as where the stream flows through the trap. Below Lambertville, the valley is again constricted where the stream crosses another bed of trap.

Just below the point where the stream passes from the trap to the shale above Lambertville, there is a terrace which represents

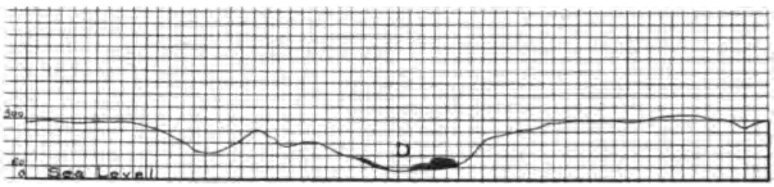


Fig. 94.

Cross-section. showing the relations of the glacial gravel along the line indicated in Fig. 93. There are two terraces, a higher and a lower.

the original surface of the valley train. It extends south to Alexsocken creek, and has a height of about forty feet above the river. A slight depression, four to eight feet deep lies between the top of the terrace and the valley bluff. At its two ends, this depression has been deepened a little by erosion. At its upper end, the terrace is separated from the trap headland by a depression now occupied by a small creek, but the depression probably antedated the creek.

The terrace is of gravel and sand, and the gravel is often coarse, cobbles three to six inches in diameter being common in the north part of the area, but less common to the south. In its essential features, this terrace corresponds to the terrace-ridges in the valley farther north. Its southern terminus, as it now exists, has been fashioned by the erosion of Alexsocken creek. Below this creek, there is a little bench of gravel below the bluff which perhaps represents the original continuation of the terrace-ridge north of the creek. If this be correct, the terrace-ridge recurved to the bluff, like that at Harmony station (Figure 83). The relations of this gravel are shown in cross-section, in Figure 94, where both the higher and lower terraces are shown.

Low terraces accompany the high, and have a much greater area. Their levels are sometimes much below that of the upper terrace, and sometimes but little. Just below Lambertville, what appears to be a secondary terrace is but little below the level of the terrace representing the original aggradation plain. Alluvial fans have been built on the terraces by the little creeks coming down from the east.

Just south of Alexsocken creek, and above the Delaware, at an elevation of between 140 and 200 feet, there is a considerable quantity of fine sand, best exposed in the gullies on the slope. Similar sand is found irregularly distributed above the highest of these levels, and below the lowest; in the former position it might readily be explained by wind action, and in the latter by local wash. But between 140 and 200 feet it is most abundant, being so disposed as not to be obviously explained by wind action. The sand belongs to the general class of molding sand already noted as occurring at Kingwood. It also occurs at various points farther south.

At Goat hill.—Between the lower part of Lambertville, and Goat hill, terraces are absent. At Goat hill, one and a half miles farther down stream, the river crosses beds of trap, and the valley is constricted. Trap recurs at Belle mountain. Between these points, the valley widens, and in this wider portion, terraces are well developed. The high terrace, representing the original aggradation level, has a length of less than a mile. Its surface is flat, and its general level is about fifty to sixty feet above the river (Fig. 95). Next the bluff it is somewhat higher, and its surface seems to have been built up by accumulations of material washed from the face of the bluff. Swells of older gravel appear to project up through material of late glacial age at this point, reaching a maximum elevation of seventy-two feet above the stream.

The low terrace is about thirty-five feet above the river just below Goat hill, its highest part being next the stream, and its lowest next the high terrace. Its surface is more or less ridged longitudinally, agreeing in this respect with the surface of most of the low terraces. Narrow benches intermediate in level between the main low terrace and the high terrace, occur at some points.

At Moore's.—Below the constriction in the valley occasioned

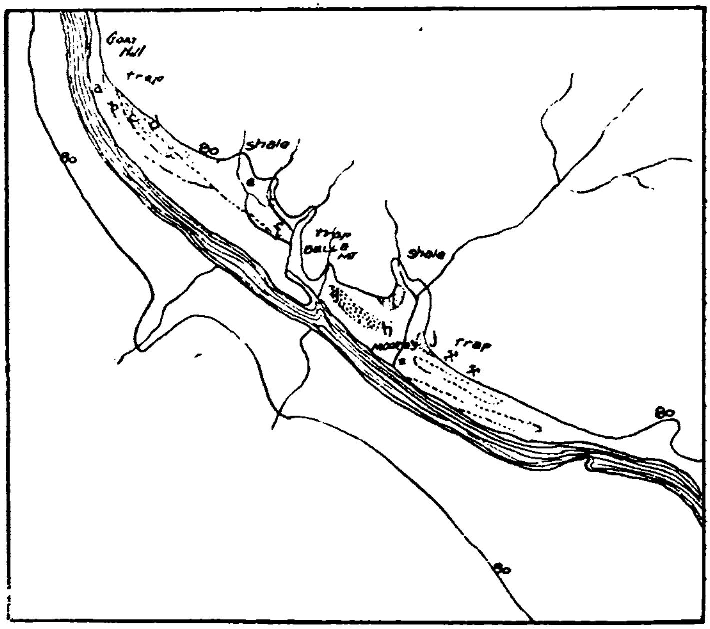


Fig. 95.

Sketch of the Delaware valley just below Goat hill, showing the position of the terrace of glacial gravel.

by the trap of Belle mountain and Bowman's hill (Pa.), the valley again widens, leaving Belle mountain as a conspicuous headland. Below it, just above Moore's (gh, Fig. 95), there is a terrace ridge of glacial gravel. Its upper end is about fifty feet above the river, and its surface slopes down stream. At its head, a depression separates it from the headland, and this depression is now occupied by a drainage line. The depression, however, is believed to have antedated the creek. On the bluff side of its upper end, the ridge is built against the upland, but a little lower down, a depression appears between it and the upland, as in the cases noted before. The ridge is cut off at the south by the valley of Moore's creek. This local terrace patch is largely of local material, brought down by the creek.

Below the high terrace are considerable areas which are to be classed with the secondary terraces. The surface is generally much cut up by erosion, so that terrace flats are mostly wanting. A low terrace extends southeast of the station for about a mile, pinching out where the river swings to the east against the bluff. Below the station, there are distinct ridges on the low terrace, comparable in form with the higher one near Belle mountain.

Between Moore's and Washington's Crossing.—Below Moore's, the river crosses the last trap belt in its course. The trap bluff on the New Jersey side is Bald Pate, and that on the Pennsylvania side is Jericho mountain. Below the constriction, the valley becomes wider and shallower. Between Bald Pate and Washington's Crossing, terrace remnants representing the original degradation plain, are essentially wanting. There are occasional trivial benches of gravel, but more commonly nothing more than a few scattered pebbles on the lower slope of the bluff, to indicate the level of the original plain, which seems to have been some fifty feet above the river, and eighty feet above sea level. The exact upper limit of the glacial gravels is difficult of determination, because the remnants are meagre, and because of the shifting of pebbles through fertilizers used on the land. Individual cases are known where great numbers of pebbles from the glacial gravel terrace below, have been carried up with manures to the lands above. Furthermore, in this part of the course of the valley, there is not a little gravel referable to a time earlier than the last glacial epoch, and where the last remnants of gravel are very meagre, it is not always easy to distinguish between certain types of pebbles of this older gravel, and those of later age.

The secondary terraces have a more considerable development than the higher, and are much more extensive on the Pennsylvania side of the river than on the other.

Molding sand, often with a disposition to become distinctly loamy, occurs just south of Fiddler's creek up to elevations of 100 feet or more. Molding sand occurs also on the slope between Titusville and Washington's Crossing, well above the level of the glacial gravels. It is most abundant at levels between eighty and 120 feet, but is not confined within these limits.

Between Washington's Crossing and Trenton.—Half a mile or less above Washington's Crossing, on the north side of a little run at this point, there is a small terrace remnant at an elevation of about eighty feet, and fifty to fifty-five feet above the river. The gravel is merely a capping to a shale bench, but it may represent the original aggradation plain of the river. From Washington's Crossing to Jacob's creek, there are traces of glacial gravel forty to sixty feet above the river, but it occurs in no considerable body. Between forty and sixty feet above the river, the shale slopes are nearly free from foreign material of all sorts, while above this level, molding sand is common.

At Somerset and below, the valley slope is rather steep from the river level (twenty feet) up to 200 feet. On this slope, gravel is essentially wanting, but molding sand is common, being rather more abundant at seventy to ninety feet than that above or below those levels, though it is present, in patches at least, up to 180 feet. From a point half a mile below Somerset to a point a mile below, there is a shale bench at about eighty feet, on which the sandy loam is especially well developed.

About half a mile above Wilburtha, on the north side of the little valley tributary from the east, there is a little terrace common to the Delaware and to the tributary, which is believed to mark the original aggradation plain of the river at this point. The terrace is mainly of rock, but its surface is covered with a thin layer of gravel, some of which is of late glacial age. Its elevation is seventy-three feet A. T., and fifty-five feet above the river.

The low terrace is well developed at Wilburtha (Fig. 96), and its surface is marked by strong longitudinal ridges, and depressions, developed by drainage. The low terrace here is largely of gravel, and in this respect is in contrast with most of the low terraces farther up-stream.

Above the quarries at Wilburtha, the sandy loam is well developed at an elevation of about ninety feet, though it has no sharp limits in altitude.

About Trenton.—At Trenton, where the Delaware river leaves the Triassic terrane, the course and character of its valley are greatly changed. From a southeast course, it changes to a southwest one,, the change in direction being rather more than ninety degrees. As it shifts to the southwest, it follows the contact of the Cretaceous terrane with the crystalline schists. The broad valley of the Assanpink, which joins the Delaware at Trenton, lies at the contact of the Triassic and Cretaceous terranes. The sudden expansion of the Delaware valley at Trenton is a plain index of the relative resistance of the Cretaceous and Triassic terranes. A second illustration of the same thing is afforded by the valley of

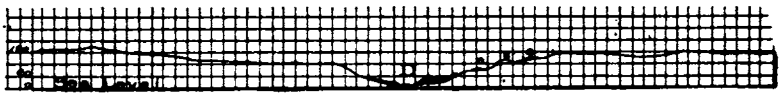


Fig. 96.

Shows the relations of the low terraces and molding sands near Wilburtha.

the Assanpink creek which, above Lawrence, is in the Trisassic rock, while below that point, it is at the junction of the Cretaceous and Triassic, the valley being cut mainly in the former.

With this change in the character of the valley goes a notable change in the disposition of the glacial gravel, for its original disposition was dependent upon the topography at the time of its deposition. About Trenton, the gravels are spread out in a broad plain about sixty feet above sea level. On this plain the city of Trenton is built, but the plain extends far beyond the limits of the city. To the northeast it extends nearly to the mouth of Miry run, and to the east well beyond the limits of Chambersburg (see Fig. 97). The expansion of the glacial gravels on the Pennsylvania side, is hardly less notable.

In this plain the gravel is by no means simply a veneer on a rock terrace, as is often the case in the valley above. The body of gravel is of considerable thickness, often as much as twenty-five feet of gravel, cobbles, etc., chiefly of last glacial origin, is known to occur. At this point the glacial gravel is mixed with materials derived from gravels of greater age, the latter having been worked over by the waters which deposited the former. At p, no glacial gravel occurs, but the gneiss is covered by two or three feet of older gravels. At s, three feet of glacial gravel is known to occur, while beneath it there is ten to fifteen feet of gravel deposited before the glacial waters came down the valley. The lower gravel at this point was probably derived from the older gravel formations in the vicinity. At o, in the railway cuts, twenty feet of glacial gravel is exposed. At m, more than twenty feet of

Fig. 98.

Section showing the dispositions of the Trenton gravels along the line of section 3, Fig. 97. The black portions represent the glacial gravel. A, the crystalline rock of the region; T, Trias.; K, Cretaceous; and Pp, Pensauken.

Fig. 99.

Section like the last, along the line of section 2, of Fig. 97. Legend as in Fig. 97. S, molding sand.

glacial gravel is known to exist, and at t, the glacial gravels attain a similar depth.

East of the localities mentioned, the glacial gravels become thinner, until, along the line x'l, they practically disappear. Even west of this line, the glacial gravels are mingled to some considerable extent with non-glacial gravels which were derived from the east. East of the line x'l, occasional pebbles of last glacial gravel are still found, but they are very subordinate to the materials of greater age which occupied the region before the last glacial waters came down the Delaware. Fig. 98 shows the general relations of the Trenton gravels in this region.

Below the point p, Fig. 97, following the analogy of what is found farther up the valley, a terrace ridge might be expected, but nothing of the sort is found.

The section shown in Figures 98 to 99 give some idea of the Trenton plain. These sections show that the Pensauken formation, Pp, made up of nearly horizontal beds, lies at levels slightly higher than that of the glacial gravels. The Pensauken formation itself is largely composed of gravel, but its material is readily distinguished from the glacial gravel of the Delaware valley. The gravels which underlie the glacial gravels about Trenton, are possibly in some cases remnants of the Pensauken at low levels, but more of them are probably river gravels derived from the Pensauken or older formations, and deposited by streams after the original deposition of the Pensauken, and before the last glacial epoch.

SUMMARY.

The gravel formation of the Delaware is continued south of Trenton along the Delaware river, and also through the valley extending from Trenton via Baker's basin, Kingston and East Millstone, to the Raritan river. The gravels between Belvidere and Trenton are, however, somewhat distinct from the rest, and may be summarized at this point.

The low terraces.—From the foregoing description, and from the maps, it will be seen that at nearly all points along the river from Hutchinson's to Trenton, where terraces occur at all, there is a terrace twenty to thirty feet above the river, which has been designated the *low terrace*. Above this prevalent low terrace, there are locally, other benches at various levels, below that of the highest terrace.

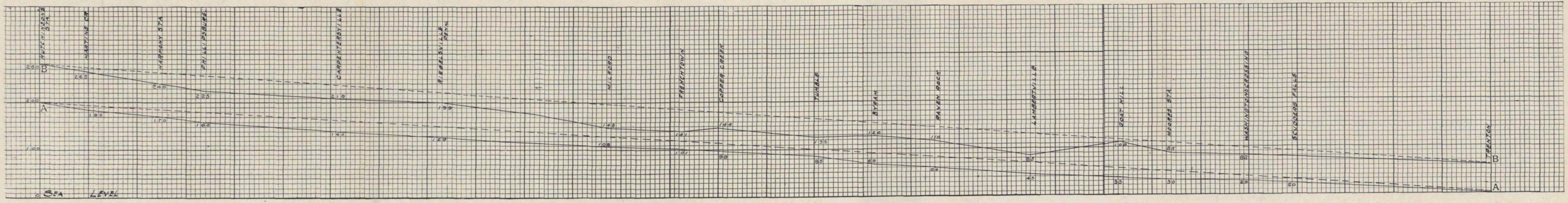
The low terraces have certain persistent characteristics. Superficially at least, they consist largely of sand; they occur at various levels between the flood plain and an elevation of thirty feet above the stream; but rarely higher; and they may often be observed to grade into the flood plain either up or down stream. They present certain rather distinctive surface features, which are common to the flood plain as well. Their surfaces are marked by ridges and furrows, whose direction is, in general, longitudinal. In particular cases, their direction is often slightly oblique to the stream.

The distribution of the low terraces appears to have been determined by the vigor of the stream, and by the form of the valley. Thus above Musconetcong mountain, the valley is rather narrow and tortuous, and the declivity of the stream relatively great. The low terraces are disposed in short, narrow bands on the concave sides of bends, and in other sheltered places, while they are absent from the convex sides of the bends and the more gorge-like portions of the valley. Below Musconetcong mountain, that is, in the Triassic area, the valley is broader, less tortuous, and the declivity less than above. Here the low terraces are broader and more continuous; indeed, counting the terraces on both sides of the river, they are continuous.

So far as constitution is concerned, there is no recognizable difference in the low terraces of the upper and lower parts of the valley, except that in the Triassic area, a small amount of Triassic material enters into their make-up. The surface configuration is likewise essentially constant, though the longitudinal features referred to show rather more of a tendency to meander in the lower, broader part of the valley, than above. The identity of configuration of flood plains and low terraces points to the same mode of development. The low terraces are indeed but flood plains of an older generation.

The mode of the development of the topography of flood plains will not be discussed here. It is sufficient for present purposes to state that a stream of the Delaware type, loaded with gravel and sand in transit, does not develop or maintain a uniformly smooth bottom. The irregularities consist of bars of sand and gravel. the positions of which, as well as that of the intervening channels, are constantly shifting. In some cases, the bars are built up, and in others, the depressions are hollowed out.

The high terraces.—From the foregoing description, it is seen that remnants of the original valley train of the Delaware river between the moraine and Trenton are relatively meagre. They are present on the New Jersey side of the river less than one-tenth, and perhaps not more than one-fifteenth, of the distance



A–A, Profile of the Delaware River from Hutchinson's Station to Trenton.
B–B, Profile of the Trenton gravel terraces.

en the moraine and Trenton. Where present, the terraces ten narrow and meagre, so that it is sometimes uncertain heir upper surfaces represent the original surface of the train. In such cases their surface material may have been rked.

te LXVI represents in profile the Delaware river and its es. The dotted line A A is a line drawn from the level of ver at Hutchinson's to tide level at Trenton, and represents verage gradient of the river between these points. The ne A A was plotted by taking the altitude of the river at is points where terraces are well developed. The declivity river is seen to be much greater at some points than at s. As a whole, it falls below the dotted line A A, showing ne fall of the stream in the upper part of the stretch between hinson's and Trenton, is greater than its average fall be- these points.

e dotted line B B is a line drawn from the terrace level at hinson's to the terrace level at Trenton, while the full line was determined by joining the levels of the terraces at us points along the Delaware where they are well developed. terrace levels are seen to fall more below the mean terrace ent, than the stream falls below its mean gradient. It will e seen that the variations in the terrace gradient are greater those of the present stream. The profiles show that the tions in the terrace and stream gradients sometimes coincide sition, and are sometimes independent. Where the varia- of the two coincide in position, they are sometimes of the phase, and sometimes of opposite phases. In the one case, terrace gradient increases where the stream gradient in- es, as from Copper creek to Tumble, and from Hutchinson's hillipsburg; in the other case, the terrace gradient decreases e the stream gradient increases, as between Frenchtown and er creek, between Lambertville and Goat hill, and between ble and Byram.

will be seen, therefore, that there is no simple or constant ion between the minor variations of the gradient of the m and of the terraces, or at least no such relation is apparent e profile.

It is probable that some of the irregularities and discrepancies which appear in Plate LXVI are the result of the incomplete data, or erroneous interpretation. Thus in some cases, the terrace level is represented as actually rising down stream. This is especially notable at Goat hill, and less so at Copper Creek. It is not improbable that some of the terraces used in plotting the line B B of Plate LXVI, for example that at Lambertville, do not represent the full height of the original plain. On the other hand, the places where the terraces are especially low, between Milford and Frenchtown, and between Raven Rock and Lambertville, are places where the valley is wide.[1] It is to be noted further, that in the construction of the line of Plate LXVI, the data used are, for the most part, drawn from one side of the river only, and the data from the other side would perhaps have removed some of the apparent irregularities.

Some considerable variations in the original surface of the plains were perhaps the result of the building of bars in the river at different stages of its height. The variations in the depth of the water, and so in the height to which bars might be built, must have been considerable in a stream subject to such seasonal flooding as was the Delaware while the melting ice water was being discharged through it.

The maximum heights of the terraces are just below the narrowest parts of the valley. This is most conspicuous in the terrace bars, the highest points of which are just below the gorge. This is in keeping with the position of the highest points on bars now forming in rivers.

Material.—In general, the material of the glacial terraces is heterogeneous, both physically and lithologically. The ice which supplied the material had come from a great variety of formations, and therefore had various sorts of material in various degrees of comminution.

Just below the moraine, the material of the overwash plain has

[1] At Raven Rock, the terrace level of the Delaware terrace proper (not that of Lockatong creek) is used, in the construction of the profiles (Plate LXVI). North of Riegelsville, the levels used are the maximum elevations of the terrace bars. If levels at certain other points of the terrace had been chosen, the line BB would have been more irregular.

as wide a range lithologically as the material of the moraine itself. Physically, it ranges from bowlders three feet or so in diameter, to sand. At Hutchinson's, about ten per cent. of the material is six inches or more in diameter, and about twenty-five to thirty per cent. is estimated to be between two and six inches in diameter. Sand is a minor element. At Milford, about twenty-eight miles below the moraine, the material is noticeably finer than at Hutchinson's. Cobbles three inches in diameter sustain about the same relation to the material as a whole, as the six-inch cobbles do at Hutchinson's. At Trenton, sixty miles below the moraine, the material is still finer, the one-and-a-half to two-inch material sustaining about the same relation to the whole that the three-inch material does at Milford.

The decreasing coarseness southward is, however, by no means uniform. Numerous places could be found where the material is much coarser than at other points farther up stream. It was noted in the description of the terrace bars, that the material was coarser near the upper ends than near the lower. Similar variations within short distances are found in the terraces apart from the bars. These variations doubtless record notable fluctuations in the velocity of the water, variations which must necessarily have accompanied its fluctuating volume.

There is also something of a lithological change in the character of the material with increasing distance from the moraine. Thus limestone pebbles become notably less numerous down the river, and practically disappear before Trenton is reached. This is probably because the limestone is relatively less resistant than many other sorts of rock, and the limestone pebbles were worn out before they had gone so far down the valley. The pebbles and cobbles of Oneida sandstone and quartzite likewise seem to become less abundant to the south, but for a very different reason. These are, on the whole, the most resistant stones in the valley gravel, and many of them are large. On account of their size, a larger proportion of them, as compared with many others, were left in the upper portion of the valley. The Medina sandstone is somewhat less resistant than the Oneida, and maintains its importance to the southward. Granites and gneisses also retain their relative importance throughout the valley. They are more easily worn than the Oneida sandstones and quartzites, and less readily than the limestone. The proportion of quartz or quartzite pebbles is not subject to great variation in different parts of the valley. Pebbles of greywacke become relatively more abundant to the south. This is perhaps partly because streams south of the ice supplied them to some extent.

One of the characteristic pebbles of the valley is the disc-shaped pebble of bluish sandstone, belonging to the general class of greywackes. These, on the whole, are more abundant in the lower portion of the valley than above. This is perhaps because prolonged wear was necessary to develop this form of pebble. Cherts are relatively more abundant below than above. This may be because some of the cherts were isolated, as the limestone in which they were originally imbedded was worn away, and partly because, in the lower part of the valley, tributary streams brought in some chert derived from gravel formations which antedated the late glacial formations. Pebbles of Triassic sandstones and shales are of course absent above the Triassic terrane, but present in the gravels below.

The percentage of unidentifiable material increases to the southward. This is perhaps in a measure the result of material brought in by tributary streams, and in part the result of the wear of material derived from the north. The pebbles which reached the southern limit of the area under consideration had been subject to prolonged wear, and the materials from various formations had been destroyed, except for the harder parts. These harder remnants, derived from various sorts of rock, sometimes fail to possess the normal characteristics of the formation from which they came, and so are not readily identified.

GLACIAL GRAVELS IN THE ASSANPINK-MILLSTONE VALLEY.

Details.

From the Delaware at Trenton there is a valley extending northeastward to the Raritan river at Finderne which, though now occupied by several streams, appears to be a unit. At the

Delaware end, the valley is occupied by the lower part of Assanpink creek, as far as Baker's basin. Above this basin, the Assanpink leaves the main valley, which is continued northeast to Port Mercer. For a mile above Baker's basin, it is occupied by the lower end of Shipetaukin creek (Fig. 97), but above the point where the Shipetaukin enters it, the valley is streamless as far as Port Mercer. In this streamless valley, at an elevation of sixty feet A. T., is the divide between the Delaware and Raritan systems of drainage. The divide is really a flat which, at a maximum, is about seven feet higher than the streams on either hand. As nature left it, the divide was a marsh, from which, in wet seasons, water flowed both ways. A dam has been constructed across it to prevent the overflow of Stony brook to the Delaware in times of flood. At Port Mercer, Stony brook enters the valley from the northward, but instead of continuing southwestward to Trenton, which would be its normal course, it turns abruptly to the northeast, and four miles beyond joins the Millstone, which enters the valley from the east at that point. The Millstone, reinforced by Stony brook, then follows the valley northward to the Raritan.

From Baker's basin north and northeast, the old valley is in the Triassic series, and though shallow, is generally rather steep-sided and narrow. Southwest of Baker's basin, the valley is at the contact of the Cretaceous with the Trias and the Trenton schist, and is broad and shallow.

The most abnormal feature of the present drainage through this valley is the course of Stony brook. From its entry into the old valley, it takes a twenty-five mile route to tide level *via* the Millstone and Raritan, instead of a seven and a half mile route, *via* the Assanpink and the Delaware, with no divide of consequence between the two routes. The course of Stony brook above its entry into the old valley is such as to lead to the conclusion that when it was developed it was tributary to the Delaware. If it once had such a course, it is incredible that it should have been diverted to the Millstone by the tributaries of that system, for no tributary of the Millstone which has to cross the Rocky Hill trap range could capture a stream which had no such obstacle in its way.

It has already been seen that the Delaware valley train of gravel expands greatly at Trenton, extending off to the northeast nearly or quite to Baker's basin. It is also true that there is a notable expansion of the glacial gravels which came down to the Raritan from the moraine near Plainfield, about the junction of the Millstone and Raritan. It is now to be added that there are traces of glacial gravels at various points along the old valley between the Delaware and the Raritan.

Figure 97 shows the expansion of the Delaware gravels northeast to Baker's basin. The sections, Figs. 98, 99 and 100, show the topographic relations of these gravels.

The continuous body of glacial gravel on the northwest side of Assanpink creek ceases half a mile or so below the junction of Shabacunk creek, but it is continued farther east (to x'l, Fig. 97) on the southeast side of the creek. Through the gravel, Pond run has cut a narrow valley which is in striking contrast with its wider valley above.

Fig. 100.

Section along the line of section 1, Fig. 97, showing the relations of the glacial gravels (Pg) in Baker's basin.

The continuity of the glacial gravel plain is interrupted by the valley of Miry run, but north of this valley traces of the glacial gravel are again found. Below a low rock boss at i, Fig. 97, there is a fan of gravel, which recalls the disposition of gravel below rock bosses at various points in the Delaware valley. The locality is (near the line x'x) where the glacial gravel, if present, would be much mixed with local gravel. In the absence of exposures, the gravel here cannot be affirmed to the glacial; but glacial material is probably present, mixed with much of non-glacial origin. The shape of the gravel fan suggests that it was built from the northeast.

East of the rock boss, at j, Fig. 97, is a hill, the crest of which is seventy-nine feet high, capped with Pensauken gravel. East of it is a low gravel ridge, three to ten feet high, which appears to be a constructional ridge (Knapp), and its form shows it to have been made from the northeast. Its material is not exposed. At h, Fig. 97, there is an indistinct terrace strewn with gravel which probably contains some glacial material.

It will be seen that for a mile or so southwest of Baker's basin, the presence of glacial gravel has not been absolutely determined, but this is believed to be due to lack of exposures, rather than to its absence. At Baker's basin, there is a considerable area where there is a distinct bed of gravel, some of which is glacial. The form of the bed is outlined in Figure 97. Its highest point is sixty feet A. T. Gravel is here exposed to the depth of ten feet. While it contains much material which is not of glacial origin, such material is mingled with that which had such an origin. Limestone, fresh granite, and the disc-shaped pebbles of sandstone so characteristic of the Delaware valley gravel, are all present. These pebbles show that the gravel of the basin was deposited after the glacial gravel reached this latitude, and that the glacial gravel was mingled, in deposition, with materials derived from the Pensauken of the vicinity.

In addition to the Delaware valley types of pebbles, there are found at Baker's basin pebbles of granite of a type not seen in the Delaware valley above Trenton, a type which, if present, is certainly not common. These pebbles appear to be identical with granite pebbles in the gravels of the Raritan valley about Bound Brook, and this is believed to have been their source.

The gravel at Baker's basin appears to be coarser to the northeast, and finer to the southwest, a fact which, like the several points mentioned above, suggests its deposition by currents from the northeast.

At b, Fig. 97, there is another small area of gravel which contains material which is distinctly glacial. Similar material is also to be seen at points east of the Baker's basin area, though nowhere east of the line x'x.

Just south of Duck Pond run (n, Fig. 101), there is a bench of gravel at an elevation of seventy feet according to the topographic map, containing pebbles of glacial material. The depth of the gravel at this point is known from a well to be at least fourteen feet.

The general form of the valley between Port Mercer and Rocky Hill and beyond, is shown in Figure 101. The lines on

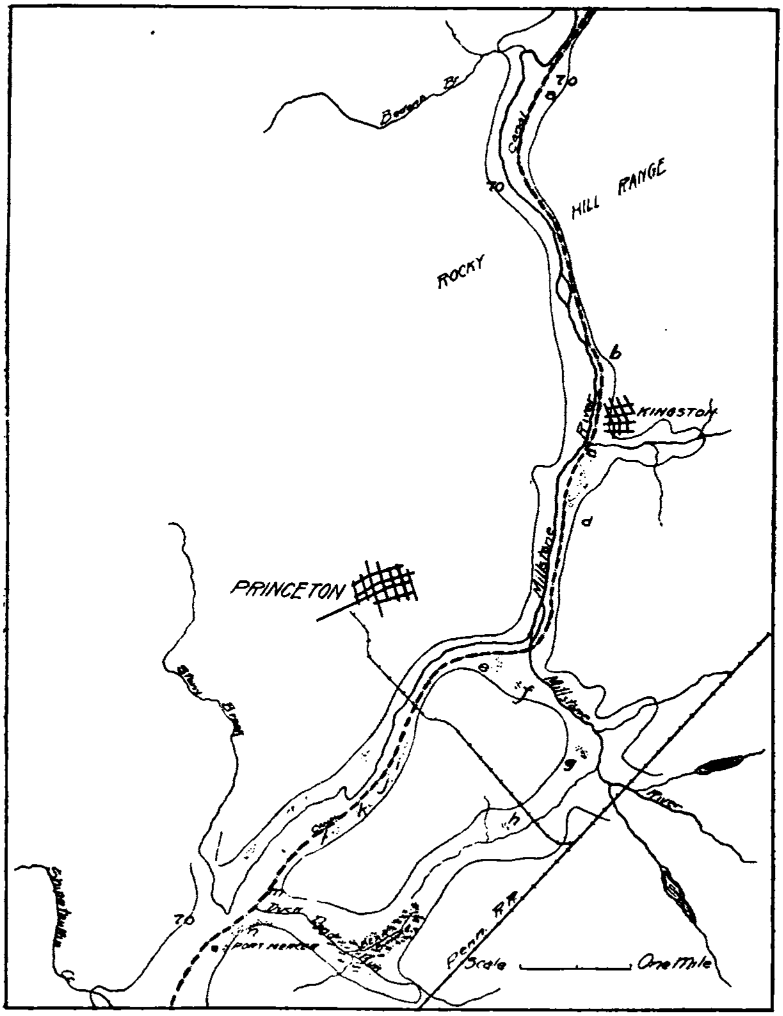


Fig. 101.

Sketch map of the Trenton-Bound Brook valley between Port Mercer and Griggstown. Traces of glacial gravel shown at several points by shading.

either side of the stream in the figure, are the seventy-foot contours. It is only the part of the valley below these contours which is of significance in this connection. The valley above Port Mercer is seen to be narrower and deeper than below.

The only traces of glacial gravel which are found in the valley of Stony brook below Port Mercer are confined to narrow belts on the sides of the valley, below an elevation of seventy feet. The area below this level extends up the valley of the Millstone above the junction of Stony brook, up the valley of Duck Pond run, and along Bear swamp. Traces of glacial gravel are found, or suggested, at several points in these valleys. Exposures are, however, wanting, and the determination cannot be said to be beyond question.

Gravel of glacial origin appears again in the valley of the Millstone below the junction of Stony brook. The first considerable bed of it occurs near Kingston (c, Fig. 101) just below the junction of Carter's brook. The gravel here is in the form of a low ridge about fifteen feet above the stream, and its crest is about fifty-five feet A. T. The material of glacial origin is here subordinate to that of local origin. Traces of similar gravel are to be seen along the sides of the valley, both above and below Kingston, up to heights of about sixty feet. Similar traces are found just south of Griggstown (Fig. 102), at an elevation of sixty feet, and one and one-fourth miles northeast of Griggstown, there is a series of short, low gravel ridges, partially separated from one another by erosion. These low ridges recall the terrace bars in the Delaware river. About twenty per cent. of their material is of glacial origin. Other traces of gravel, containing a distinct element of glacial material, are found at m, l, k, j and h (Fig. 102), at levels fifty to sixty feet A. T.

At East Millstone and a little farther north, there is a considerable body of gravel at fifty feet or above. The gravel is largely of red shale material, but with this material of local origin there is a small amount of glacial gravel. A more considerable deposit occurs at f, while near Weston (c d, Fig. 102), there is a considerable body of gravel which contains a larger percentage of glacial material than most of that in the valley to the south. At Hillsboro, b, there are extensive exposures of gravel containing about the same proportion of glacial material as that at Baker's basin. Gravel of similar origin extends west as far as Somerville.

Molding sand.—Along with the gravel of this old valley, there is more or less molding sand and loam, similar to that in the lower part of the Delaware valley. It occurs on the slope west of Baker's basin (f, Fig. 97), on the slope south of Kingston (d, Fig. 101), chiefly at levels between eighty and 100 feet; again at e, Fig. 102, north of East Millstone up to seventy feet; while at East Millstone it ranges up to elevations of 100 feet or more. Nowhere does it appear to have a well-defined upper limit, but it is much commoner at levels just above those of the glacial gravel, than elsewhere.

Some of this molding sand has been compared by Mr. Knapp with the sands of the Delaware valley which were clearly deposited by water, and with others which are clearly of eolian origin. The molding sand is distinctly finer and more homogeneous than any of the distinctly dune sands with which it was compared (Knapp),[1] though the situations where it occurs are situations where the valley bottoms contain material of considerable heterogenity, so that all grades of material which the wind handles were available. The analysis was not exhaustive, but it tended rather to throw doubt on the eolian origin of the molding sand (Knapp). Physically, it was found to be very similar to the Miocene sands of South Jersey, which are unquestionably of aqueous origin.

The fact that the molding sand is a valley phenomenon, that it has its best development at a tolerably constant level, and that this level is about the same as that of the glacial gravels and sands with which it is usually associated, suggests their general community of origin. The glacial gravels and sands contain material which, if separated from its associations, would closely resemble the molding sand, and the absence of sharply defined limits in the distribution of the latter strongly suggests, without proving, its eolian origin.

There is independent reason for thinking that there was some-

[1] In the analysis, beach dune sand was not used, but dune sand which lies along the Delaware.

thing of submergence just at the close of the glacial epoch, or perhaps after the deposition of the main part of the glacial gravels.

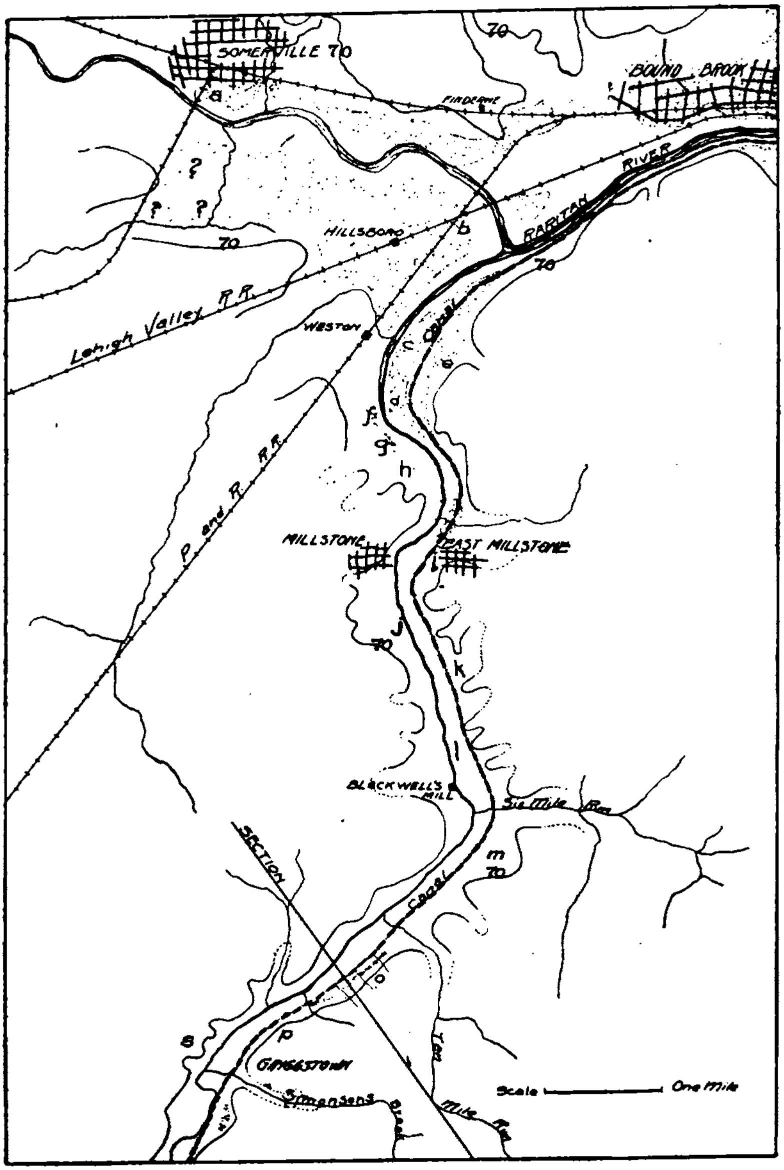


Fig. 102.

Sketch map, showing the lower end of the Trenton-Bound Brook valley and the distribution of the glacial gravels.

It is possible that these sands were deposited at this time, though they have no distinctive marks of an aqueous origin.

Summary.

The Trenton-Somerville valley presents the following conditions so far as the gravels in question are concerned:

At the Raritan end of the valley, there is a very considerable development of the gravels of last glacial age. But for post-glacial erosion, these gravels are continuous with those of the outwash plain at Plainfield. The gravels at the Trenton end of the valley are continuous with the glacial gravels of the Delaware valley. Between these points *via* the Millstone valley and Baker's basin, glacial gravels are meagre, but present. They are generally confined to altitudes of sixty feet or less, but locally reach altitudes of seventy feet, according to the topographic map. On the basis of composition, the gravels of the valley are judged to have come from the north, since they contain pebbles of granite of a variety not common in the Delaware gravels, but common in the gravels to the northeast. The forms of some of the few constructional ridges of gravel found in the valley, are such as to suggest that the currents which built them moved from the northeast to the southwest.

In vertical distribution there is nothing to indicate the direction whence the gravels came, since they maintain a fairly constant elevation throughout. So far as they depart from a constant level, they occur at higher levels in the central portion of the valley, than at either end.

Interpretations of the Glacial Gravels in the Valley Between the Delaware and the Raritan.

Several possible explanations of the gravel in this valley suggest themselves. 1) Was it deposited by a stream, and if so. was the stream *a*) a glacial river, that is a river discharging glacial waters? Or was it *b*) a post-glacial stream which redistributed glacial gravels already deposited? Or 2) was the gravel in the valley distributed by sea-water, perhaps by tidal currents?

The valley in question appears to be older than that now followed by the Raritan river below Bound Brook. Did the Raritan river, in pre-glacial times, leave its present valley at Finderne, and flow up the present valley of the Millstone to Stony brook, up the valley of Stony brook to Port Mercer, over the low divide to Shipetaukin creek, and thence down the Shipetaukin and Assanpink to the Delaware? To this question an affirmative answer may be given with some degree of confidence. If it be asked whether the Raritan held this course until the last glacial epoch, an affirmative answer can be given with less confidence. With such a course, a stream working back from the present site of Raritan bay would have been in a favorable position to tap the stream above Bound Brook, and lead it away by the shorter route, and over less resistant strata, to the sea. This diversion may or may not have taken place before the last glacial epoch.

If the Raritan had its present course at the time of the last glacial epoch, and if the land had the same elevation as now, how would the drainage from the ice have affected the river? The headwaters of the South Branch reach back to the moraine at Budd's lake. This stream must, therefore, have received waters from the ice at its source. Judging from the topography of the land along the edge of the ice at this point, the waters from about three miles of the ice front would have come down this valley. This would perhaps not have swollen the river greatly in its lower course, yet it would not have been without appreciable effect in strengthening the current, at least in the summer season when melting was rapid, even down to tide water.

The North Branch of the Raritan does not head back to the moraine, but when the ice had reached its moraine position, Lake Passaic was overflowing through Moggy hollow, the water reaching the North Branch near Bedminster. The water coming into the North Branch by this route was the drainage from about eight miles of the edge of the ice (Summit to Morristown), and its volume must have been considerable.

At Burnt Mill, the North Branch is joined by the Black river, which by way of Succasunna plains, brought down the drainage from about three miles of the ice edge. Below the junction of the

North and South Branches, therefore, the Raritan was carrying the drainage from about fourteen miles of the ice front. This was by no means equal to the volume of ice water which the Delaware carried, for fourteen miles is about the amount of ice frontage *in New Jersey* which the Delaware drained. The frontage in Pennsylvania was much greater.

It is to be noted that in the case of two of these three feeders, and probably in the case of the third as well, the drainage came through lakes, namely, Budd's, Passaic, and probably Succasunna, (the last two now extinct). It is to be noted, too, that the lakes lay at the margin of the ice, and that only after escaping from them, did the water enter the rivers. This accounts for the absence of glacial debris along the courses of the streams, for the debris was left at the heads of the lakes. The absence of abundant debris is, therefore, no evidence of lack of abundant water. Under these circumstances, the Raritan, assuming its gradient to have been as now, should have been a vigorous stream, even though its gradient was low;[1] but down to the point where it received the drainage from the Plainfield area, the river carried little glacial debris, and its velocity was apparently not greatly impeded by load.

Under these circumstances, what would have been the course of events where the Green brook-Bound brook drainage came in? On the hypothesis that the Raritan had its present course, it is to be noted that before the Green brook-Bound brook drainage joined the Raritan, it had been flowing overland eight to twelve miles, over a nearly plane surface, with a relatively low gradient. These are conditions favorable for deposition, and it is probable that at first much of the sediment of the extra-glacial waters was left near the moraine, and that only later, as the moraine edge of the plain was aggraded, did its slope become great enough for sediment to be carried out in quantity to Dunellen and beyond.

It is to be noted that glacial gravel lies *south* of the Raritan, at South Bound Brook, at Weston, at Hillsboro, and farther west, and that above Bound Brook, there is much more of it south of the river than north of it. Now sand and gravel from

[1] From Raritan to the tide water level, it is now about two feet per mile.

the north could not have crossed the present trench of the Raritan. It could not have descended to the present stream level (seventeen feet A. T. at Bound Brook), and then ascended the opposite slope (to sixty feet A. T.) at South Bound Brook. No more could it have descended to the channel where the Millstone comes in, and then have risen on the other side, building up the flat at fifty feet and more about Hillsboro. For the gravel to have reached these positions south of the Raritan, that part of the valley which is below sixty feet must have been temporarily obliterated; temporarily, because the character of the valley is such as to preclude the hypothesis that it is of post-glacial origin. Clearly it was in existence before the deposition of the glacial gravels, and therefore before the moraine was made.

There is apparently but one way in which the valley could have been obliterated, and that is by being filled. After it was filled, the debris from the north was carried out across it in considerable quantity.

Had the Raritan, flooded by the relatively clear waters from Budd's, Succasunna, and Passaic lakes, had its present course and gradient, would it have been choked by the debris brought out from the moraine at Netherwood by drainage which had come eight miles or more over a gently sloping plain? The chances would seem to be altogether against an affirmative answer. The total volume of sand and gravel which got as far southwest as Bound Brook was not large. In Bound Brook, and for a considerable distance north of it, the thickness of the sand and gravel is but a few feet, and the surface slope is far too low for any considerable body of drift to have been carried across it without heavier deposition. On the south side of the river, the area of the gravel is perhaps three square miles, but the average thickness of the gravel over this area is probably less than ten feet, and much of this is made up of bits of red shale, which probably did not come across the valley at all.

Making due allowance for the gravel which has been cut away in post-glacial time, and the amount of this is readily estimated, the total volume of sediment which can have reached the Raritan at Bound Brook would seem to have been insufficient to have choked the river, if it had had its present gradient. If the gradient were less than now, the obstruction of the stream by deposition would have been correspondingly less difficult.

If the choking of the Raritan took place by the deposition of sand and gravel washed in from the north, the process must have been a slow one, and before it was accomplished, much sand and gravel should have gone down its lower course to Raritan bay. It is true there is a little sand and gravel in the valley below Bound Brook which might have had this origin. Below South Bound Brook there are traces of gravel and sand, well down toward Raritan Landing, but these traces are meagre, and are comparable to those up the Millstone above Weston. They might well enough have been carried to their present position when the Raritan opened out its present channel in post-glacial time.

In the transportation of the glacial gravel up the Raritan valley to Somerville, there is good evidence that the stream had ceased, at least temporarily, to flow eastward.

All in all, the evidence seems to be strongly against the view that the Raritan had its present course, in its present relations, when the moraine was formed. If it had this course, before the ice came on, it was apparently diverted to the Millstone-Stony brook-Shipetaukin-Assanpink route in the early stages of the glacial epoch, by the deposition, in the vicinity of Bound Brook, of gravel and sand washed out from the moraine at Plainfield. In this case the paucity of glacial gravel in the old valley of the Raritan below Bound Brook would be explained, for relatively little northern debris would have passed the dam which obstructed the stream.

If, on the other hand, the Raritan was flowing *via* the Millstone-Assanpink valley to Trenton when the ice came on, the paucity of gravel down the present Raritan valley below Bound Brook would be equally well explained; but in this case more might have been expected in the present Millstone valley. If this were the course of the Raritan, it would still be necessary to have its valley aggraded up to sixty feet or more, in order to get the gravel from the north side of the valley over to Hillsboro, and it would still be necessary to have the gravel going *up* the Raritan, for it runs up the valley at least four miles above the junction of the Millstone.

The phenomena therefore seem to be quite as difficult of explanation on the supposition that the Raritan was following its early course in glacial times, as that it was following its present course. Neither hypothesis seems satisfactory, for neither accounts for the gravel which went up the Raritan from Bound Brook. There is no third course which the Raritan may have followed.

The presence of glacial gravels up the Raritan from Bound Brook, and their extreme paucity down the present valley below that point, and up the present valley of the Millstone above Weston, suggest that the Raritan ended somewhere above the western limit of the glacial gravel at the time they were deposited. If there was no current down the Raritan below Raritan, gravel from Bound Brook might have been carried westward up the present valley, and very little need have been carried either east or south of Bound Brook. Could the current of the stream have been done away with, except by the ponding of the stream by the deposition of glacial gravels and sands?

To this question two answers seem worth considering: First, the ice at Perth Amboy might have pushed out across the bay, making a dam and ponding the waters above, making a great lake in the lower course of the river. There is high land at South Amboy, and if the ice pushed out so much as a mile beyond Perth Amboy, it would have crossed the head of the Raritan bay, and might have formed a dam. In this way, the water level could have been held up to a level of 100 feet or so, in the lower Raritan.

Against this hypothesis, there are fatal objections. In the first place, there should have been drift left at South Amboy; but there is none now, and it is not probable that there has been enough erosion since the ice epoch to have removed it all, had it once existed. Furthermore, the course of the moraine from Metuchen to Perth Amboy, and thence across Staten Island, is such as to make it improbable that the ice extended across the head of Raritan bay. If it pushed south of Perth Amboy, its extension must have been very thin, too thin to dam the Raritan. This hypothesis, therefore, seems untenable.

If this part of the State were then lower than now by fifty feet, there would have been no current along the course of the Raritan below the junction of the North and South branches. This would have been equally true whether its course, previous to the sinking which drowned its lower end, was to Raritan bay or to Delaware bay.

In this event, there would be no difficulty in transporting the gravel and sand from Plainfield across the valley to the south side, for there was no river current to prevent the filling of the shallow valley. There would be no difficulty in having the gravel spread up the present valley to Somerville, for there was no opposing current. The paucity of gravel down the Raritan from Bound Brook, and up the Millstone from Weston, would offer no difficulties, for there were no considerable currents in either direction to carry the material. The presence of the little material of glacial origin which there is in these valleys would present no serious difficulty, for it might have been transported by tidal currents, if such current passed through the valleys, or it might have been distributed by post-glacial drainage. In the last case, it would be necessary to suppose that the Raritan flowed to the Delaware for a time after the ice was gone.

On this hypothesis there should be, above the filling of gravel and sand at Bound Brook and Hillsboro, slack water deposits at levels at least as high as the surface of the gravels and sands. Such deposits occur in abundance about Somerville and elsewhere, but they present a new difficulty in that they are not limited to the level of the gravels, but are found at much higher levels as well.

Though this hypothesis escapes many of the difficulties of the preceding, it has difficulties of its own. For example, if the drainage from the moraine near Plainfield entered standing water, there should have been deltas or subaqueous overwash plains developed. They have not been recognized, and it is not probable that they have been destroyed.

Again, if the land were much lower than now, the ice could hardly have advanced as far south as it did at Perth Amboy and on Staten Island. In both situations it reached surfaces which are now at sea level. Thick ice may push out some distance into shallow water, and a depression of the amount here suggested, might not have interfered with the advance of the ice to the position it is known to have attained.

Some of the difficulties of the situation would be met if the level of the land was inconstant in relation to sea level.

THE PHENOMENA OF THE DELAWARE VALLEY BELOW TRENTON.

On the New Jersey side of the river, the glacial gravels of the Delaware valley have little development below Chambersburg (Trenton), and are not known to be present at any point between Chambersburg and Florence. Between these points, however, there are terrace flats which correspond in elevation with the plain at Trenton, and are its topographic equivalent. They are believed to have been developed at the same time.

The terraces along the east side of the Delaware, and along its eastern tributaries below Trenton, which are believed to be the equivalents of the glacial gravel terrace at Trenton, are made up of materials contributed to the Delaware valley by the tributaries from the east. Up the valleys of the tributaries the terraces rise to elevations considerably above the Delaware. In all cases, the material of the terraces of the tributary valleys is such as might have been derived from the basins of the streams. Except near the main valley, the terraces in the tributaries behave as normal river terraces. Thus in Crosswicks creek, the terrace surface rises from about sixty feet near the Delaware, to about 120 feet at Walnford, 130 feet at Hornerstown (up Lahaway creek), and 140 feet at Prospertown.

In general, the terraces of the tributaries are composed of coarser and more distinctly stratified material near the streams, and of finer and less distinctly stratified material back from them. Their upper edges are not usually well defined topographically. Their surfaces are often coated with loam, which seems to cover not only them, but in many cases the divides between the streams as well.

Locally, this loam mantle is so clayey as to be used for brick clay. This is true at Kinkora, a mile south of Fieldsboro, and in the vicinity of Bordentown. There can be little doubt that the clay loam of these localities is the time equivalent of the surface loam of the Trenton gravel plain.

From Florence to Burlington there is a recurrence of glacial gravel in the Delaware valley. The material of glacial origin, however, is generally very subordinate to that of local origin. Most of the gravel of this sort which is found in this region occurs at levels of thirty feet or less, and its base is at least as low as tide level. Here, as farther north, the gravel is covered by clay loam, which locally develops into brick clay.

Between Burlington and Palmyra, pebbles of glacial origin have been no more than doubtfully identified, but there are indications of their presence, along with much other material, about Edgewater Park, Beverly, and Riverside, and at other points as far south as Camden, and perhaps even below.

The material in this part of the valley belongs rather to the geology of the southern part of the state, and will not be discussed here. Suffice it to say that the phenomena of the lower Delaware indicate that by the close of the glacial epoch, if not before, the lower portion of the Delaware valley was submerged to the extent of thirty to fifty feet, and that this submergence was probably one of the reasons why more glacial material was not carried south of Trenton. This submergence is also a partial explanation of the filling of the lower Delaware valley which occurred at this time. The filling of this part of the valley was, however, not dependent upon the submergence, and it is believed that some part of it occurred before the valley itself was drowned. The filling of the Delaware valley necessarily involved the deposition of material along the tributaries leading down to it.

The development of clay loam over the terraces of the lower Delaware is one of the distinctive phenomena of the region. This clay loam seems to be continuous from the terraces over the interstream divides, and to be confined to no distinct level. It rises to heights of at least 200 feet, and is often of such a character that it cannot be regarded as residual from the underlying formations, and is often of such a character as to make it difficult to ascribe to it an eolian origin. Locally, it is clearly a deposit made in standing water. This is true, for example, near Edgewater Park, where the clay is full of organic matter, which, locally, is so fresh as to retain the vegetable fibers in quantity.

The discussion of this mantling loam would lead us far afield. It really involves the phenomena of the southern part of the state, with which this report is not concerned.

OTHER VALLEY TRAINS.

In the valley of the Musconetcong.—Aside from that of the Delaware, valley trains were not well developed in New Jersey. There was a feeble train of gravel down the valley of the Musconetcong from the moraine near Hackettstown, but it is not comparable in extent with that of the Delaware, nor is it so well developed as might have been expected from the general relation of valley and moraine. Just below the crossing of the moraine, the plain is nearly a mile wide, but within three miles it narrows to an eighth of a mile. Below that point, the material deposited by the water issuing from the ice at the moraine is nowhere present in quantity, though it is found interruptedly in narrow belts down to the Delaware. Nowhere does it form well marked terraces.

The head of the train just below the moraine has an altitude of 600 feet. Its surface declines forty feet in the first fourth of a mile, and twenty feet more in the next fourth, the material becoming finer as the surface becomes lower. Below the first quarter of a mile, the average gradient to Stephensburg, a distance of six miles, is about sixteen feet per mile. The river has a fall of 120 feet in the same distance. The gravel, therefore, is found at a greater elevation above the stream at Stephensburg than farther up the river, if the uppermost end be left out of consideration.

The discontinuity of the gravel below Beattystown is the result either of its failure to be deposited, or its subsequent removal or burial. It probably failed of deposition at some points where the channel was narrow, and the current swift. It has been removed at points where post-glacial erosion has been considerable, and it has perhaps been concealed by later deposits at some points. That the gravel of the Musconetcong valley does not constitute well-marked terraces is the accident of later erosion.

In the valley of the South Branch of the Raritan.—Passing to the eastward, the next stream in a position to have developed a valley train, was the South Branch of the Raritan. The waters from the ice which reached the headwaters of this stream went first into Budd's lake, through which the sediment was not carried. This stream therefore developed no valley train.

Considerable deposits of gravel and sand were made at the head of the lake. They are disposed as a wide valley train, or narrow overwash plain. The area of this plain of drift is small, about a mile in length, and a fourth to a half as wide as long. It has an elevation of about 960 feet next the moraine, and declines about twenty feet to the lake. The gravel, which is coarse next the moraine, becomes finer to the south. Just north of the lake, the planeness of the plain is interrupted by hills of coarser material, not known to be stratified.

In the valley of the North Branch of the Raritan.—The North Branch of the Raritan received glacial water through Moggy hollow, two miles west of Liberty Corner, but like that which entered South Branch, it had come through a lake (Lake Passaic), whence it issued without sediment. This valley, therefore, has no valley train.

OUTWASH PLAINS.

The Plainfield plain.—Of overwash plains, there is but a single good example in the State, and even that grades into a valley train, besides having several peculiar and confusing relations. This is the plain which skirts the moraine from Scotch Plains on the northwest to Ford's Corners on the southwest, and which will, for convenience, be called the Plainfield plain.

Along its moraine edge, this plain has the features and relations normal to such plains. It is highest next the moraine, from which it declines gradually and with diminishing gradient. Its materials are coarse near the moraine, and become finer and finer with increasing distance from it. Its outer edge is generally of sand, and often poorly defined. Its limit was probably poorly marked at the outset, and it has been made still more indistinct by the wind, which has shifted its marginal sands out over the territory to which water did not reach, and by stream erosion. Its original limits have perhaps been still further obscured by submergence (see p. 511).

Before the ice came in, the area of the Plainfield plain was low, and had but slight relief. Its surface was probably comparable to the lower parts of the plain underlain by the Brunswick shales, such as that about Somerville. Its lower parts, forming the deeper valleys, were about sixty feet above sea level, and its higher parts about 120 feet.

When the ice reached the position of the moraine, there was no considerable valley so situated as to receive and carry off the waters to which it gave rise, and the many streamlets which issued from it flowed out as they might through the shallow valleys on the low flat surface. Depositing their burden of sand and gravel, they soon filled up the shallow depressions of the surface. In this process, the deposition was greater near the ice than far from it, and as the present plain was built up by the aggradation of the surface of slight relief, its slope from the moraine became greater. Over its increasingly steeper surface, gravel and sand were carried out progressively farther and farther. The condition of the edge of the plain at each step in the process of its building was the same as that at the edge of the ice when the aggradation began, and at each stage the sand was being carried out farther along the depressions, through which the water flowed. When these depressions had been filled, the streams meandered indiscriminately over the aggraded and unrelieved surface. Between Metuchen and Ford's Corners, the waters which carried out the debris from the moraine finally escaped through the present Mill Brook valley, but most of its deposits made in this valley have since been carried away. Immediately about Metuchen the drift was not carried out far from the moraine, for the topography was such as to divert the drainage partly to the eastward down Mill brook, and partly to the westward down Bound brook. The upper course of the latter stream is nearly parallel to the moraine, and the sand and gravel, mainly the former, were carried out to the valley and to the north base of the low ridge which forms the divide between it and the valley of Ambrose's brook.

From a point a little east of South Plainfield to a point a mile west of New Market, the channel of Bound brook marked the southern limit of the outwash. It was brought down to the present channel, but was not carried up on the other slope. It may have displaced the channel, shifting it southward parallel to its former course, but the amount of such displacement was not great. West of a point a mile west of New Market, the deposition was great, and the valley of the Bound brook was completely filled, and the drainage of the area tributary to Bound brook must have escaped by meandering over the surface, after the fashion of depositing waters.

From the L. V. railway east of South Plainfield, to Scotch Plains, the drainage from the moraine escaped southwestward along a valley which occupied the site of the present Green brook. As this valley was aggraded, its bottom became broader and broader, and the waters meandered more and more widely.

As the preglacial valleys of the surface southwest of the moraine were filled, the sand and gravel rose to higher and higher levels on the low hills and ridges between them, till most of those near the moraine were completely buried. Near the moraine, the gravel and sand often have a thickness of thirty to forty feet. Farther from the moraine, the deposits were thinner, and the tops of the shale knolls failed of being deeply buried. Areas of shale which were but thinly covered occur north of Samptown, and New Market.

The surface of the moraine edge of the outwash plain is not always plane. Locally it becomes so undulatory that the line of demarkation between it and the moraine is indefinite. In general, however, the two phases of drift are fairly well differentiated, and the doubtful zone between them is never wide (see Plates IX and XXVII).

In the northern part of Plainfield, and between Plainfield and Scotch Plains, were two knolls of shale capped with gravel, which the new drift, brought out by drainage from the ice, did not cover. The highest of these rises to a height of 140 feet, and the other, a little farther from the moraine, has a height of between 120 and 130 feet. These areas are not now knolls of notable elevation. The higher one, indeed, is surrounded by the outwash, which rises to within less than ten feet of its top. The lower and larger one is not completely surrounded by the new drift, but on its east side the gravel and sand rise to within about fifteen feet of its summit.

Low as these knolls are, they are most significant. Their gravel caps are remnants of the Pensauken (or Bridgeton) formation which once covered the whole of the area between First Mountain, the moraine, and the Raritan. It extended an unknown distance north of the moraine, while south of the Raritan, it covers, or did cover, a large part of the state. The nearest place where other remnants of this formation occur is at New Durham, eight or ten miles to the south. These remnants show that after the deposition of this formation, and before the last glacial epoch, erosion was very extensive, for most of the formation was carried away by erosion, and the surface on which it rested lowered a variable amount, but often as much as sixty or seventy feet. If this older gravel is the marine equivalent of a sheet of early glacial drift, its remnantal condition in this part of the State indicates that the time between the deposition of the old drift and the new, was long.

To the southwest, the Plainfield plain narrows, with a tendency to take on the character of a valley train. North of Bound Brook, its northern edge lies against the base of First mountain. To the south it is interrupted at the Raritan, but beyond the interruption it is continued south and southeast to South Bound Brook and Fieldville, southwest to Weston, and west to Somerville. The gravel of these localities south of the Raritan is discussed in another connection (p. 720-735).

In the southern part of the Plainfield plain of gravel and sand, water-worn fragments of red shale, contributed by local streams, are mingled with the materials of glacial origin. Deposits of red shale gravel, with no admixture of fluvio-glacial pebbles, are also found, as, for example, in the valley of Peter's brook in Somerville. Such materials, added to those which came down from the ice, would give such deposits as are found at Hillsboro and Weston.

Near Denville.—South and southeast of Denville, outwash gravel and sand border the moraine, occupying the space between it and the railway. A half mile and more northwest of Denville there is a pitted plain standing in the same relation to the moraine. This is perhaps as good an example of a pitted plain as has been found adjacent to the moraine.

The Dover-Rockaway plain.—South of the moraine at Dover, and along the valley of the Rockaway for two miles east of Dover, there is a considerable area of stratified drift outside the moraine. It lies on both sides of the river east of Dover, and has a considerable expansion south of the river, just above Mill brook. In the eastern part of Dover it has the form of an outwash plain, but the distinctions and relations are lost to the east, where the stratified drift does not lie against the moraine. At Rockaway, the ice covered the present channel of the river, and may have dammed it. If so, a lake must have existed over the site of the stratified drift referred to. Distinctive lacustrine features in the deposits are not known.

The Succasunna plains.—On Succasunna plains, in the upper part of the Black river basin, there are considerable deposits of stratified drift, which belong to the general class of overwash plains. The stratified drift here fronts the moraine interruptedly for about three miles, and slopes off to the south, its material becoming notably finer in that direction. The plain is interrupted by various rock hills and ridges, which divide it into several parts. A small part lies west of the hill north of Drakesville, a larger part between this hill and the ridge northeast of Kenvil, and the largest extends from the moraine northeast of Kenvil, south to Ironia and beyond.

The part of the plain northwest of Drakesville has an elevation at the moraine of about 820 feet, but it declines to 760 feet at Drakesville, where it joins the middle section of the plain extending south from Rustic. The head of the middle section is north of the D., L. & W. railway at Rustic (Mt. Arlington), and its extension is southward between the ridges running northeast from Drakesville and Kenvil respectively, nearly to Carey's. At its head, this section of the plain has an elevation of about 820 feet, but it declines to 760 feet a little south of the railway, and to about 720 feet at its southern terminus. The gravel of the plain is coarse at the north, and becomes increasingly finer to the south.

The eastern and largest section of the plain heads in the moraine east of Kenvil, and extends south through Succasunna to Ironia, though the plain is not well developed more than a mile below Succasunna. Above Ironia, the valley becomes marshy, but about the marsh, patches of gravel and sand, similar to the material of the plain to the north, are found. To the north, the surface of the plain is affected by shallow sinks, especially east of the Central railway. The slope of this part of the plain is less than that of the western parts, being from about 750 at the north, to 700 feet at the south end. At the north, the material is coarse gravel, and bowlders are not wanting; at the south, it is chiefly of fine gravel and sand.

What is known of the depth of the gravel and sand of this plain, is from the data afforded by wells. About a mile southeast of Drakesville, a well is reported to have penetrated sixty feet of gravel and sand, and then sixty feet of clay without pebbles, without reaching rock. Depths of twenty to forty-five feet of gravel and sand have been reported from other parts of the plain, without reaching the bottom.

The exact history of the plain is not known. If, as conjectured, the pre-glacial drainage of the upper part of the present Black river valley was northward, a lake should have come into existence over the Succasunna plains, when the ice blocked the northward outlet. In this lake a *delta,* or *subaqueous overwash plain,* should have been built. The surface material of the plain is in keeping with such an hypothesis of its origin; but there is a complete absence of the delta fronts which, under most circumstances, should characterize such a formation. If the lake was shallow, as seems probable, the delta plain may have been built out from the north quite across it, thus obliterating the lake by filling its basin. This may have been what took place. If so, deep cuts should show that the beds of sand and gravel beneath the surface slope; but no sections are available. If this is the history of the stratified drift of the Succasunna plains, the level of the surface of the lake must have corresponded approximately with the level of the swamps along the valley below Succasunna.

There is some evidence that this was the fact, and that fine sand covered this flat, for a good deal of sand, apparently wind-blown, occurs on the eastern slope of the valley well above its bottom.

SUBAQUEOUS OVERWASH PLAINS.

The especial characteristics of deltas and subaqueous overwash plains are flat tops, steep fronts, lobate margins with deep re-entrant angles and projecting cusps, and a tripartite structure, as seen in vertical section, consisting of nearly horizontal beds at the top underlain by beds dipping steeply towards the front, which in turn rest on horizontal layers of fine material (see Figure 40, p. 131).

In the basin of Lake Passaic.—Along its course across the basin of Lake Passaic, the outer margin of the moraine is bordered by a subaqueous overwash plain of goodly proportions. Near West Summit, the extramorainic plain of stratified drift is developed, and has three prominent marginal lobes. West of Madison, the flat top of the plain is a third of a mile wide, and has a slope of about ten feet, but its steep front falls off sixty feet in 100 to 200 yards. As will be seen from Figure 3, Plate XXXIV, a map prepared from a careful survey of the plain, the cusps and re-entrant angles are here very pronounced. Southwest of Convent station, the plain is half a mile wide, declining twenty to twenty-five feet from its upper edge at the moraine, to its outer edge, where it descends abruptly about fifty feet in 125 to 150 yards.

Kettle holes occur in the plain, varying in size from shallow, saucer-like depressions to huge sinks fifty feet in depth, although such large ones are not abundant. The largest may be seen from the D., L. & W. railway, just west of the track, a third of a mile northwest of Convent station.

The material of the plain varies from coarse gravel containing large cobbles, to fine sand. Layers of sand are often intercalated between beds of coarse gravel. Lithologically, the material is similar to that found in the moraine, and was derived from the melting ice. No exposures were found which showed the complete tripartite structure which deltas theoretically possess, nor are there any extensive exposures showing both fore-set and top-set beds, although one or the other may be seen at a number of places.

To fix the exact water-level in which these subaqueous overwash or glacial delta plains were formed, is a matter of considerable difficulty. In a general way it may be said that the line marking the junction of the gently sloping upper surface of the plain with its abrupt front, marks the water-level. While this general statement is near the truth, there are several reasons for supposing that it does not represent it precisely; for it has been found that even where the change of slope is most marked and can be accurately fixed, its height varies three, five, or even seven feet within comparatively short distances, that is, the line of change from the top to the front is not a horizontal line, but a more or less irregularly curved line. The water can not have stood five or six feet higher at one point than at another less than a hundred yards away. Furthermore, a consideration of the manner in which a delta is formed shows that the pronounced change of slope must mark the point where the bottom current of the running water which is rolling the coarse gravel along its bed, loses its momentum when it reaches the deeper water of the lake. It would seem, therefore, that the steeper slope cannot, at a maximum, be built nearer the surface of the lake than the depth of the current which at that particular point is supplying debris. Since the depth and velocity of each stream supplying the detritus is different at different points in its cross-section, and since a subaqueous overwash plain is built by a number of streams, or by the distributaries from a single stream, the several currents having various depths and velocities, it is perhaps to be expected that the upper limit of the frontal slope would be of various heights on adjoining lobes, and even on different parts of the same lobe. We must conclude, therefore, that the lake-level was at least as high as the highest of the "fronts," and that at some points the water covered the outer and lower part of the gently sloping top[1].

In the basin of Succasunna lake.—The drift of the Succasunna plain bears none of the topographic marks of a subaqueous over-

[1] See Report on Lake Passaic. Ann. Rept. 1893.

wash plain, but if its history is correctly interpreted, such was its origin, in part at least. This plain has been referred to in another connection (p. 742).

LACUSTRINE CLAYS AND SILTS.

In the extra-morainic part of the basin of Lake Passaic, there is some drift beyond the subaqueous outwash plain, much of which consists of lacustrine clays and silts. The clays and silts of a glacial lake possess certain characteristics by which they may be readily recognized. They are finely laminated, and they are of such materials as could be furnished by the waters draining into the lake. The finer silts and the clayey deposits are found at some distance from the shore line where the water was relatively deep, and where waves did not greatly disturb the bottom, while the coarser materials are nearer the source of supply. Toward the shore, clays and silts give place to coarser deposits—sand, gravel, or berg till.

Clays and silts of lacustrine type are found at various points outside the moraine. At the brickyards just south of Morristown, at an elevation of 320 feet and less, there is laminated and slightly calcareous clay which contains unique concretions of lime carbonate. In the vicinity of Pleasant Plains, seven miles or so south of Morristown, the low plain (about 230 feet) is covered to a considerable depth with similar laminated clay, equally rich in concretions. The same clay extends over a considerable area in this vicinity, extending northeastward to Green Village and beyond, and westward and northwestward as far as Logansville, at least. About Green Village the laminated clay is more or less covered with sand, which likewise mantles it for a mile or two farther southwest. Near the western extremity of the area where the clay has been observed, it is likewise somewhat concealed by sand.

From the basin of the Great swamp, the lacustrine or subaqueous clay reaches up on the lower portions of the north slope of Long hill to a height of at least 250 feet, though it is not always traceable to this height. On the bases of the mountain slopes, its characteristics are not identical with those which it possesses on the lower land. It is here frequently concealed by sand, so that its exact limits are not easily determined. It is probable that the whole of the Great swamp is underlain by clay of lacustrine origin, although a part of it is probably of later date than the ice epoch, since this area remained in a lacustrine condition after the main part of the waters had been drained away (p. 157 and Plate XLII).

Between Second and Third mountains the existence of clay deposited beneath water is also known. It has not, where seen, the distinctly laminated character which marks much of the lacustrine clay, but it possesses other features which seem to clearly indicate its subaqueous origin. In the summer of 1892 this was well seen in the vicinity of Berkeley Heights, in two temporary exposures. Near this place, the distinctly subaqueous clay does not seem to run much above the 230-foot contour, and west of Millington it seems to be limited, according to the determination of Mr. Whitson, essentially to the 220-foot contour. This is hardly above the present flood plain of the river at this point. These clays may be partly post-glacial.

The depth of the subaqueous clay can rarely be determined, except where it is very shallow. Where it is deep, wells of considerable depth are rare, since water can be obtained near the surface. Not far from Long Hill village a well thirty feet deep is said to be excavated entirely in clay. A well has penetrated the clay to similar depth northwest of Pleasant Plains. Half a mile east of Pleasant Plains, according to Mr. O. Lindsley, a well seventy-two feet deep penetrated only soft "alluvial" material. The surface at this point has an altitude of about 230 feet. According to Mr. Lindsley a well one mile southwest of Green Village, at about the same elevation, reached red shale at a depth of twenty-two feet; while a third well, 172 feet deep, at the edge of the swamp a mile and a half south of Green Village, penetrated nothing that was recognized as rock. The lowermost third of this well was in sand, while the material above was of a clayey nature. If the material penetrated by this well is all drift, the statements on pages 151 and 522 might be emphasized.

Traces of subaqueous clay similar to that about Pleasant Plains may be seen beneath the sand at the edge of the sand-and-gravel plain bordering the moraine.

The topography of the clay and silt-covered plain in the extra-morainic part of the basin of Lake Passaic is undulatory near the moraine, but level to the westward. The same is true of the corresponding area between Second mountain and Long hill.

The plane surface which prevails to the west begins to be affected by sinks and swells about half way between Sterling and Gillette. The nature of the surface material changes at the same time, becoming sandy and gravelly.

KAMES.

Southwest of the moraine and the subaqueous overwash plain at Madison, an area of kames stretches away to the southwest, covering the northeastern part of the low, flat area of stratified drift which covers the Great swamp and some surrounding territory. This stratified drift is of late glacial age, but of aqueous origin. The undulatory surface is most strongly marked near the moraine, and becomes gentler and gentler with increasing distance from it. The diminution in roughness is accompanied by a diminution in coarseness of material. Near the moraine, sand and fine gravel predominate. But the sand is in excess of the gravel, which, to the southwestward, soon disappears. In the same direction, the sand becomes finer and grades into silt. The disappearance of the sand is coincident with the disappearance of the undulatoriness of the surface.

The explanation of the kames, in this anomalous position outside the moraine, is not clear. On the whole it seems probable that the ice advanced somewhat beyond the position of the moraine, shortly before the development of the latter, and that these extra-morainic kames were made while the edge of the ice was in this advanced position.

ICEBERG AND GLACIAL DEPOSITS.

At various points throughout the extra-morainic area of Lake Passaic, scattered bowlders similar to those of the moraine are found up to altitudes of 340 feet, and rarely to 360 feet, the approximate level of the lake. They are more common below the upper limit of their range than at that limit. They are occasionally in clumps, but more commonly isolated. Some of them are of large size. Some of them were probably floated to their position by icebergs.

In some localities not distant from the moraine, there are considerable bodies of drift which may perhaps have been deposited by icebergs, or by ice which at some stage, pushed out a few miles beyond the moraine.

Southwest of Summit, in the valley of the Passaic, in the valley between the two crests of Second mountain, and in the valley between Second and First mountains, there is more or less till. In the valley of the Passaic it is confined to low levels. It covers the surface about New Providence, reaching as far southwest as Union Village. It does not constitute the surface formation at levels below 220 and 230 feet. It does not rise above 260 feet at Union Village, nor does any bed of it exist above 300 feet south of Berkeley Heights. Traces of it extend up on the slopes to a somewhat greater height, east and northeast of Murray Hill station. In the vicinity of New Providence, the surface of this drift is comparable to that of a poorly developed terminal moraine; that is, it is marked by hillocks and sinks of irregular arrangement.

Throughout this area, the till is clayey, very sticky, and possesses the characteristics which have elsewhere been referred to as marking subaqueous till. It is believed that this till stood beneath the waters of Lake Passaic after it was formed. It is possible that some of it may be berg till.

Below a level of 220 to 230 feet, the till is commonly covered by lacustrine clay, which is distinctly laminated, and which was deposited in Dead lake (p. 157) after the ice had left this part of the State.

Three-fourths of a mile southeast of Murray Hill, and from this point southwestward for two miles along the valley between the two crests of Second mountain, there is a small amount of drift, which is confined strictly to the valley. There are no deep exposures in it, and there is less opportunity to determine its extent and thickness than could be desired. It is best exposed along the road crossing the valley between Feltville and Murray Hill, where its till-like character is shown. A mile farther southwest, down the valley, on the east side of the road leading north from Scotch Plains, there are some large granitic bowlders, the largest being about nine feet in diameter. In the valley, a half mile southwest of the road last named, there are a number of huge bowlders, which in this place are most striking. The largest has a diameter of about twelve feet, and all the large ones are of gneiss or Green Pond mountain conglomerate. They do not have the appearance of being notably older than the material of the moraine. They do not occur so far to the southwest as the till on the north side of Second mountain, though they occur at a greater elevation.

Between First and Second mountains, and on their lower slopes, especially on the lower slope of First mountain, there is considerable drift in the vicinity of Feltville. This extends northward to the moraine, though the morainic drift and that which is outside do not correspond very closely in character. The drift extends in patches to a point a mile southwest of Feltville.

Much or all the drift referred to in the preceding paragraphs is probably of last glacial age.

At several other points late glacial drift is found a few rods, or a fraction of a mile, outside the moraine. Most of the places where such drift occurs have been mentioned in the preceding pages in connection with the outer border of the moraine.

CHAPTER XIV.

EXTRA-MORAINIC GLACIAL DRIFT.

CONTENTS.

GENERAL SUMMARY.

Previous to the summer of 1891, no evidence had been published, so far as the writer is aware, that glacial drift existed in New Jersey south of the terminal moraine. That drift deposited by water had a considerable distribution south of the moraine, as at Trenton, was well known.

In 1889, Professor T. C. Chamberlin and the writer visited certain localities in New Jersey and Pennsylvania, south of the terminal moraine. Observations made at that time between Belvidere and Phillipsburg, as well as at corresponding points on the west side of the Delaware, led us to suspect the existence of drift older than the moraine outside the immediate valley of the Delaware. The observations made at this time were limited, and the tentative conclusions were never published.

When the writer first visited New Jersey, early in the summer of 1891, he learned from Professor Smock that he likewise had been led to think that there might be drift in New Jersey deposited by an ice sheet which antedated that whose southern limit is marked by the terminal moraine.

The extra-morainic drift of New Jersey, of greater age than the moraine, is believed to have been deposited in part by glacier ice, in part by streams contemporaneous with the ice, in part by streams during intervals of deglaciation, subsequent to the beginning and before the end of the glacial period, in part, perhaps, by the waters of the sea at the time the ice first encroached upon the territory of the State. The present chapter will concern itself primarily with the subaërial, not with the submarine, phases of the drift. Between the drift deposited by the ice and that deposited by water, it is not always easy to distinguish.

It is to be remembered that there is some extra-morainic drift of late glacial age outside the moraine. Such drift was deposited during a temporary advance of the ice beyond its moraine position, or was carried out by running water. The drift here to be considered is to be regarded as a portion of an older formation of glacial drift, most of which was removed by erosion before the last ice invasion, destroyed by the latest ice sheet, or buried beneath its drift.

Southern limit.—The general distribution of the extra-morainic drift which is thought to be of glacial origin, directly or indirectly, is shown on the map, Plate XXVIII (in pocket). The line marking its southern boundary has been traced in some detail from the Delaware to First mountain. Farther east, no line has been equally well determined, and probably never can be. The early drift is obscured by the later in the basin of Lake Passaic, and east of this basin the ice is thought to have reached the sea, which then stood higher than now relative to the land.

Commencing at the Delaware, the line marking the limit of the extra-morainic glacial drift runs through Hunterdon, Somerset and Middlesex counties. At the Delaware, it is opposite Monroe, a little more than a mile south of Riegelsville. From this point it bears a little to the northeast for two or three miles, then turns nearly due east through Spring Mills, bears slightly south through Pittstown, beyond which point it follows a direction slightly south of east for two or three miles. Thence it turns to the northeast, reaching the South Branch of the Raritan river near Lansdowne. From this point it runs through Allerville, where it bends to the northeast, and continues in this direction nearly to the Central Railroad of New Jersey between Lebanon and Annandale, rather nearer the latter place than the former. Thence it curves around the north side of Cushetunk mountain, nearly to the railway. At the east base of the mountain, it bends south again to a point just west of Drea Hook, and thence southeast to Readington. A short distance southeast of Readington it crosses the county line between Hunterdon and Somerset counties, and at this point reaches its southernmost limit between the Delaware and Somerville, in latitude 40° 34'. The line is continued eastward in Somerset county to the junction of the North and South Branches of the Raritan. Thence its course is in a general northeasterly direction, running a little north of Raritan, and reaching First mountain two miles north of Somerville. It is not to be understood that all the drift between this line and the moraine is of glacial origin, though it is believed that glacier ice reached the limit indicated.

Farther east, the ice of the early glacial epoch is believed to have covered most of the area north of First mountain, as far east as Summit. East of First mountain at Summit, glacial drift is not thought to have been deposited farther south than the moraine during the early glacial epoch, though its marine equivalent is believed to have covered a considerable area south of the moraine.

Discontinuity of the extra-morainic drift.—The extra-morainic glacial drift is far from constituting a continuous sheet within the area where it occurs. A large part of the surface has no drift, and where it occurs it is often very meagre, being represented only by scattered bowlders derived from formations farther north. Thin beds of drift, two or three feet in depth, are common, while in not a few places the drift is of considerable thickness, locally as much as thirty feet.

The lack of continuity of drift in this region is in striking contrast with the condition of things north of the moraine, where drift in greater or less thickness is essentially continuous. It is true that there are frequent outcrops of rock north of the moraine; and it is true that there are, here and there, areas of some size where the drift is thin. But the areas where the drift is very thin are much less extensive north of the moraine than south of it.

The relationship may be expressed in some such terms as the following: North of the moraine, four-fifths of the surface is so deeply covered with drift as to conceal the underlying rock, and the products of its decay; south of the moraine and north of the drift limit, four-fifths of the surface is nearly free from drift. Just as the one-fifth north of the moraine has occasional bowlders and small patches of drift, so the four-fifths of the area south of the moraine and north of the drift limit, has occasional bowlders, and small amounts of drift in other forms. The amount of drift per square mile on the four-fifths to the south is probably less than the amount on the one-fifth to the north.

Striæ.—Striæ have been recorded at two points in New Jersey south of the moraine, and at one point on the other side of the river, not far from the State line. These localities are as follows: 1) Three-fourths of a mile south of Riegelsville on the gneiss ledges near the railway. The surface of the rock here is somewhat weathered so that there is a possible question concerning the striæ, but there are grooves which seem to be glacial, having a course S. 50° W. (Smock and Kümmel). 2) On a quartzite ledge by the roadside one and two-thirds miles north of Clinton and one mile west of High Bridge well defined striæ trend S. 33° W. (Kümmel and Weller). 3) The third locality is on Chestnut Hill, at Easton, where the course of the striæ is S. 29° W. The striæ were exposed in an excavation at the site of the waterworks.

It will be most instructive to describe the extra-morainic drift in connection with the underlying formations, since in this way some of its peculiarities of topographic distribution are best brought out. To appreciate fully the significance of the position of the drift here described, reference should be made to the topographic maps. The areas of drift, shown on the map accompanying this report, can be located without difficulty on the contour sheets.

The extra-morainic drift was described in some detail in the Annual Report for 1893, and the detailed description given in that place will not be repeated here. A resumé[1] of the facts then published is here presented.

[1] pp. 76-85.

ON THE TRIASSIC SERIES.[1]

A. On the Uplands.

Beds of drift.—In the report referred to above, seventeen localities and groups of localities were enumerated where beds of extra-morainic drift lie on the Triassic terrane. These areas are shown on the geologic map, Plate XXVIII (in pocket). They are as follows: An area just west of Little York, three miles north by northeast of Milford, at an altitude of 400 feet; just east of Pattenburg, at an altitude of about 480 feet, where glaciated material is of common occurrence; a mile and a quarter south of Pattenburg; near Hensfoot, a mile and a half southwest of Perryville; near Potterstown, at an elevation of about 325 feet, between the North and South Branches of Rockaway creek, north-northwest of White House, where its maximum altitude is 261 feet; a mile northwest of White House, at altitudes varying from 226 feet down to about 160 feet; at Drea Hook, a mile south of White House, at altitudes varying from 300 feet to 200 feet, where bowlders are abundant up to twelve feet in diameter; east of Readington, on the divide between Holland's brook and the North Branch of the Raritan, between altitudes of 227 and 180 feet, where bowlders eight to fifteen feet in diameter occur; about Mechanicsville, east of White House, at altitudes of 243 feet and less; at various points between the North Branch of Rockaway creek and Lamington river, at altitudes of 200 to 250 feet; at several points between the Lamington river and the North Branch of the Raritan, at altitudes ranging from 250 to 375 feet; north of Raritan, at an altitude of about 175 feet; between Somerville and Pluckamin, along the base of First mountain, at altitudes ranging as low as 160 feet, and as high as 250 feet, where abundant glaciated material occurs; north of the west end of First mountain; a mile west of Liberty Corner, at an elevation of about 430 feet; and south of Basking Ridge. To this list should be added an area north of Lebanon.

[1] Some of these areas of drift were first located by Mr. A. R. Whitson.

Scattered bowlders.—Besides the beds of drift on the Triassic (Newark) series, scattered bowlders are found in greater or less abundance over most of the area of shale and sandstone which lies between the crystalline schist area on the north, and the drift boundary on the south. In some places the bowlders are abundant, and in others, very rare. The solid dots on the map between the areas of drift show something of their distribution. Near the crystalline schists, the underlying Trias is in places conglomeratic and made up of a great variety of rock constituents, such as quartzite, limestone and gneiss. In such places it is often difficult, and sometimes impossible, to distinguish between drift, and bowlders which may have come from the conglomerate. There is probably not an area a square mile in extent north of the line marking the outer limit of the drift where bowlders may not be found, but there are some square miles where they are so scarce as to be very hard to find. On the other hand, over more of the area there are very many to the square mile. Bowlders are abundant about the borders of most of the drift areas, and where beds of drift occur on summits, bowlders are found on the slopes below, and to some extent in the valleys at their bases. Their occurrence in such positions suggests that they are erosion remnants, and that the imbedding matrix has been carried away since they were deposited.

Thickness.—The thickness of the extra-morainic drift is not well known. Most of it occurs in situations where it is not well exposed, and where it has not been penetrated by wells, so that knowledge concerning its thickness is largely confined to the data gathered from shallow roadside exposures. The maximum thickness known, more than thirty feet, is near Pattenburg. Depths exceeding twenty feet have been reported from several places. Exposures of eight and ten feet, without showing its base, are not rare. In many places, however, exposures four to ten feet deep reveal the shale beneath. In spite of the meagre data on this point, it is safe to say that its average thickness is slight, probably less than ten feet, even for the areas where beds occur.

Constitution.—The drift consists of a matrix, varying from fine sand to a rather tough clay, and stony material varying from small pebbles to bowlders fifteen feet in diameter. The matrix is always thoroughly oxidized, and is nowhere calcareous. It generally lacks all indication of structure, though foliation is to be seen in some of the deeper exposures. The stony material, largely angular, is made up principally of gneiss and quartzite, with lesser quantities of black flint, yellow-brown sandstone (quartzitic on the exterior), bluish or grayish shale, and trap. In many cases most of the decomposable elements have been disintegrated, the gneiss which remains firm generally containing but a small amount of feldspar. At some points, however, as north of Somerville and southeast of White House, many of the gneiss bowlders at the surface are firm. The few trap pieces found have a deeply-oxidized layer on the outside. The whole aspect of the drift is that of age. Limestone has nowhere been found in the extra-morainic glacial drift which lies on the red shale. While glaciated bowlders are not abundant, they can hardly be said to be rare, and are more common in some localities than in others. In its constitution, and in the relations of its constituents, the drift corresponds with till.

The material of the drift, so far as it is not strictly local, came from the Highlands and the Appalachian province to the north. The crystalline schists, the Triassic conglomerate between the schist and the red shale, the Hudson River sandstone and shale, the Cambrian sandstone, and the Oneida and Medina sandstones, contributed to it.

Topographic distribution.—In almost all the areas where extra-morainic glacial drift lies on the Triassic shale, it caps isolated and more or less flat-topped hills, and the exceptions are not such as to diminish the significance of the rule. The exceptions are certain areas which lie at altitudes considerably above the others, as at Hensfoot and certain areas where the drift is banked against a considerable elevation, as north of Somerville. Those parts of the areas near Liberty Corner and Basking Ridge which lie above the level of Lake Passaic, fall in one or the other of the above categories. Except along the Highlands or against trap ridges, and outside the basin of Lake Passaic, every area of extra-morainic and extra-valley drift on the Triassic shale occupies the summit of an isolated hill or ridge. The isolation is the work of stream erosion. Within the same area, every drift-covered hill or ridge but one, has a crest more than 200 feet high. The exception is the hill just north of Raritan, where the drift is somewhat unlike that at most other points, and is very likely not of glacier origin. North of the limit of drift, nearly every red shale hill which rises to an altitude of 220 feet or more, has a drift covering. The summits of the isolated drift-capped hills have a vertical range of only eighty feet. Except along certain valleys where it is of later origin, no body of drift occurs below an altitude of 160 feet, although there are extensive tracts of land at this and slightly lower levels adjacent to the areas enumerated above. The drift occurs down to 160 feet, and indeed, below 200 feet, only where connected with drift-capped summits which rise to a height of more than 200 feet, the Raritan area being excepted. The drift thins out promptly on descending the slopes from the summits of the drift-capped elevations. The whole relationship of the drift to topography indicates that the drift on the slopes has largely if not wholly descended from the summits.

Considering the sources of the drift, its physical and lithological heterogeneity, its structure, the occasional striation of its bowlders and stones, and its topographic distribution and relations, we have no option but to conclude that it was of glacial origin.

Topography of the surface on which the drift was deposited.—From the topographic distribution of the drift, we are shut up to the conclusion that the isolation of the drift-covered hills in the vicinity of White House took place *after the drift was deposited*. Since within the area affected by the drift, no hills (the hill north of Raritan being excepted) whose summits are below 200 feet, and few whose summits are below 220 feet are drift-capped, and since the vertical range of the drift is so limited, it is inferred that the surface of the shale was no more than gently undulating when the drift was deposited, and that general level corresponded approximately with the surface which is now 225 to 275 feet above the sea. From New Germantown on the north to Readington on the south, and from a point two miles northwest of White House on the west, to Somerville on the east, the general altitude of the surface did not rise greatly above or fall greatly below these limits.

Original distribution not controlled by topography.—It is to be noticed, further, that an extensive area, similar in altitude and topography to that where the drift occurs, stretches off to the south beyond the limit of the drift. Since the topography and topographic relations of this driftless tract south of Holland's brook, lying partly in Hunterdon county and partly in Somerset, appear to be identical, in all essential respects, with the corresponding drift-spotted country to the north, the conclusion is inevitable that the drift never extended farther south than the above brook. Since it did not, the drift cannot be referred to the sea, or to any other body of water, for any sea which could have deposited the drift which centers about White House, must also have covered the areas at equal and less altitudes to the south and east, and would have left some signs of its presence here.

Erosion since the drift was deposited.—The larger streams of this area now flow at levels more than 100 feet below the levels of the lowest summits on which the drift occurs. Two miles east of White House, the Rockaway creek has an altitude of 100 feet. A mile northwest of Pluckamin, the North Branch of the Raritan has the same altitude. Near Readington, the bed of Holland's brook has the same altitude, while the junction of the two Branches of the Raritan is below fifty feet. In the same region, the drift is mainly above 200 feet.

It is not merely that the streams have valleys so much below the level of the drift summits. The valleys are wide, and their slopes gentle, showing that the drainage system is well advanced. The area of the surface which is below the drift level is several times as extensive as the area which rises to it. This will convey to the geologist some definite idea concerning the amount of erosion which has been accomplished in the region since the drift was deposited. Careful study of the topographic map (sheet 5) in connection with the map accompanying this report, will emphasize, as words cannot, the point here made.

In forming a judgment as to the length of time necessary for accomplishing this amount of erosion, it is necessary to remember that the region is twenty to thirty miles from the sea, and that its altitude is not great. The rock in which the valleys have been excavated is shale, and shale which is, on the whole, easily eroded. But even an easily eroded rock cannot be eroded rapidly unless the streams which do the eroding have steep gradients. The forms of the valleys prove that their excavation has been a slow process, in spite of the fact that the rock is not resistant.

Nowhere within the moraine, or within the area covered by drift contemporaneous with the moraine, is any such amount of erosion known to have been accomplished, *under similar conditions,* since the ice retreated. No hesitation is felt in saying that no area of the moraine, and no area north of it, so situated as to be comparable to the drift area about White House, *has suffered any considerable fraction of the erosion which this area has.*

With erosion as a measure, the drift described above must be *very much* older than that of the moraine. The physical and chemical constitution of the drift lead independently to the same conclusion.

B. In the Valleys.

In addition to the drift on the uplands, there is a considerable amount of drift outside the moraine in some valleys in the Triassic shale. This is partly within, and partly without, the limit of the glacial drift.

In the valley of the South Branch of the Raritan.—Outside the limit of the old glacial drift, the only valleys which contain drift are those of the Delaware and the South Branch of the Raritan. These are the only valleys which head north of the drift limit. The deposits of other valleys are strictly local; that is, of material derived from their own drainage basins. In the valley of the South Branch, valley drift forms a nearly continuous bed from Lansdowne to Three Bridges, though there is an interruption near Stanton station. From Three Bridges to the village of South Branch, drift is present in the valley in patches only. At Lansdowne, its elevation is about 180 feet; at South Branch about seventy feet. The fall of the river in the same stretch is from 160 feet to sixty. The drift of this valley reaches a maximum height of about thirty-five feet above the stream at Flemington Junction, and extends thence down to the flood plain. Its depth has not been determined at many points, but near Flemington Junction, its thickness is twenty feet, a figure which is probably well above its average. It is often disposed in the form of more or less clearly defined terraces, as at Flemington Junction, Woodfern, and west of South Branch village.

In composition, the valley drift may be characterized as clayey gravel. Its stony constituents, mainly of gneiss, range up to six and eight inches in diameter. Sandstone, quartzite and shale of non-Triassic origin, occur sparingly, and bits of Triassic shale are mingled, frequently in considerable quantity, with the materials of more distant origin.

The matrix of the valley drift is sometimes stiff clay, and sometimes more or less arkose. It appears to have been derived largely from gneissic material, but to have received a considerable addition of clay from the red shale. It is not usually distinctly stratified, though few good exposures have been seen. The best seen were at Sunnyside, Flemington Junction, and Woodfern.

In the valley of the North Branch.—Extra-morainic valley drift of pre-morainic age is also found in the valley of the North Branch of the Raritan, north of the southern limit of the old drift. It forms a low and tolerably continuous plain, fifteen to twenty feet above the river, from the vicinity of Bedminster to Milltown. Its altitude in the former place is about 150 feet, and at the latter sixty to seventy. The drift is more or less terraciform, the terraces being occasionally well defined, as at North Branch village, and north of Burnt Mill.

Comparable phenomena exist in the valleys of the Lamington river and Rockaway creek. On the whole, the valley drift of these valleys is more clayey than that along the North Branch.

The upper limit of the valley drift within the area of the old drift is not sharply defined. It does not rise to a certain distinct and readily traceable level, and there stop; but grows thinner towards its upper limit and seems to "fray out" on the slope. Above the valley drift, scattered stones and bowlders are often found, even to the summits of the elevation on which the beds of drift already described occur.

It is believed that the valley drift within the area covered by the early ice sheet, as well as some of that farther south, was deposited by the present streams long after the glacier had left this region. It is believed to have been derived in part from the old glacial drift which was brought down into the valleys after they had been excavated essentially to their present level.

In the valley of the Delaware.—The valley drift of the Delaware, so far as it occurs in the Triassic region, was referred to in Chapter XIII, and described in the Annual Report of 1893.[1] It occurs in well-defined patches at Raven Rock, at Titusville and at Washington's Crossing. At Raven Rock, this old drift occurs on a rock or bench at an elevation of about 200 feet, and 140 feet above the river. Most of the material is on the west side of the Lockatong. A glaciated bowlder was found in this area, but most of the material appears to be water-worn. Bowlders are by no means rare. The old drift material is scattered over the slope below its summit level, nearly or quite to the level of the late glacial gravel. This valley drift seems to have been deposited when the river flowed at the level of the bench on which it rests, and its lower part to have washed down the slope since. Its topographic position is in keeping with that of the extra-valley drift. There is nothing to determine whether this valley drift is a remnant of a valley train of the old drift, or whether it was derived from the old drift and deposited by the river after the early glacial epoch.

At Titusville, there is valley drift similarly disposed, but seventy to eighty feet lower than that at Raven Rock. Bowlders of Oneida, Medina and Cambrian sandstones, and of gneiss, are here so plentiful that fences are built of them. The stony material of this older drift is in striking contrast with that of the terraces of younger drift below.[2]

At Washington's Crossing the old valley drift covers a rock bench which has an altitude of 130 to 140 feet, and is rather more than 100 feet above the river. The material at this point is much finer than that at Titusville and Raven Rock.

---

[1] pp. 117-122.

[2] Ante, p. 705.

Traces of valley drift, comparable in kind and position to that of the localities mentioned, are found at some other points.

The drift at these several localities is believed to have had a common origin. It occurs in similar situations and in similar relations at all points; the stony materials are the same in kind and in condition at the several localities, and their relative proportions are essentially constant. From the size of the bowlders, and from the fact that distinctly glaciated stones exist, it is inferred that floating ice assisted the river in their transportation. The testimony of the drift therefore seems to point clearly to its connection with some stage of the ice period. The drift is clearly separated in origin, and separated by a considerable interval of time, from the late glacial gravels which lie below it.

Before the last glacial epoch, the epoch during which the new glacial gravel was deposited in the bottom of the Delaware valley, the stream appears to have cut its channel down essentially to the present level. At Washington's Crossing this level is about twenty-five feet above sea-level; at Titusville its level cannot be more than five feet higher. At the first of these points, therefore, the old valley drift is 105 to 115 feet above the river; at Titusville about 100 feet. If the drift at Raven Rock, Titusville and Washington's Crossing was deposited by the river when it flowed at the levels of the benches on which the drift now lies, any earlier valley below the level of the benches must have been filled up to this level, at the time of the deposition of the old drift. The vertical distance between the terrace bench with its old drift, and the bottom of the valley as it was before the last ice incursion, would accurately represent the amount of inter-glacial stream erosion in this valley. In this case we would have the following maxima of erosion for this period: at Washington's Crossing, about 110 feet; at Titusville, about 100 feet; at Raven Rock, about 140 feet. It is to be noted that this amount of erosion may not all have been in solid rock, for the depth of the rock valley prior to the deposition of the Raven Rock-Titusville drift, is unknown. If these beds of valley drift, or if even those at the lower levels (Titusville and Washington's Crossing), accumulated during submergence of the sites where they occur, it is not necessary to suppose that so much erosion took place between the deposition of the old drift and the new. The drift might have been no more than a coating on the slope of the valley, up to the height to which the water rose. The trough of the valley may have remained a trough still, after the deposition was completed.

The relation of this valley drift to gravels outside the Delaware valley farther south, seems to aid in a decision as to whether these patches of old valley drift are fluvial or marine. That at Titusville and Washington's Crossing has about the same height as the Pensauken formation about Trenton Junction, and elsewhere, and the composition of the two is similar. To explain the latter, subsidence is necessary, though it is probably partly of fluvial origin. The former may have been largely fluvial, antedating the time of submergence, but the places where it occurs were probably submerged before the close of the Pensauken epoch. The drift at Titusville, Washington's Crossing and Raven Rock, therefore, is regarded as probably of Pensauken age, and as the time-equivalent of the older glacial drift. After its deposition, the river excavated a valley through such deposits as existed in its channel, and through more or less rock beneath, down to its present level. Then came the partial filling of the valley with the gravels of late glacial age, described in the last chapter.

NORTH OF THE TRIASSIC AREA[1].

Much of the extra-morainic drift of this area was described in some detail in the Annual Report for 1893[2], and those descriptions will not be repeated here. The general facts and relations only are summarized.

The extra morainic drift of this region, like that of the Triassic area of the south, occurs partly in the valleys and partly on the uplands. In the latter situation, it is most commonly found on surfaces of slight relief, and in cols, and is not present in any considerable quantity in other situations. Bowlders are found

[1] Some of these areas of drift, especially in the western part of the area concerned, were studied in detail by Dr. Kümmel, and a few of them located by him. Some of those farther east were studied by Mr. Peet.

[2] pp. 93-117.

much more widely than beds of drift. They are interpreted as the remnants of a former sheet of drift, most of which has been carried away, except in those topographic situations where its preservation has been favored.

A. On the Uplands.

On Musconetcong mountain.—Extra-morainic drift occurs in distinct beds on Musconetcong mountain, a little more than a mile north of Spring Mills (four miles northeast of Riegelsville), and a mile and a half northwest of Little York (two miles south of Bloomsburg). Materials from the Oneida and Medina formations are recognizable, together with glaciated pieces of shale which were perhaps derived from the Hudson River beds. These materials are mingled with those of gneissic origin. Most of the drift is at altitudes of 660 to 690 feet. About Swinesburg, and again two miles east of Riegelsville, surface bowlders are so abundant as to lead to the conclusion that drift may be present in much greater quantity than the shallow exposures show. In the former situation, the bowlders have an altitude of about 940 feet, and in the latter between 600 and 700 feet. Scattered bowlders are found very generally on the mountain, but especially about the borders of areas where there are beds of drift, in cols, and in high areas of slight relief. On the northeastward continuation of Musconetcong mountain isolated patches of drift occur near Newport, at an elevation of 600 to 700 feet. Striated stones are not rare.

On Schooley's mountain.—Drift is found on various parts of Schooley's mountain, chiefly at altitudes between 1000 and 1180 feet. One of the more considerable areas extends northeast from the village of Schooley's Mountain, and another lies west of Budd's lake. In the former locality the area of drift is about three square miles in extent. It contains material from the Oneida, Medina, Hudson River and Cambrian formations to the north, as well as black flints and gneiss. The area of drift west of Budd's lake is more considerable, six or seven square miles in extent, and the drift is similar. In both localities, the drift appears to be till, and in both places, striated stones are found. The depth of the drift is known to exceed ten feet at some points, and to reach twenty-five feet at Drakestown. While the elements of the drift were not originally unlike those which make up the moraine to the north, the drift is now more highly colored than that of the moraine, indicating a higher state of oxidation. The extra-morainic drift west of Budd's lake reaches north to the moraine at some points, and in this area some fresh drift lies a little south of the moraine. This was noted especially half a mile east of Drakestown. The fresh drift is stratified and lies in a valley open toward the moraine from which it is about three miles distant.

Other patches of drift occur east of those mentioned, on the highland which is virtually a continuation of Schooley's mountain. The character and relations of the drift are similar to those of the areas already mentioned.[1]

On Marble and Pohatcong mountains.—Scattered bowlders, but no beds of drift, are known on Marble and Lower Pohatcong mountains, but beds of drift of small extent occur at various points on Upper Pohatcong mountain. These occur a mile and a half northeast of Port Colden; a mile northeast of Karrville; a mile north of Rockport, where the drift attains an altitude of 1200 feet; and a mile and a half north of west of Rockport and northeast of Mt. Bethel. Some of these areas are only a mile or so from the moraine, but they are 150 to 300 feet above it. Scattered bowlders are not rare on Upper Pohatcong mountain, even where beds of drift are absent.

On Scott's mountain.—On Scott's mountain areas of drift occur half a mile north of Lower Harmony, and one and three-fourths of a mile northeast of that place at an altitude of 600 to 700 feet; a mile north of Montana and three-fourths of a mile northwest of that place at altitudes exceeding 1100 feet; and south and west of Oxford Furnace, where there is an area of drift two or three square miles in extent. It is best exposed near Little York and Oxford Furnace. Striated material occurs wherever there are good exposures. In the vicinity of Oxford Furnace, there is also some drift of morainic age (see p. 238), though most of that outside the moraine is old.

[1] See Annual Report 1893, p. 96.

The yellow-brown color of the drift throughout its entire thickness, so far as exposed; the pronounced weathering and complete disintegration of many of the pieces of gneiss; the disintegration of the shale and the weathered condition of the sandstone; the complete leaching out of the calcareous ingredients at most points, puts the old drift of this mountain in contrast with the drift of the moraine close at hand.

On that part of the mountain which lies northeast of Oxford Furnace, there are a few small areas where the drift occurs in considerable quantity. These are a mile southeast of Oxford Furnace, on the Washington road, in a col at 800 feet; two miles east of Oxford Furnace, likewise in a col, a small area at an altitude of 1,080 feet; another small patch half a mile northeast of the last, ill-defined; and another col area a mile or so north of Karrville. Scattered bowlders may be found on most parts of Scott's mountain, though they are sometimes so rare as to be very inconspicuous. The drift of these localities, less than three miles from the moraine, is some 600 feet higher than the moraine where it crosses the Pequest valley south of Townsbury, and more than 100 feet higher than the highest part of the moraine on Mt. Mohepinoke.

On the highlands east of the South Branch of the Raritan.—Drift in the form of scattered erratics, if nothing more, is found over the whole of the Highlands east of this valley and south of the moraine. Most commonly the drift consists of scattered bowlders only, and these are distributed without respect to topography, except that they are rather more likely to be present on elevated, flat-topped areas, and in cols, than at other points. The extra-morainic drift is more abundant near the moraine than at considerble distances from it, yet considerable beds of it occur as far south as Bernardsville, on the extreme southern limit of the highland area.

The general constitution of the drift is the same throughout most of this area. Its stony material is made up of gneiss or crystalline schist, which is usually little or not at all worn, of quartzite, sandstone and conglomerate of various sorts, and of black flints. At no point east of the Black river has Hudson River sandstone or shale or limestone been found in the extra-morainic drift. In its general features of distribution and constitution, the drift of this region is altogether similar to that farther west.

East of Succasunna, and between the moraine on the one hand and the parallel of Morristown on the other, drift is present in sufficient thickness to constitute beds, over an aggregate area of about fourteen square miles. This is mainly near the moraine. Except on steep slopes and sharp peaks, there is a somewhat general covering of drift over a belt a mile or two wide just outside the moraine, from a point midway between Tabor and Littleton, westward to the valley at Succasunna. Many of the highest points within this area are free from beds of drift, but even on these summits, and on the abrupt slopes, bowlders are sometimes present. They have been found in such situations that it is safe to say that there is no part of this area too high to have bowlders, although it cannot be said that they are especially characteristic of the highest points.

The drift is well exposed at but few points, but wherever exposed, it has an aspect somewhat different from the drift of the moraine, though the difference in many cases is hard to define. Generally speaking, the material outside the moraine is much more highly oxidized than that of the moraine itself. A reddish brown color characterizes the former, and a greyish color, the color of pulverized gneiss, the latter.

Another point of difference is found in the relative abundance of striated material. Generally speaking, striated stony material is several times as abundant in the moraine as outside it, though there are places where the material outside the moraine is not poor in striated stones, and places in the moraine where striated stones are not abundant.

So far as concerns its lithological make-up, the stony material of the extra-morainic drift cannot be said to be markedly unlike that of the moraine. It is often true that materials are found in the extra-morainic drift which are not present in the moraine near at hand, but it is also true that no variety of stony material is found in the extra-morainic drift which is not found at some point in the moraine or north of it. On the other hand, it is true that essentially all the varieties of stony material found in the moraine, are found at some point outside it. In general, the proportions of material are not the same in the moraine and outside it. Limestone is frequently found in the moraine, but at no point east of the Black River valley has it been found in the drift beyond. Quartzite forms a much larger proportion of the stony material outside the moraine than in it, and gneissic and granitic rocks occur in greater variety in the moraine than outside it. There is also a contrast, in many places very marked, in the amount of wear which the gneissic bowlders in the moraine have suffered, as compared with that shown by corresponding bowlders outside. The apparent lack of wear in the latter case is partly, perhaps chiefly, the result of subsequent weathering.

It is true that the extra-morainic drift of this region does not everywhere bear such distinctive evidence of age as in some other parts of the State. This is especially true of the drift very near the moraine. Thus the railway cut west of Tabor, and the exposure near Mill Brook, do not look so markedly unlike the drift of the moraine that it need be supposed that they are far separated in time of origin. The idea is entertained that the ice which made the moraine may have advanced somewhat beyond the position of the moraine, perhaps shortly before the latter was formed, and that some of the extra-morainic drift near the moraine is the product of such advance. A specific bit of evidence bearing in this direction is found in the form of a gravel hill two and a third miles southwest of Rockaway. This gravel hill is somewhat kame-like in form, and rises about forty feet above the gravel plain of the Rockaway. The gravel has the appearance of being of late glacial age, and the ice is believed to have reached this point during the epoch when the moraine was made.

Among the localities east of the South Branch of the Raritan and west of Succasunna where considerable bodies of drift occur, are the following: An area of about one-fourth square mile, a mile southwest of Mount Olive, at an elevation of about 1040 feet; an area of about half a square mile, north of Drakesville, at an elevation of 900 to 1000 feet, and cut through by the D., L. & W. railway between Arlington station and Shippenport; an area about a square mile in extent a mile west of Drakesville, where the drift reaches a maximum altitude of 1190 feet, and where the proportions of the various sorts of stony material are very different from those of the moraine close at hand; half a mile west of the last area; and a mile northwest of Flanders, where the drift caps a hill.

East of Succasunna, where stratified drift of late glacial age extends some distance south of the moraine (p. 742), there is abundant drift on the Highlands for a distance of three to five miles from the moraine. In this belt it is not continuous, but is oftener present than absent, except on steep slopes and narrow summits. The depth of the drift in this area varies from zero, to a known maximum of thirty feet. Throughout this area the extra-morainic drift is in part old, and in part of morainic age. The latter is sometimes stratified. South of the body of drift which is very generally present from three to five miles outside the moraine, there is drift in smaller quantity. Scattered bowlders, now abundant, and now scarce, occur nearly everywhere to the southern limits of the Highlands. Locally, they are so few as to be hard to find, and there may be areas a square mile or even more in extent, where none occur; but their distribution is general.

There are a few considerable areas well south of the moraine, where considerable bodies of drift are found. Such an area, a square mile or more in extent, occurs at Mendham at an elevation of 500 to 600 feet. As in many other places where the old drift is present, the soil of this area is not notably different from that of the gneiss hills which have no drift.

Other interesting areas of drift occur about Bernardsville, where they reach a maximum altitude of about 500 feet, and a minimum of a little less than 400. The drift is well exposed in the eastern edge of the village, on the road leading from Bernardsville to Madisonville; by the roadside a half mile south of Bernardsville; and at the railway cut north of Basking Ridge station. Farther west there is also a considerable body of drift at Roxiticus. This occupies an altitude ranging from 400 to 600 feet. It lies well down in the valley, which appears to owe its existence quite as much to the fact that the underlying rock is limestone as to river erosion. The drift is best exposed at a limestone quarry just west of the railway.

In the east part of Bernardsville, a part of the drift has every appearance of till. It overlies a considerable bed of yellow sand, the bottom of which is not exposed, and the age and relations of which are not known.

The cut south of Bernardsville, where the drift exposed appears to be wholly till, is of even greater interest than that east of the village, because of the extreme decomposition of the stony materials. Hardly a stone is to be found in the freshly exposed drift which is not thoroughly decomposed. Every feature betokens great age. A few rods east of the cut last mentioned, at a slightly lower level, there are considerable sand pits, where the sand corresponds in character with that beneath the till east of Bernardsville. This sand is identical with that shown at certain pits in the Basking Ridge hill.

From its structure and its constitution, there seems to be no doubt that the drift exposed east and south of Bernardsville is till. Though rare, two beautifully striated bowlders have been found in the cut east of the village. One of the singular features of the till at both the localities mentioned, but especially at the point a half mile south of the village, is a considerable amount of Triassic shale and sandstone. The altitude of the exposures is between 440 and 460 feet. There is no red shale in the region at any such elevation. There are two possibilities with reference to the method by which it was introduced into the drift. Either it was carried up from the lower Triassic area to the northeast, or it was formed when the Triassic rock close at hand was at greater heights than now—that is, before the adjacent surface had been cut down to its present level. The former of these suppositions is perhaps more probable.

From Bernardsville to Mendham bowlders are more rare than at any other point within the area which is believed to have been covered by ice, though they are found here and there in favored situations. Those which can be recognized as erratics are almost all from the sandstone and quartzitic ledges near Succasunna. Some of them are reddish purple in color, not unlike some portions of the Green Pond mountain conglomerate, although not conglomeratic.

B. In the Valleys.

As will be seen from the accompanying map, there is a very considerable amount of drift in the capacious valleys between the moraine and the southern limit of the old glacial drift, notably in the valleys of the Pohatcong, Musconetcong and the South Branch of the Raritan. There is also some in the valleys of the Black river and Lopatcong creek, the Delaware river, and the North Branch of the Raritan.

In the Pohatcong valley[1].—The amount of drift in the Pohatcong valley is in marked contrast to that on the mountains adjacent. Only in the vicinity of Oxford Furnace is there a considerable body of drift on Scott's mountain. Elsewhere it occurs only in small patches and in the form of isolated erratic bowlders; but in the Pohatcong valley, there is an extensive bed of drift. Its upper end is near Karrville, and it stretches uninterruptedly down the valley through Washington and New Village to Stewartsville. Beyond this point, its continuity is somewhat interrupted, but it is nearly continuous down to the Delaware at Carpentersville and Phillipsburg.

The drift of the Pohatcong valley has an altitude of about 600 feet above Karrville, and an altitude of 300 to 400 feet in the vicinity of the Delaware. It occupies the surface nearly down to the level of the stream, as far down as Stewartsville, and runs up on either side of it to heights of from sixty to 100 feet. On the slopes of Scott's and Pohatcong mountains above the valley, there are no more than traces of drift, chiefly in the form of scattered bowlders.

The drift is well exposed 1) along the D., L. & W. railway north of Washington, where there are cuts fifteen to thirty feet deep; 2) near the Morris canal, northwest of Washington, where there are cuts fifteen feet deep; 3) along the D., L. & W. railway, between Broadway and Stewartsville, where twelve to fifteen feet of drift are exposed; 4) along the road east by north of Stewartsville, six feet exposed; and 5) at the Thatcher Hematite mines, two miles south of New Village, where fifteen feet of drift partly

[1] For fuller details, see Annual Report for 1893, p. 108.

stratified, are exposed. The drift of this valley is continuous with that of the lower Lopatcong and the Delaware. Exposures in the drift of the Lopatcong valley occur half a mile southwest of Port Warren, at the Hamlin Hematite mine; exposures in that of the Delaware valley occur along the L. V. railway two and a half miles southeast of Phillipsburg, and at the Warren foundry in Phillipsburg.

The drift of the Pohatcong valley presents essentially common characteristics throughout its whole extent. In general it has the appearance of till. Its color is yellow-brown, with locally a reddish tinge. The stony material includes bowlders from the following formations: Cambrian, Oneida, Medina, crystalline schists (gneiss) and Hudson River. Black flints are also present. Gneiss and schist bowlders are more abundant than all others. They are often four to five feet in diameter, while bowlders of other sorts rarely exceed one or two feet. The gneissic and schistose material is so much decayed that while it constitutes a large part of the stony material in section, it sometimes makes little showing at the surface.

The absence of limestone is to be especially noted, since the drift occurs in a limestone valley. The matrix of the drift is often arkose. Striated materials are present, but not abundant. Striæ are most common on the shale, but are not unknown on the other sorts of rock. Locally, as at the locality marked "Thatcher Hematite" on the topographic map, stratified drift is intercalated between beds of unstratified.

In various parts of the valley, the line of demarkation between the drift and the gneiss debris from the adjacent mountains is not sharp, for the latter has covered the former to variable depths.

The disposition of the drift in this valley is such as to show that the valley has suffered little deepening since the drift was deposited. If it be glacial, the valley has been deepened but little since the early glacial epoch. It is possible that much of this drift is in secondary position.

In the Musconetcong valley.—The old drift in the Musconetcong valley is not so extensive nor, on the whole, so well developed as that in the Pohatcong. It occurs in patches from Hackettstown to Bloomsbury. Its topographic distribution is, in general, similar to that of the drift in Pohatcong valley, but it does not generally so closely approach the level of the stream. It is, on the whole, less distinctly confined to the valley, although it lies well below the mountains on either hand.

There is a considerable area of drift at Hackettstown and southwest from there, at a maximum elevation of 657 feet, and exposed in railway cuts just north of the Hackettstown depot, and along the canal a half mile or so to the north. There is another considerable area of drift south of Rockport at a maximum elevation of about 700 feet, or about 200 feet above the river at this point. At the southern end of the principal railway cut in this drift, there is a layer of sand and gravel, traceable for as much as fifty yards beneath unstratified till-like material. In its general constitution, the drift of this locality corresponds closely with that of the Pohatcong valley. South of the river south of Rockport, the drift comes down to within thirty feet or so of the stream.

Farther down the valley, at Port Murray, there is another considerable area of drift ranging from 640 feet to 440 feet. Its streamward edge reaches the trench cut by the Musconetcong in recent times. The composition of the drift is much the same as that at Rockport, though it contains less gneissic material. The railway cut gives a good exposure of about ten feet, though the drift attains a maximum of nearly thirty feet.

About Port Colden, and south of there, drift ranges from an elevation of 600 feet down to 420 feet, or to within forty feet of the Musconetcong river. The drift is here similar to that of Port Murray. Northwest of Junction, there is another small area of drift which lies at an altitude varying from 420 to 360 feet, the river flowing at about 340. There is no positive evidence that there is any considerable bed of drift at this point, as decisive exposures are not at hand.

Below Junction, the best-defined areas of drift in the Musconetcong valley are a mile west-northwest of Asbury, and a mile northwest of Bloomsbury. The former area is not in the immediate valley. Foreign bowlders of considerable variety, though not in great numbers, are imbedded in a matrix which is largely of gneissic origin. The thickness of drift at the Hematite mine is nearly thirty feet.

Just west of Valley there are abundant erratics on the surface, and it is probable there is something of a bed of drift at this point, sixty or eighty feet above the Musconetcong; but exposures are absent.

A half mile and more northwest of Bloomsbury there is a considerable area more or less thickly covered with drift, the character of which is like that of other localities farther up the valley.

The best exposures are in the railway cut one and a half to two miles west of Bloomsbury. The gneiss material is by far the most abundant, making eighty or ninety per cent. of the whole, but Cambrian, Oneida, and Hudson River sandstone bowlders, or stones of smaller size, are sparsely imbedded in the drift. The drift in some parts of the cut is at least twenty feet thick. Locally it rests on gneiss residuary.

Below Bloomsbury, there is little drift in the valley of the Musconetcong.

If the drift in the valley of the Musconetcong be glacial, its position, like that of the drift of the Pohatcong valley, implies that the stream has done little eroding since the drift was deposited.

In the valley of the Delaware.—Between the moraine and the limit of early glaciation, drift older than that of the moraine occurs in the valley of the Delaware at several points, notably about Harmony station, Phillipsburg, and Carpentersville. Some of the drift is stratified, and some is not.

The drift above Phillipsburg which is not stratified is, in general, like the extra-morainic drift already described, except that it contains little gneiss, a fact which is clearly the result of its position with reference to the crystalline schist formations. The best exposures in the old drift of the valley above Marble mountain are afforded by two gullies about three-quarters of a mile southeast of Harmony station. The upper part of the cuts is rather gravelly, but beneath the gravel, and in places reaching to the surface, is a bed of till, containing many bowlders three to four feet in diameter, some of which are distinctly striated. The greatest known depth of drift in this area is twelve feet, but this does not represent the full section, since at this depth the bottom of the drift was not reached. Gneiss bowlders are almost entirely absent.

This area is separated from another small one to the northeast by the late glacial gravels of the Buckhorn valley. This second area lies west of the Buckhorn and east of Roxburg station. At the southern end, the drift has the general characteristics of the extra-morainic drift, but at its northern end, the indications are not so conclusive. Many of the bowlders here appear to correspond with those farther south, but there is also a considerable admixture of fresher looking material. Striæ are more numerous and limestone bowlders, essentially absent to the south, are common. There are here no exposures, but the surface indications suggest that the ice pushed out upon the northern part of this area during the moraine epoch, and incorporated a certain amount of fresh material with that which existed there before. The proportion of fresh material increases toward the moraine, which is less than a mile distant.

Reference has already been made to stratified drift in connection with the unstratified in the Pohatcong and Musconetcong valleys. Stratified drift also occurs in the valley of the Delaware in intimate association with the early glacial till.

On the brow of the hill, a half mile southeast of Harmony station, there is a very considerable bed of gravel, composed largely of shale. At first sight it appears to be fresher than the till which succeeds it higher up the slope, but the difference in appearance is probably due to difference in composition. Whether the gravel passes under the till is not evident at this point. Again, east of Martin's Creek station, there is a narrow area above the limit of the last glacial gravel, covered by gravel made up, to a considerable extent, of shale. It is clearly older than the Trenton gravel. The same thing is true south of Roxburg station.

About Phillipsburg there is a considerable area of old drift varying in altitude from about 450 feet down to 300 feet. Some of it is stratified, and some of it is till. It is best exposed in the L. V. railway cut, two and a half miles southeast of Phillipsburg, along the D., L. & W. railway a mile northeast of the city, and at the Warren foundry. At the last place a very compact clayey bed of stony drift, averaging three or four feet in thickness, but ranging as high as six feet, grades downward into a clayey gravel, and that into a cleaner gravel, and then into coarse sand. This stratified drift varies from three to six feet in thickness. In one part of the pit, as exposed in 1893, another bed of compact drift was seen to underlie the stratified layer. In other places gravel and sand are underlain by a fine, reddish, clayey loam, without stone. The line of demarkation is sharp and undulatory. The underlying yellow loam is perhaps residuary material. All the drift exposed is deeply oxidized, and nowhere calcareous.

The unstratified material is exceedingly compact. The stones are so firmly imbedded that they frequently break in being removed. The stony material is generally of rather small size, barely reaching a foot in diameter. Gneiss cobbles, generally little worn and much decayed, form a small percentage of the stony material. Cherts and flints of various colors constitute about one-sixth of the whole. Fragments from the Cambrian, Oneida and Medina formations are the most abundant constituents, and in the order named. Hudson River greywacke and shale are very common among the smaller stones. The stratified bed contains a much larger percentage of slate and shale than the unstratified. Limestone is not present. Striæ are rather common on the slate fragments, and are present on some of the sandstones.

In the cut on the D., L. & W. railway, a mile northeast of Phillipsburg, scarcely five per cent. of the bowlders and cobbles seen on the surface are derived from the crystalline schist areas. Cambrian, Medina and Oneida bowlders and masses of flint predominate. The paucity of gneiss bowlders continues to the north and northwest, becoming greater towards the southwest end of Marble mountain.

The ice movement in this region as shown by striæ on the lower part of Chestnut hill, Easton, was S. 29° W. This direction of movement would cause a distribution of gneiss bowlders very similar to that which we find in this vicinity. That part of the ice which moved obliquely across the narrow ridge of Marble mountain, incorporated much less gneissic material into the drift than that part which passed over Scott's mountain. The result was that the part of the valley lying in the lee of Marble mountain received but little gneiss, whereas that lying south of Scott's mountain received much more. The distribution of the gneiss in the drift, so far as observed, would seem to imply a more southerly movement of the ice which deposited the drift above Still Valley, than is indicated by the striæ at Easton.

The high level gravels along the Delaware at Harmony station, east of Martin's creek, south of Roxburg, at the Warren foundry at Phillipsburg, at the D., L. & W. railway cuts northeast of that city, and a quarter of a mile southeast of Lopatcong, are presumed to have a common origin.

All these localities are within a mile or so of the Delaware river, and this distribution might suggest an origin connected with the drainage of the river. But similar gravels have been found two and three miles from the river. Half a mile southeast of Still Valley it occurs on both roads leading up the side of the hill. In the vicinity of Springtown station, on the Central Railroad of New Jersey, it occupies a considerable area. Toward the higher ground, it seems to pass under the till, but there is no section which distinctly shows this relationship.

The various altitudes at which these gravels have been observed are as follows:

Southwest of Roxburg station,	280 +
Near Martin's Creek station,	320 +
Harmony station,	420 to 440
Warren Foundry pit,	300 to 320
Railroad cut near Warren Foundry,	280 to 300
Southeast of Lopatcong,	240 to 320
Southeast of Still Valley,	320 to 340
Springtown station,	300 to 320

This gravel seems to be always closely associated with the till, being either overlain or underlain, or both, by it. It occurs on side hills and near the brows of hills, places where it may have been readily revealed by the erosion of the overlying till. The gravel readily washes and creeps down slopes, giving it the appearance of having a wider vertical range than it really has.

This stratified drift seems to be distinctly separated from the gravel train which heads in the moraine, and which, farther down the Delaware, is known as the Trenton gravel. On the other hand, it seems to be distinctly unlike the extra-morainic drift of any other series of localities. In spite of its unlikeness, it is believed to be connected in time with the great body of extra-morainic drift and to represent merely a local phase of it.

The disposition of the old drift in the Delaware valley about Riegelsville is such as to suggest that the valley has been deepened some 100 to 150 feet since it was deposited. This is in keeping with the phenomena farther down the valley (p. 762). At first sight, these seem to be out of harmony with the phenomena of the Hopatcong and Musconetcong valleys. But it is to be remembered that the deepening of the last named valleys had to wait on the deepening of the Delaware. The altitude of the drift in the tributary valleys is greater than that in the Delaware, which suggests that the early glacial erosion had not affected them notably, before the last ice epoch.

Drift in and near the valley of the South Branch of the Raritan.—From a point a short distance south of Kenvil, drift is found in considerable abundance above the sand plain, which was contemporaneous in origin with the moraine, and extends south and southwest to Ironia and Flanders. It reaches a maximum elevation of 900 feet, the adjacent valleys having an elevation of about 700, so that it is not strictly valley drift, although the area which it occupies is well below the high lands east and west. It rises above the overwash plain connected with the moraine to the north, and widens southward until its maximum width is reached in the latitude of Flanders, where it covers the area from the immediate valley of Drake's brook to the valley of Black river. Most of the drift of this locality has the appearance of being much older than that of the moraine. It is well exposed at a sand pit southeast of Carey's. The stony materials consist of gneiss, Hudson River shale, quartzite of various types, sandstone and black flint. Flints were not noticed in the moraine northeast of this point, nor were the yellowish-brown quartzitic sandstones, which are especially abundant in this drift. Both these types of stony material, however, are present in the moraine at various points. No limestone was seen in the extra-morainic drift, though it is by no means rare in the moraine to the northeast of this locality.

West and northwest of Ironia, the drift has a distinctly fresh appearance. At some other points, as at the school-house between Succasunna and Drakeville, the drift has not the appearance of being extremely old, though it is more highly colored (oxidized) than the drift in the moraine. There is probably not a little drift in this vicinity which dates from the moraine epoch.

From Flanders to Middle Valley, the drift is nearly continuous on the east side of the valley, and north of Bartley it is on the west side of the valley as well. The remarkable thing about the drift here is, that while it overlies limestone, it contains no material derived from it. As shown by exposures just north of Flanders, and at the railway cuts between Flanders and Bartley, the stones of the drift consist of gneiss, black and yellow flints, yellow-brown quartzitic sandstone, and quartzite of various colors. There is a little drift in the valley between Middle Valley and Lower Valley, which seems to be a continuation of that from Flanders.

In this connection another small area of drift, comparable to that from Bartley to Middle Valley, may be mentioned. It lies one mile east of Gladstone. Here also the underlying formation is limestone. The matrix of the drift is rather loamy and has a pronounced yellow color, and contains the usual variety of stony material.

In the Black River valley.—Along the east side of the valley of the Black river, from a point a mile north of Ironia to a point 100 yards south of the Chester branch of the Central Railroad of New Jersey, west of Chester, there is more or less fine yellowish sand. With one exception, it is absent from the west side of the valley. The exception is where Tanner's brook joins the Black river. At this point there is a small area of sand on either side of the brook.

The northern limit of the sand is about one mile north of Ironia, at an elevation of 840 feet. Its upper limit declines southward until at Ironia it has a maximum elevation of 760 feet. South of Ironia the sand continues along the river, above the swamp, rising 180 feet above the river east of Horton's station. It is found more or less distinctly south of Cooper's mines. It is absent in the upper course of the small creek west of Cooper's mines, just north of Chester, though it is present in the lower course. South of the Chester depot of the D., L. & W. railway it again rises to an elevation of 760 feet, and then declines southward. At its southern terminus, the sand is last seen at an elevation of about 680 feet. South of Ironia the sand sometimes has an indistinct terrace-like form at an elevation of about 740 feet; that is, about forty feet above the level of the stream.

The sand along the Black river is well exposed at a few points near Horton's station, in road cuts and old mining shafts. It can be distinguished from the sand of the overwash plain below by its higher position, and by its higher coloration. It is possible there may be a distinction made between that on the hills and that in the valleys above the overwash plain, but no certain criteria for such discrimination were found in the field.

The age and origin of this sand are uncertain. It may be, in part at least, eolian sand of last glacial age. Some of it, however, does not seem to be thus explained.

AGE OF THE EXTRA-MORAINIC DRIFT.

The glacial formations of the Mississippi valley have been referred to several glacial epochs (Chapter VI). The glacial series in the east is less fully developed. The sheet of drift bordered by the Belvidere-Perth Amboy moraine is referred with confidence to the Wisconsin epoch (p. 186)); but the extra-morainic drift cannot be referred with equal confidence to one of the epochs recognized elsewhere. It cannot even be asserted that it is all referable to one epoch.

On the whole, most of the extra-morainic drift seems to correspond more nearly with the drift of the Kansas epoch (p. 182) than with that of any other, so far as the physical and chemical condition of the drift, and its topographic position, warrant a conclusion. On the other hand, it is not to be lost sight of that in the proximity of the moraine, and at a few other points, there is drift which looks distinctly less old than most of that which lies outside the moraine. Some of this is doubtless of Wisconsin age. Perhaps some of it may be of an age intermediate between the Wisconsin and the oldest drift.

INDEX.

INDEX.

A.

B.

C.

H.

I.

J.

K.

L.

N.

O.

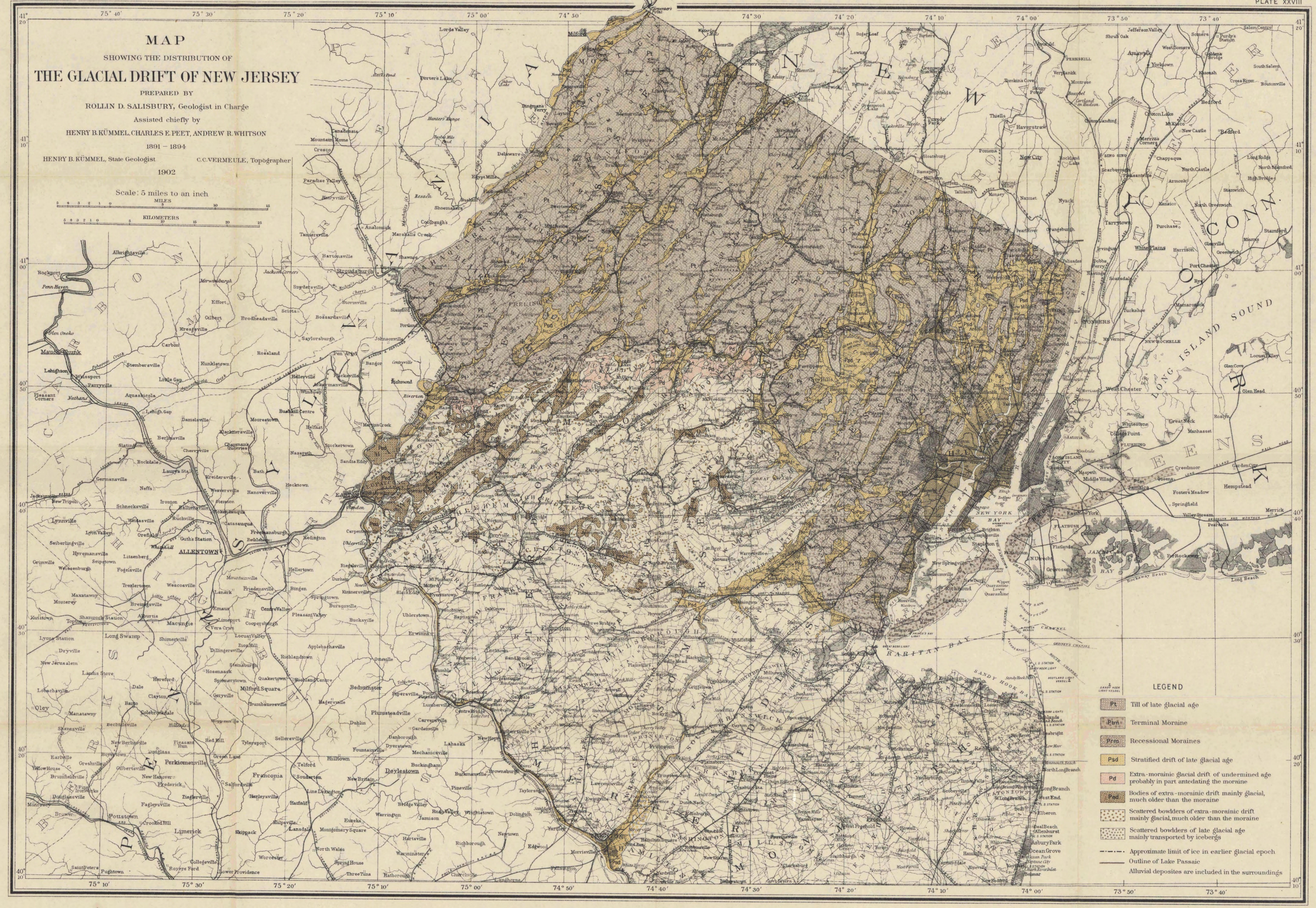
P.

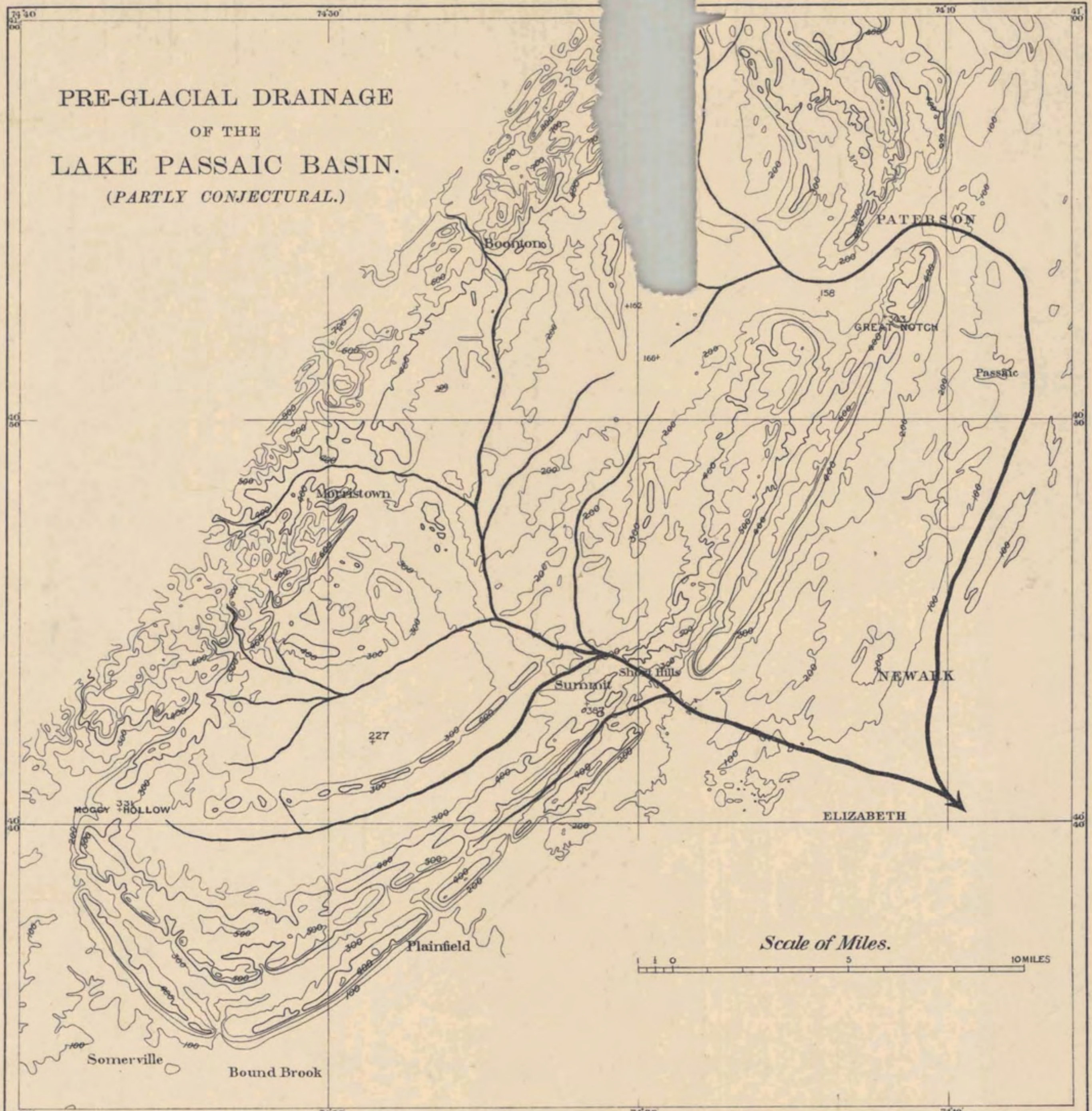
T.

U.

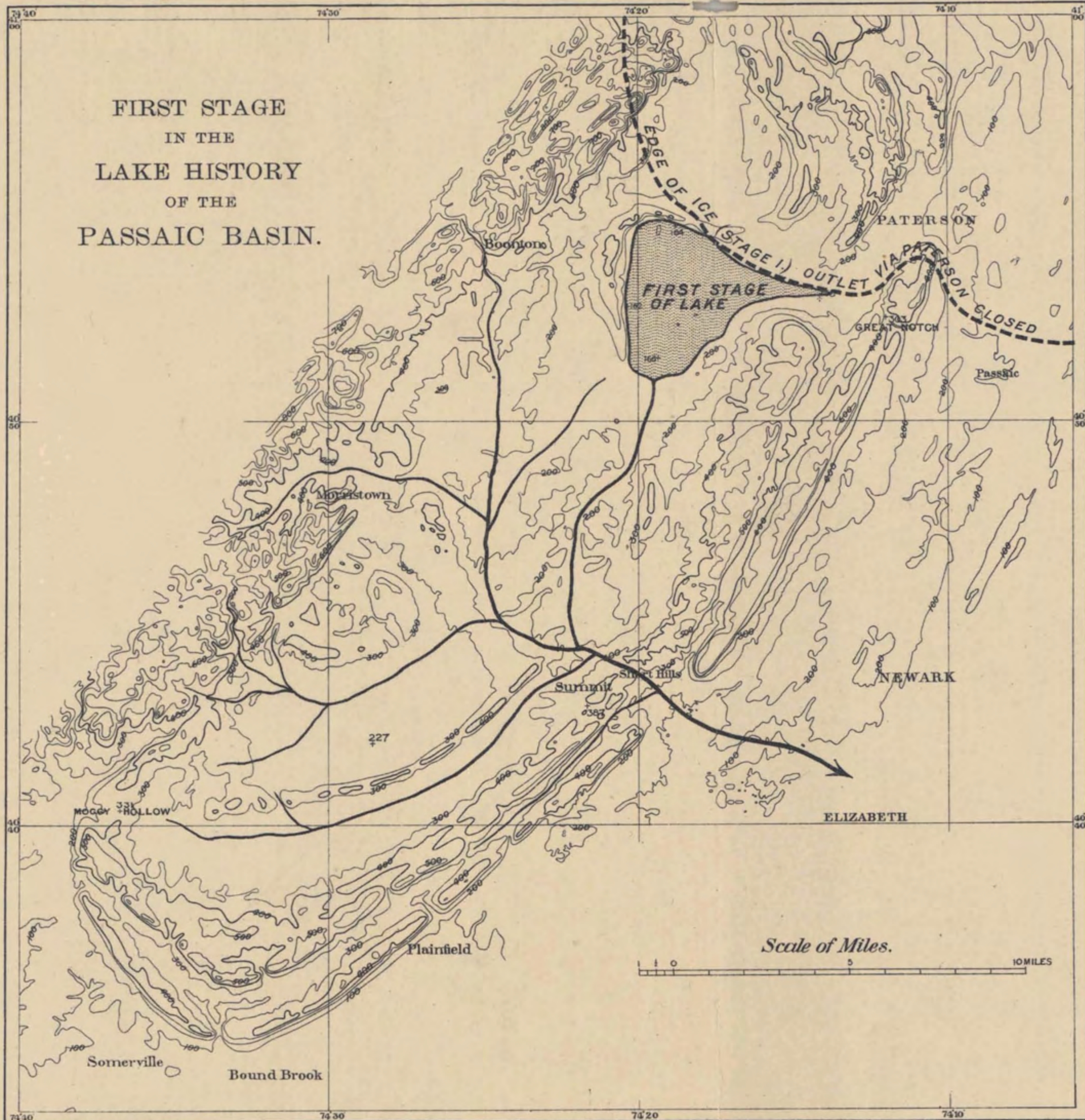
V.


GEOLOGICAL SURVEY OF NEW JERSEY
MAP SHOWING
THE DIRECTION OF
ICE MOVEMENT
IN
NORTHERN NEW JERSEY
HENRY B. KÜMMEL,
State Geologist.
C. C. VERMEULE,
Topographer.
ROLLIN D. SALISBURY,
Geologist in Charge of the Pleistocene.
Scale
Based upon the Topographical Survey.
Port Jervis
Newton
Water Gap
DELAWARE RIVER
Belvidere
Dover
Morristown
Easton
Somerville
Flemington
New Brunswick
Paterson
Hackensack
Haverstraw
Yonkers
HUDSON RIVER
New York
Newark
Jersey City
Brooklyn
Elizabeth
NEW YORK BAY
75° 10'
75° 00'
74° 50'
74° 40'
74° 30'
74° 20'
74° 10'
74° 00'
73° 50'
41° 20'
41° 10'
41° 00'
40° 50'
40° 40'
40° 30'

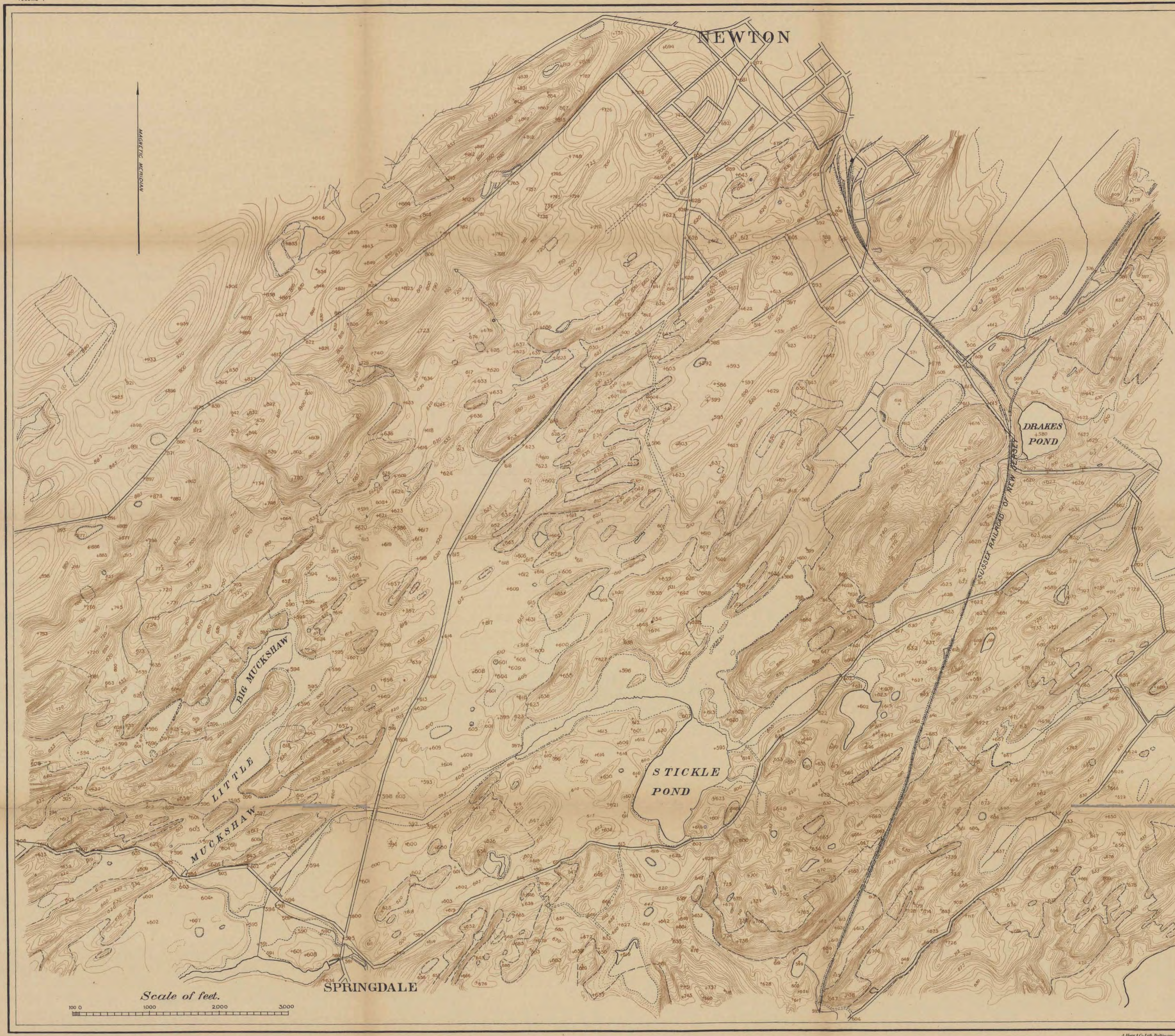

MAP
SHOWING THE DISTRIBUTION OF
THE GLACIAL DRIFT OF NEW JERSEY
PREPARED BY
ROLLIN D. SALISBURY, Geologist in Charge
Assisted chiefly by
HENRY B. KÜMMEL, CHARLES E. PEET, ANDREW R. WHITSON
1891 – 1894
HENRY B. KÜMMEL, State Geologist
C.C. VERMEULE, Topographer
1902
Scale: 5 miles to an inch
MILES
KILOMETERS
LEGEND
Pt Till of late glacial age
Ptm Terminal Moraine
Prm Recessional Moraines
Psd Stratified drift of late glacial age
Pd Extra-morainic glacial drift of undermined age probably in part antedating the moraine
Ped Bodies of extra-morainic drift mainly glacial, much older than the moraine
Scattered bowlders of extra-morainic drift mainly glacial, much older than the moraine
Scattered bowlders of late glacial age mainly transported by icebergs
Approximate limit of ice in earlier glacial epoch
Outline of Lake Passaic
Alluvial deposites are included in the surroundings
Port Jervis
NEW YORK
CONN.
LONG ISLAND SOUND
RARITAN BAY
ALLENTOWN



A. HOEN & CO. BALTIMORE.



A. HOEN & CO. BALTIMORE.



THE TOPOGRAPHY SOUTH OF NEWTON

NEW JERSEY GEOLOGICAL SURVEY

Geology by
Henry B. Kümmel

THE SURFACE GEOLOGY SOUTH OF NEWTON

NEW JERSEY GEOLOGICAL SURVEY