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GLACIAL WATERS IN THE LAKE ERIE BASIN

BY

H. L. FAIRCHILD

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Hon. Andrew S. Draper LL.D.
Commissioner of Education

My dear sir: I beg to communicate herewith for publication as a bulletin of the State Museum the manuscript of a paper entitled *Glacial Waters in the Lake Erie Basin* by Prof. H. L. Fairchild, expert assistant on the geological survey.

Very respectfully yours

John M. Clarke
Director

Approved for publication, January 15, 1906

A. S. Draper

Commissioner of Education

New York State Education Department

New York State Museum

JOHN M. CLARKE Director

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GEOLOGY 11

GLACIAL WATERS IN THE LAKE ERIE BASIN

BY

H. L. FAIRCHILD

INTRODUCTION

In former papers on the glacial waters of central western New York the writer has described mainly the phenomena in the Ontario basin. The present paper is the result of study distributed through several years in the Erie drainage area, and it discusses glacial effects which antedate those in the Ontario basin. The writing is intended as the first of a series describing the effects of glacial waters in New York State and treats of the westernmost geographic area, where the phenomena are of earlier date than those eastward, as the greater glacial lakes invaded the territory from the west.

There has also been a personal reason for delay in this writing. The studies of Mr Frank Leverett on the Pleistocene geology of Ohio and the Erie basin led him in 1893 into New York as far as the Genesee river. The results of this earlier work have been awaiting publication and the writer has delayed the completion of his own study in the Erie basin in order to give precedence to that which now has been published as Monograph XLI of the United States Geological Survey. The present writing covers ground traversed in Leverett's report and deals with the same phenomena; but the manner of treatment is somewhat different, the description is more detailed and in some points the interpretation or explanation of the phenomena is not the same.

The writer has ventured to differ from Leverett's description or interpretation only where the facts seemed imperative, and his best apology is the statement that much greater opportunity for study of the region has given superior advantage. The greater part of the field work was done before Leverett's descriptions and maps appeared, but these have been suggestive and helpful and have caused reexamination of some districts. In the belt of stream channels and lake beaches nearly every highway has been traveled, many in both directions, and many features have been examined from different viewpoints. Some districts have been visited several times, yet there is a mass of interesting detail almost untouched, which possibly has entailed some minor errors in fact or interpretation in the paper. A resident in almost any portion of the area can find, after training his eye and mind to see and understand them, many other interesting features resulting from the work of the glacier or the glacial waters. The writer has satisfaction in the thought that many people living in the area described will find a new source of pleasure in having their attention directed to these romantic geologic phenomena.

LITERATURE

Very little systematic work on the phenomena of glacial waters in the New York portion of Lake Erie basin has been done except by Mr Frank Leverett, although the beaches have long been recognized. In Leverett's Monograph XLI he gives on pages 28-49 a full list of works which contain any reference to the glacial geology of the region. It is not desirable to repeat that list here, but a few writings which have more immediate reference to the New York area are noted below.

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Tarr, R. S. Geology of the Chautauqua Grape Belt. Cornell Univ. Agric. Exp. Sta. Bul. 109. 1896. p.91–122.
Taylor, F. B. Correlation of Erie-Huron Beaches with Outlets and Moraines in Southern Michigan. Geol. Soc. Am. Bul. 1897. 8:31–58.
—— The Great Ice Dams of Lakes Maumee, Whittlesey and Warren. Am. Geol. 1899. 24:6–38.
Upham, Warren. Origin and Age of the Laurentian Lakes and of Niagara Falls. Am. Geol. 1896. 18:169–77.

AREA. MAPS

The area described in this paper may be defined briefly as that part of New York State which drains into Lake Erie; but the history of the glacial waters involves territory far east of the present Erie drainage, as the valleys of Oatka, Genesee, Hemlock and Honeoye were forced to send their overflow westward into Lake Warren for a time during the later stages of our history.

The principal phenomena herein described lie in a belt parallel to the present Erie shore and having a direction nearly northeast and southwest [*see* pl. 1]. From the Pennsylvania state line to the valley of Cattaraugus creek the belt is only 5 to 10 miles wide, and from the Cattaraugus eastward the phenomena are not spread over a much wider belt until near the Tonawanda valley. The distance covered by the belt in direct course from State Line to Indian Falls is about 90 miles.

The territory is included in the counties of Chautauqua, Cattaraugus, Erie, Wyoming and Genesee. In plates 1–6 the reader will have before him the following sheets of the New York topographic map: Westfield, Dunkirk, Cherry Creek, Silver Creek, Buffalo, Depew, Attica, Batavia and Caledonia.

GEOGRAPHY. TOPOGRAPHY

The relation of the geographic elements in horizontal plane is shown in the maps [pl. 1-6]. The vertical relation or relief is indicated on the maps by the contour lines which give altitude in feet above ocean level, and are drawn with a vertical spacing of 20 feet.

As a broad statement it may be said that the slope of the land surface is toward Lake Erie. This is strictly true for the western part of the area, but the eastern part inclines more to the northward, or toward the Ontario basin. The slope is not a steady or uniform inclination, as a large part of the fall is concentrated in a relatively narrow belt, which is shown by the contoured maps. It is along this steepest slope that the greater number of drainage channels occur.

The Cattaraugus valley is the only broad embayment which breaks the continuity of the Erie slopes. South of the Cattaraugus the slope is not cut by any large preglacial valleys, but the surface north of Cattaraugus is more dissected.

From State Line to the Cattaraugus valley the divide or waterparting between Lake Erie and the Allegany river drainage lies only some 5 to 10 miles from the lake. The altitude of the divide is over 1300 feet, while the lake surface is 572 feet. It is therefore apparent that the land slope in this section is very steep, falling in 5 to 10 miles about 700 feet from the lowest passes or cols to the lake, and from the hilltops falling about 900 or 1000 feet. This fact of the steep slope facing lakeward is of special importance to the clear comprehension of the glacial lake history. For more particular description it will be necessary to discuss the area by sections.

From State Line to beyond Fredonia about one half the total fall from the divide to the lake, or 400 to 500 feet, is found in about 1 mile of horizontal distance. This steeper slope forms the conspicuous high ground which bounds the view when looking landward from the highways or the railroads. Just below the steepest slopes lie the shore lines of the ancient glacial lakes. From these old beaches to the present lake the land has a gentle slope, being the silted and leveled floor of those extinct lakes.

The Cattaraugus valley carries the divide far inland (eastward), the farthest points being some 40 miles from Lake Erie. The old beaches and glacial stream channels, however, curve up the valley only as far as Gowanda.

From the Cattaraugus embayment to Hamburg the topographic features are quite similar to those west of the valley. Beyond

Hamburg, north and east, the land surface is more dissected by streams and the general slope is more gradual. In consequence of these characters the glacial stream and lake phenomena are distributed over a wider belt and more irregularly.

With reference to both ancient and modern drainage there are two sets of baselevels. The lowest is the present water surface of Lake Erie, taken as 572 feet over ocean. The other baselevel is the series of ancient and higher waterlevels of the great glacial lakes Whittlesey and Warren. These old high-level beaches are spread through a vertical space of about 70 feet, and lie just below the foot of the steepest land slope.

The ancient shore lines are no longer horizontal, but have suffered along with the land surface on which they lie a tilting or differential uplift, so that they now rise toward the northeast at the rate of nearly 2 feet a mile [*see* p. 77].

OUTLINE OF GLACIAL HISTORY: THEORETIC PROBLEM

It will help the reader to a clear mental grasp of the subject if the broad features in the topography and the main events in the geologic story can be clearly appreciated apart from details.

There are four distinct elements in this study. (1) The general topography or the broader configuration of the land surface. (2) The location and trend of the front of the glacier, which is the variable factor. (3) The flow of the escaping waters, or the stream phenomena, which changed along with (2). (4) The position and the effects of the lake waters which followed the retreating ice front. We will discuss these briefly in order.

(1) The general topography has already been described as a broad valley or basin extending northeast by southwest. The present Lake Erie has no part nor significance in this history, it being only the successor of the ancient glacial lakes, and giving its name to the basin, and marking the lowest part. The Lake Erie basin should be recognized as continuing northeastward beyond the lake, and as blending with the Ontario basin. The southern slope of this general basin, facing northwest, and extending from the Pennsylvania boundary northeastward to Batavia, is the stage on which our glacial drama was enacted.

(2) The geologic events which we are studying belong to the time when the last ice sheet of the glacial period was disappearing from the region. At an earlier time, when the great ice body was at its maximum, it had covered, practically, all of New York State, and the movement of the ice mass had been toward the southwest,

following the axis of the Erie basin. But at the time we are considering the ice sheet had long passed its maximum stage, and the front had receded, due to the excess of melting at the margin over the supply by flow from the northward. There now lingered over the Erie basin a great mass or lobe of the continental glacier which, since it was no longer subject to great pressure or push from the ice mass on the north, was reposing in the basin as a comparatively stagnant mass. It was not a rigid, inflexible body, like a small block of ice in the summer sunshine, but its great bulk and weight gave it a practical plasticity and a slow spreading movement, like a block of pitch or asphalt in the summer heat. This spreading flow was naturally radial or outward from the center, and consequently the direction of flow of the Erie ice mass over our district was from the northwest. The margin of the ice was at right angles or normal to the direction of flow, and hence extended northeast by southwest along the northwest-facing land slope. As the recession of the ice front was very slow it reposed for ages (we have no way of measuring the time) against the steeper part of the valley slope, and its position there, slowly falling or backing away, is indicated by the lines of rock rubbish or moraine drift dumped at the ice margin, and by the stream channels cut by the drainage past the ice front. Other belts of moraine farther landward mark earlier pauses in the ice retreat [*see* fig. 1, p. 12].

(3) The drainage. If the reader now apprehends the relation of the ice body to the general land surface (a huge ice mass filling the bottom of the Erie valley and resting against the northwest-facing land slope with its margin extending along the horizontal contours of that slope) he will appreciate the fact that the stream flow of that time must have been very unlike the present. On the higher, exposed land surface the streams must have flowed down the slopes (northwestward) as they do today. But the ice front opposed their course and they could pass neither through, over, nor beneath the glacier; they could flow only alongside or past the ice margin. This land drainage along the ice border was augmented by the abundant water derived from the melting of the ice body itself.

The question will now arise as to the direction of escape for the waters, whether to the eastward or westward. It has been found that the eastward escape was impossible, not only because the neighboring land is higher in that direction, but for the reason that at this stage in the glacial retreat the Ontarian ice lobe was pressing against the high ground in central New York. The escape was southwestward along the ice margin to the open lake waters in the western part of the Erie basin, with ultimate overflow to the Mississippi. This brings us to the matter which is the special subject of this writing—the history of the glacial waters, the stream phenomena and the lake records.

(4) The lake waters. As the ice body melted away, obliquely, from the land slope the lake waters crept in along the ice margin and occupied all the open space below their level. Beaches, as gravel bars and spits, and delta fillings mark the borders of these glacial lakes, which followed the waning ice front and expanded to vast extent. Before we can fully and properly describe the stream channels and the greater glacial lakes and their effects it is necessary to discuss some other features, specially the moraines and the local glacial lakes which occupied at various levels the valleys sloping toward the glacier.

ICE MARGINS: MORAINES

The glacial period probably included several epochs of ice invasion with intervening epochs of ice retreat or deglaciation. In western New York we have accepted evidences of only the last epoch of glaciation, called the Wisconsin. All the phenomena described in this paper relate to or are connected with the waning and disappearance of the Wisconsin ice sheet, and particularly of the Erian and Ontarian lobes.

The pauses in the recession of the ice front are marked by terminal accumulations of marginal drift, or recessional moraines. The series of recessional moraines for the whole Erie basin are given, somewhat theoretically, in Leverett's Monograph XLI. The correlation of the later moraines in western New York with those across the basin, in Ontario, Can. has not yet been made, although essential for full knowledge of the glacial lake history. The succession and altitude of the glacial waters were determined by the successive positions of the ice front, acting as a barrier, at certain critical localities. As any possible mapping now of the correlated or corresponding moraines in Michigan, Ontario and New York would be conjectural and probably misleading no attempt is here made to map or represent them.

The terminal moraine, which marks the greatest expansion of the Wisconsin ice body in the Lake Erie basin and western New York, lies near Olean and Salamanca. From this locality it extends both southeast and southwest into Pennsylvania, showing that the ice front there had an indentation or reentrant angle.

Between the terminal moraine and the present Lake Erie the several recessional moraines are roughly parallel to the latter, or have a general trend in the Erie basin northeast by southwest. They decline or fall away to the westward and pass under the lake. Of course they pass under the planes of glacial lakes Whittlesey and Warren, which are more than 200 feet above Erie. This fact is shown in the sketch map, which also shows that the ice front was convex westward, in the direction of flow.

Three factors combined to make the westward extensions of these moraines weak and discontinuous. The glacial streams flowing past the ice margins swept away more or less of the moraine detritus within their reach, in some sections removing it entirely. The portions of the moraines which were deposited under water were spread out and subdued by the water action. Thirdly, the stretches of moraine lying near the levels of the lakes were destroyed by wave erosion and converted into beaches and water-laid drift. In addition to these destructive effects during the glacial history are those of weathering and rain and stream erosion during all subsequent time.

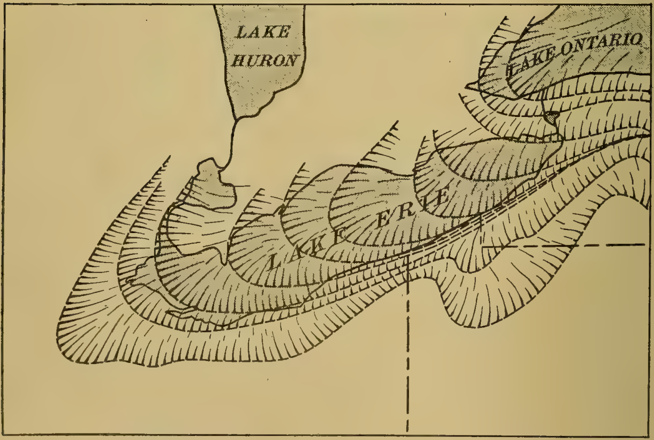


Fig. 1 Diagram of the Erian ice lobe. The concentric lines indicate approximately the successive forms and positions of the margins of the ice, as shown by moraines. The lines are generalized and are not intended to be exact.

The Cleveland moraine, as named by Leverett, includes the irregular drift masses in the belt east and west of Chautauqua lake. With this and the earlier moraines we have no special concern, as they lie landward of the water-parting between Erie and Allegany drainage and outside of our glacial lake territory.

The morainal belt which forms the divide or water-parting from the Pennsylvania state line eastward, along the heads of Chautauqua lake and Cassadaga and Conewango creeks was called by Leverett the Lake Escarpment moraine, a description of which may be found on pages 654-72 of his monograph, with plates. Streams of the glacial drainage [*see* p. 19] flowed along the landward side of the Escarpment moraine in the stretch from the Pennsylvania line to Chautauqua creek. Eastward the moraine is cut by transverse outlet channels where the glacial waters held in the valleys escaped across the divide (constituted by the moraine) to the Allegany drainage. The drift-filled valleys heading in the moraine at these outlets and leading southward, as shown on the map [pl. 2], are remarkable features.

West of the meridian of Fredonia the Escarpment moraine is the last one now existing, as below this the north-facing slope was all swept by glacial streams or washed by the lakes, and the debris which the ice had dropped was removed or scattered by the waters. East of this meridian other and later morainic belts occur [*see* pl. 3-6].

The next succeeding moraine has been named by Leverett the Gowanda. Appearing in fragments east of Fredonia it curves around to Forestville and then swings eastward to the Cattaraugus valley at Gowanda, whence it passes northeast to join the broad interlobate moraine tract in Wyoming county. Near Fredonia we find interesting evidence of the destroyed moraine. Lying 2 miles east of Fredonia in the Belmore (Whittlesey) beach, close to the west side of the Townline road, is a conspicuous mound of till [*see* pl. 7]. It is evidently an erosion remnant of a frontal moraine which has been mostly removed by Whittlesey waves and Prewhittlesey drainage. Three fourths of a mile southwest from this knoll is another less prominent till mass by four-corners. Doubtless these fragments represent the southwestward extension of the Forestville moraine.

Another belt of moraine which extends northeast from Hamburg has been named by Leverett after that village. As suggested by him, the ice margin probably extended southwest from Hamburg but the drift was removed or leveled by the glacial waters. An isolated tract of moraine of about 2 square miles area, lying midway between North Collins and Irving and 2 miles north of Cattaraugus creek, probably belongs to the Hamburg moraine. This lies beneath or lower than the Warren plane, which south of Brant and west of Fenton has buried the moraine. Between Brant and Hamburg the moraine is either washed away or buried. East from Hamburg the moraine belt widens rapidly. It lies north of East Aurora and south of Alden and passes eastward into Wyoming county.

The Marilla moraine of Leverett is, at least at the west end, only a part of the Hamburg moraine. The distinction which is based on a line of glacial drainage is not valid, as the whole breadth of the moraine has been cut equally by the streams past the ice front [*see* pl. 5]. The Hamburg moraine extends north to the Warren beach all the way from Hamburg east to Alden, the beach forming the present northern edge of the moraine. The Whittlesey beach, which is weak here, lies on the moraine.

Lying farther north and running east and west on the north-facing slope of the Ontario basin are belts of moraine drift which Leverett has named in successive order northward, the Alden moraine; Pembroke ridges; Batavia, Barre and Albion moraines. The two last are on ground lower than the surface of Lake Warren and consequently do not figure in the history recorded in this paper.

Two of the moraines named above correlate with events in the lake history. While the Hamburg moraine was forming, Lake Whittlesey was destroyed and was succeeded by Lake Warren, as described in a later chapter [*see* p. 64]. No evidences of lake action at the Whittlesey level are found beyond the Hamburg moraine, east of a line joining East Aurora and Alden. With the removal of the ice front from the Batavia moraine and from the limestone escarpment east of Indian Falls the Warren waters were allowed to pass eastward into central New York.

All of the moraines between and including the Escarpment and Batavia moraines have been cut and channeled by stream work past the ice front, while their western extensions have been subdued or even buried by lake action, in consequence of which they are imperfect on all the territory lakeward of the divide. Leverett's divisions of the moraine belts do not sufficiently recognize this fact. If there had been no removal of the moraine drift it would be impossible to distinguish all the belts named above. For example, east of East Aurora the Gowanda, Hamburg and Marilla moraines are virtually only a single moraine, cut by stream channels throughout its entire breadth. The Gowanda belt is probably only the northern edge of the Escarpment moraine; and the Marilla is the same part of the Hamburg moraine.

Mention has been made of isolated fragments of the eroded moraines. Others will be seen on the maps; particularly a mass

Plate 7

"Christy hill," $2\frac{1}{2}$ miles east of Fredonia. Looking s. 25° w. The knoll is composed of till and is a remnant of a moraine which has been mostly obliterated by glacial drainage and Lake Whittlesey. The house stands on the Whittlesey bar.

2 miles southwest of Portland, and one 2 miles northeast of Brocton. All these fragments should correlate with recognized moraines.

The close association of the moraine deposits on the land slopes facing Lake Erie with the scourways of the glacial drainage and the work of the glacial lakes must be clearly recognized in order to understand the various and intricate phenomena. The several maps suggest this intimate relationship.

GLACIAL DRAINAGE CHANNELS

These effects of the glacial waters are not so prominent as the lake shores but are much more widely distributed. They are not so conspicuous features to the untrained eye as the bars and continuous beaches, but when once recognized they are unmistakable. The more definite channels are valleys or notches or terraces of various sizes, in either rock or drift, and with or without present streams. The stronger of them are evident in their origin, having all the characters which distinguish the work of streams, namely, fairly uniform grade and width, curves with radius proportionate to size or strength of stream, definite banks, and with correlating areas of drainage on the one hand and receiving water bodies on the other. All gradations will, of course, be found down to small, shallow and indefinite scourways made by short-lived currents, even to those of doubtful origin. Along steep slopes the stream cutting is commonly shown only by more or less decided notches or shelves or terraces in the slope, the ice having been the lower wall of the channel. The removal of the ice has in these cases left us the anomaly of water courses with only one confining bank, the down-slope wall being, so to speak, in the air. We need to restore the bank of ice in our imagination. Plates 2-6 give the location of these ancient and extinct channels. It must not be thought that the water channels are unique or peculiar to this region, for they are found wherever the great glacier was holding bodies of water in depressions of land slopes. They occur not only throughout the entire district described in this paper but eastward along the south slope of the Ontario basin to Rome and down the Mohawk valley to Little Falls. The largest glacial channels in New York lie in the Syracuse region, with huge cataracts that rivaled Niagara in size and were the predecessors of Niagara in fact, as they carried the falling Warren waters eastward to lower levels.[1]

[1] Descriptions of the channels and cataracts in the Syracuse district and eastward will be found in papers by the author in the 20th, 21st and 22d annual reports of the New York State Geologist.

Across the main divide to Allegany drainage

The reader should clearly appreciate the relation of the ice body to the general land surface. While the ice margin was lying on ground having free southward drainage the waters utilized the valleys leading south and away from the ice front and they had no occasion for making new channels. The copious waters from the summer melting of the ice mass, combined with that from the local rain and snow fall, produced heavy floods in the south-leading valleys; and vast quantities of debris from the ice were swept far down the valleys and filled them to great depths. This is well illustrated in the valleys of Cassadaga and Conewango creeks as shown in plates 2-3. The present creeks meander listlessly over the broad plains of valley-train drift left by their larger glacial predecessors, and are contributing only a surface layer of fine materials or are intrenching themselves in the older deposits.

When the ice front receded to the northward of the divide the waters which were then ponded in the valleys facing the ice had to escape across the divide, through the lowest passes or cols, which were often deepened or cut down by the water flow. The divide was usually formed, at least in the valleys, by the moraines left by the ice, and in our district the transverse channels are in drift and not in rock.

The general ice front adapted itself to the larger land configuration, and lobations of the ice pushed forward into the greater valleys, as shown in figure 1 for the Erian lobe. It will be seen that the broad relation of the ice and land was such that the south-leading channels were, in general, opened successively from west to east; but the precise relation in time is uncertain and is not important here. These channels will be enumerated here very briefly and discussed again in a later chapter in connection with the local lakes which they drained.

The south-leading outlets for the glacial waters held in the basin of the Genesee were described in 1896.[1] The Genesee lakes lay on the eastern border of the territory described in the present paper, and the more southerly of the Genesee outlets were probably effective while the ice was yet lying over all of our area. Probably some of the small primitive lakes held by the ice in the eastern part of the Cattaraugus basin were tributary for a time to the Genesee waters, but these details have not been studied.

The easternmost channel which carried only Erie basin waters is probably the one at Machias, in Cattaraugus county, with elevation of 1646 feet. This was the outlet of the glacial lake in the upper

[1]Glacial Genesee Lakes. Geol. Soc. Am. Bul. 7:423–52.

part of the Cattaraugus valley. Some 6 or 7 miles west of the Machias outlet is a pass near West Valley with altitude over 1700 feet which could have been the point of overflow of only the local waters of the Ashford creeks since it was higher than the Machias outlet that was already open.

The next effective channel, later in time and lower in altitude, is at the Persia flag station between Dayton and Cattaraugus stations of the Dunkirk branch of the Erie Railroad, some 7 or 8 miles southwest of Gowanda. The head or intake of this channel is close to the steep west bank of the south branch of the Cattaraugus creek. The water-parting is a swamp and the channel is about ¼ mile wide. The channel leads northwest ½ mile, where the railroad crosses it by a low filling, then curves around sharply to the southwest and opens into a valley tributary to the east branch of the Conewango. As it is about 300 feet lower than the Machias outlet it probably succeeded the latter as the outlet of Cattaraugus glacial waters.

All the other outlet channels which carried waters from the Erian basin over into southern or Allegany flow are represented in the accompanying maps, except possible points of overflow west of Chautauqua lake in a district not yet surveyed for the topographic map, but which are doubtless inconsequential as the waters could have formed only small lakes close to the divide.

In the district between Mayville, at the head of Chautauqua lake, and Westfield, near Lake Erie, there is an interesting complexity of the drainage, shown in plate 2. The branches of Chautauqua creek (which has no relation to the lake of that name but drains the Erie slope, passing northwest through Westfield) have cut three deep "gulfs" in the Portage shales and the features which were left by the glacial drainage are somewhat obliterated. The earliest and highest overflow of the glacial waters in this district is shown on the map as 3 miles west of Mayville, with altitude according to the map contours under 1380 feet, the waters escaping east to Chautauqua lake. A later, lower and more important southward outlet for the waters of the ancient Chautauqua creek valleys is a broad swamp col at the head of the Little Inlet creek, 2½ miles north of Mayville, with map altitude 1320 feet. These cols must have been uncovered by the ice retreat so nearly at the same time, judging by their relation to the general slope, that the earlier and higher outlet could have been effective only a relatively short time.

Four miles north of Mayville and over a mile southeast of Prospect station on the Pennsylvania Railroad is a short channel by the four-corners at the "Elm Flat" church, with altitude of 1340 feet. This is at the head of the swamp in the "big inlet" of Chautauqua lake and could have carried the overflow of only a limited area and for a short time.

The next outlet is at the head of Bear lake valley, 3 miles southeast of Brocton. This is a broad swamp col, still in timber, with map altitude of 1320 feet, which carried a heavy drainage for some time. The close correspondence in present altitude between these several channels is probably merely coincident. The northward tilting of the region in Postglacial time has lifted the Bear Lake outlet 10 to 15 feet higher, as compared with the Big Inlet pass, than it was when effective.

The col 5 miles south of Fredonia, between the heads of Canadaway and Cassadaga creeks, must have been the overflow point for a large volume of water. It lies close to the Upper Cassadaga lake in the valley moraine with altitude not much over 1300 feet, but does not exhibit clear channel characters. This seeming inconsistency and the peculiar features and relationship were discussed in the 20th Annual Report of the State Geologist, pages 132-35.

Passing eastward we find three groups of cols at the heads of three branches of the Conewango creek [*see* pl. 3]. The only well defined channel is on the western col, 1½ miles west of Mud lake in the town of Arkwright. The waters of Walnut creek valley found escape here over to the west branch of the Conewango at altitude of 1420. While the drift filling of the broad south-leading valleys shows that they carried heavy detritus-laden floods from the melting ice front, it would seem that little water passed across the cols into the valleys of the North branch and the Slab City branch of the Conewango, apparently for the reason that the conformation of the ice front to the topography was such that little was ponded here north of the divide. From south of Forestville eastward to Perrysburg no basins faced the ice front and the drainage was fairly free past the ice to the westward.

No other cols across the main divide between Erie and Allegany waters have any relation to the glacial overflow in our district. The passes at the heads of the several strong north-sloping valleys in Erie and Wyoming counties simply carried their waters over to the Cattaraugus basin, from whence it found further escape by channels above described. Three miles northwest of Cherry Creek is a fine channel which was the outlet to Farrington Hollow glacial lake, but both features are wholly in southern drainage.

Plate 8

Bed and south bank of glacial river, at head of "Wheeler's gulf," 3 miles south of Fredonia. Looking southeast [compare pl. 9 and 10].

Along the ice front westward to Erian waters

West of the Cattaraugus embayment. *State Line to Westfield* [pl. 2]. In this section the Escarpment moraine lies against the steep valley slope, to the extent that it has not been swept away by the glacial waters. The most definite and strongest stream channel of this class lies south, or landward, of the Escarpment moraine, south of Ripley, and at altitude of 1400 down to 1200 feet and lower. About 3 miles of the upper part of this ancient channel is shown on the Westfield sheet, and its continuation appears on the Clymer sheet. It has been deepened by modern drainage and is now occupied by the north branch of Twentymile creek. As a deep ravine the channel continues southwestward into Pennsylvania and swinging west and northwest crosses the railroads a mile west of State Line [*see* fig. 2].

The considerable stream which cut this large channel carried not only the waters from a long stretch of the melting ice front for a long time but also the land drainage of a large territory, and the latter service is continued by the present stream.

When the ice front finally melted back from the summit and rested at lower and lower levels against the steep land slope the drainage lay usually close against the ice front, following the latter in its retreat, and made few noticeable channels west of the Westfield meridian. The only one mapped near Ripley is about 1½ miles southeast of the village, crossing the highway that climbs the slope, at 1200 feet by the map.

Along this steep slope above Ripley and for several miles to the northeast the moraine drift was mostly removed by the stream work past the ice, the characteristic morainal features being found in patches and more at the foot of the steepest slope. The modern drainage has also helped to destroy the old drainage lines and the drift deposits.

On the west side of the "Gulf," 3 miles south of Westfield, are three gullies leading eastward which have been partly cut, along with the "Gulf," by recent drainage. However, they were probably initiated by the glacial waters flowing into the primitive valley of the "Gulf" and then on across the divide into Chautauqua lake by channels already described. These east-leading channels have their heads at about 1400 feet, and lie on the landward side of the moraine. They are unique in being the only cases found in the Erie district where any drainage along the ice front was not westward; and they really belong to the early overflow across the divide to southern drainage.

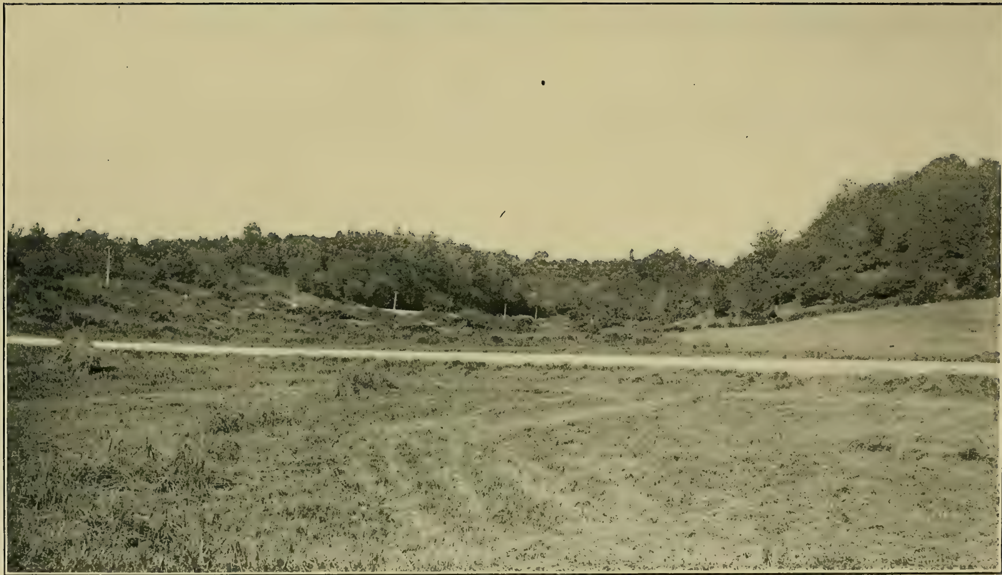
South of Westfield, 2 and 3 miles, west of Chautauqua creek and also between the gulfs, the old glacial stream work is conspicuous. This is shown very well on the two north and south roads west of the creek, at altitudes from 1000 down to 820 feet. On the two ridges between the three ravines the crosscutting by the glacial flow is very striking. The general surface is morainal but the knolls are cut into terraces or even into double-walled channels. On the east ridge cuts are found at 880, 960, 1020, and an excellent channel at 1200 feet (by the map contours), above which is a strong remnant of the moraine. Correlating with these cuts on the east ridge are others on the west ridge, naturally at a lower altitude, while those already noted as lying on the north and south roads west of the creek are in continuation of the same flow. This series of interrupted channels converges toward Forsyth, where the stream flow debouched into Lake Whittlesey and produced the delta deposits which have chiefly been built into the broad beaches of Whittlesey and Warren.

Westfield to Portland. One and one half miles southeast of Westfield is a series of east and west scourways which lie at altitudes of about 850 up to 1000 feet, according to the somewhat unreliable contours of the map. These channels probably represent in part the same flow as the lower cuttings southwest of the village. Evidence of stream work is also found along the higher slope farther southeast, up to 1200 feet. Several strong and sharp stream-cut notches and channels occur on the north and south roads north, west and south of Prospect station, $2\frac{1}{2}$ to $3\frac{1}{2}$ miles east and northeast of Westfield. There are at least seven of these channels, ranging from 860 up to 1300, and all in rock. The detritus borne by these streams probably supplied part of the material of the broad sand plains east and west of Westfield. Further representation of these channels is found northeastward along the tracks of the Pennsylvania Railroad as shown on plates 1 and 2.[1]

Portland to Fredonia [pl. 2]. Extending from Portland southwest for 3 miles to West Portland church is an extended delta, lying between the Whittlesey (Belmore) and the Warren (Forest) beaches, and also landward. The explanation of this broad gravel deposit is found in a river channel which debouches south of Portland and

[1]*Explanation.* The interrupted character of the stream channels as represented on the maps is not wholly true to nature but is partly due to the fact that they have been mapped only where actually observed, chiefly along the highways, and are not indicated hypothetically. It would be a tedious labor to trace all the scourways throughout the Erie district. Students interested in the subject can appropriately trace and map the features in precise detail in special districts. The author will be very grateful for such information.

Plate 9



Glacial river channel. Head of "Wheeler's gulf," 3 miles south of Fredonia. Looking westward (downstream). The road in the middle ground of this view is seen from the opposite side in plate 8.

which has been traced upstream for 8 miles to the Canadaway valley south of Fredonia. The head of this river channel lies within ½ mile of the Shumla reservoir and nearly 3 miles south of Fredonia. It here forms a dry gorge, about 100 feet deep and 2 miles long, known locally as Wheeler's gulf [pl. 8-10], and utilized for grade by a detour of the Dunkirk, Allegany Valley & Pittsburg Railroad. Beyond this gorge is an open section of about ½ mile in length below which the channel forms another gorge 1½ miles long, ending a mile south of Lamberton. For the remaining 4 miles to Portland the channel lies just above and landward of the Whittlesey beach. The head of the river channel is 1100 feet in altitude and the debouchure is 800 feet.

Some traces of stream cutting earlier and higher than the Wheeler's gulf channel have been noted southeast of Portland, and such must occur along all the slope to the northeast, which is quite destitute of morainal drift up to about 1000 feet.

Above Wheeler's gulf higher scourways are seen, one of which is tributary to the gorge. Below the gulf, on the Fredonia meridian, all the slope from 1100 feet down is swept bare to the rock, and a series of rock shelves head at 1050, 1000, 960, 900 and 860 feet by the map, declining westward. The higher ones converge and unite with the Wheeler's gulf channel south of Lamberton, but the lower ones debouched into Lake Whittlesey east of Lamberton and helped to form the delta deposits south of the village.

Fredonia to Forestville [pl. 2-3]. The stream cuttings which head south of Fredonia carried waters which were ponded in the Canadaway valley at levels corresponding to these outlets. We may call these waters the Shumla lakes, after the hamlet in the valley. The depth of the lake when Wheeler's gulf was the outlet was about 200 feet, and the breadth about 1 mile. The reader will appreciate the fact that the lakes must have been fed by glacial drainage past the ice front from the east, and the proofs of such action are abundant. From below Shumla to below Laona, about 2 miles, the east wall of the valley holds a great volume of delta deposits banked against the slope. The higher of these form conspicuous terraces, visible for miles and plainly seen from the railroad. These have an elevation under 1100 feet, thus correlating with the lake level when this was fixed by the Wheeler's gulf outlet. But the delta deposits extend down the valley to Fredonia through all levels to 750 feet, the lowest level of Lake Warren.

The conspicuous delta terraces in the valley east of Laona were built in the Shumla lake by the rivers from the northeast, the strongest channel, about 2½ miles long, heading in the south edge of Sheridan township, at 1260 feet altitude, and debouching at the delta as low as 1000 feet. The uniform slope facing northwest and lying 4 miles east of Fredonia is entirely denuded of drift and strongly terraced by stream work, similar to the slope south of Fredonia. The highest stream work noted lies above the Laona channel, at altitude over 1300 feet, and the lowest is the broad, smooth scourway facing the Whittlesey beach at altitude about 840 feet. Theoretically there must have been westward flow of water on this slope at 1400 feet, or just inferior to the outlet across the divide to the Conewango, at the head of the Walnut creek valley with elevation of 1420 feet; and such flow is indicated on plate 3.

West and southwest of Forestville the land slope has more irregular surface and the stream cuttings are intricate. From the Walnut valley, where the waters were ponded in a lake which we will call the Walnut lake, the waters escaped westward between low hills forming a series of scourways with oblique directions, as shown in plate 3. The lowest is at the foot of the hill west of Forestville and not much above the Whittlesey level. South of Sheridan station a portion of the Gowanda, or Forestville moraine lies landward of the beach for a stretch of 3 miles, and the lowest stream work cuts the moraine. On the north and south road south of the station two narrow channels intersect the moraine. The detritus carried by the streams along this section helped to make the delta deposits south of Fredonia and the massive beaches northeast of the town.

Forestville to Gowanda [pl. 3]. This section of the land slope swings around into the Cattaraugus valley with change of face from northwest to northeast. The earlier waters were the overflow of the Cattaraugus lake into the Walnut lake. The stream cutting is complex and the reader should consult the maps. Northeast of Forestville and east and west of Smiths Mills the channels are strong and deep cuts in the rock.

The highest flow on the northeast slope can not be over 1300 feet, since the Persia outlet [*see* p. 17] of the Cattaraugus lake was not much over that hight. The highest stream work noted is close to Perrysburg, at elevation by the contours of 1300 feet. Local waters in the Walnut basin cut channels southeast of Forestville as high as 1400 feet. As in other regions already described the slopes show little morainal drift, this having been carried away by the glacial streams.

Plate 10

Glacial river channel. "Damon gulf," 3 miles southwest of Fredonia. Looking westward (downstream). This is a continuation of the "Wheeler's gulf" channel, shown in plates 8 and 9.

From Forestville northeast to Smiths Mills station, nearly 4 miles, the rock terraces cut by the glacial flow along the ice front are very conspicuous and can be clearly seen from the Erie Railroad which crosses them obliquely.

In the region of Smiths Mills the irregular ground has been cut into pronounced channels or gorges, and the detritus has been swept into the delta fillings in the Walnut valley at Forestville and northward.

It will be understood that the broken appearance of the channels on the maps, specially the higher ones, is partly due to want of complete knowledge, as they are rarely denoted on the maps unless actually seen, which is mostly on the highways. Interpolation of hypothetic cutting is indicated by broken bands. However, the channels are not usually continuous for long distances on irregular slopes, or where the ice front was oblique to the slope.

East of the Cattaraugus embayment. *Gowanda to Hamburg*[1] [pl. 4]. Over the territory thus far considered we have the help of the topographic sheets. The remaining territory, about one half of the whole area, has been studied at great disadvantage with the aid only of county and road maps. The altitudes given are mostly by aneroid and are only closely approximate. The channels are indicated only where seen, mostly along the highways, and the following descriptions are very general.

In the southern half of this section the land slope faces west, and the glacial stream flow was southward. Toward Hamburg the slope faces northwest, while south of the village it faces north.

The highest scourways in this section were determined by the hight of the cols at the heads of Eighteenmile creek, leading over into the Cattaraugus at Wyandale and eastward. These cols have not been positively determined and no attempt has been made to locate the very highest scourways. The important and interesting fact is proven, that all the steep slopes north of Shirley have been water-swept and cut into notches or terraces, and the morainal drift removed. The stream cuttings are more commonly shown as terraces than as double-walled channels, but this distinction is not always indicated on the map.

From Gowanda north to Shirley, a distance of about 8 miles, the slopes bear scattered morainal or kame knolls, which proves that this slope has not been severely stream-swept. The reason for this

[1]In the study of this section the writer has had the assistance of Mr B. W. Law, whose summer home is near Collins. His observations are incorporated in this writing without special designation, but with this grateful acknowledgment.

exemption seems to be as follows. Until the lobate ice front had receded from the Cattaraugus valley as far as Shirley in this district the waters in the Cattaraugus embayment were held as high-level lakes, having their outlets across the slopes north and northwest of Perrysburg. In this case no stream flow could occur along the ice front in the Shirley district or on the slopes north of Gowanda until the lake waters were drained to a level lower than the ice border. The kames (knolls of sand and gravel) which are scattered over the slope from Collins north to Shirley were produced by glacial streams debouching into standing water that faced the ice border. The reader will appreciate how such phenomena as these, along with the relationship in series of the stream channels and deltas, enable us to determine the position of the receding ice front and to find the relationship or correlation of the several features.

On the road leading east from Shirley there are some weak scourways which suggest glacial drainage, but are not strong enough to map with confidence. Northeast of Shirley and east of North Collins some scourways, not very strong, are indicated on the map [pl. 4].

The lowest stream work at North Collins is a steep bank facing the Whittlesey beach east and south of the village, at altitude about 850 feet. The highest channel noted is 2 miles east of the village, near four-corners, with altitude over 1100 feet.

At the three-corners 1½ miles south of Eden are interesting channels cut in black shale, with remnants of the rock left as islands or outliers. One mass is exactly at the corners; another lies south with a ridge form; and small ones occur on the west side of the road.

The Whittlesey shore in this section lies frequently along cliffs of rock which may have been partly cut by glacial stream work before the wave work by the lake. Examples of these cliffs may be seen in North Collins; and east of the ridge road for 3 miles south of Eden, and for a mile north of Eden.

Strong channels in rock lie north, south and west of East Eden. About a mile north of the village and just south of the Lutheran church are two fine channels. West and northwest of North Boston the slopes are cut; and the conspicuous Whittlesey cliff 2 miles southeast of Hamburg was probably made partly by stream action.

The detritus carried by the streams at North Collins was probably swept into the Cattaraugus valley below Gowanda. The channels

Plate 11

Glacial river channel, 3 miles east of Fredonia. Looking northwest, across the channel.

south of Eden may have contributed detritus to the sand plains west of North Collins; while the deltas at Eden and Eden Valley were built by the later drainage south of Hamburg.

Hamburg to East Aurora [pl. 5]. In this section, lying between Eighteenmile and Cazenovia creeks, the stream phenomena become more complex, as the land slope is not steep and the surface is dissected by large creeks. The maps show the observed channels. The highest channel noted is 4 miles due east of Hamburg, and over 1100 feet altitude. The lowest channels are apparently connected with Whittlesey lake erosion.

At the four-corners, 2½ miles east of Armor and 2 miles south of Orchard Park, is a heavy bluff, pictured in plate 12, which is a continuation of the large channel 2 miles southeast of Orchard Park, crossing both the highway and railroad with a southwest direction. The head of this river course is a channel 3 miles west of East Aurora at Longs Corners, on the "Quaker" road, figured in plate 13. It lies just south of the three-corners, with direction nearly east and west; the bluff being 35 to 40 feet high, in rock, and the clear channel 10 to 15 rods wide. The head of this cut lies across the east and west road with a scourway 20 rods wide. The total length of this river channel is something over 5 miles.

South of East Aurora the slopes are smoothed and broadly terraced by water flow, carrying the overflow of the east branch valley of Cazenovia creek, but the scourways are not definitely mapped.

The detritus carried by this eastward drainage from the Cazenovia creek was contributed to the broad delta filling on which Hamburg stands.

East Aurora to Cowlesville [pl. 5]. This section, extending from Cazenovia creek to Cayuga creek, has a most interesting development of moraine, channels and deltas, and the phenomena are complicated by the change of base level from the Whittlesey to the Warren plane. In all the territory thus far described, lying westward to Pennsylvania, the stream phenomena ended at the Whittlesey level, as that lake water was the receiving body and the base level of drainage. While the ice front was lying in this section the outlet of Lake Whittlesey across the "Thumb" of Michigan was abandoned [*see* p. 42] and the lake waters were lowered to a new outlet, thus establishing Lake Warren. East of Marilla the lower stream channels are cut down to the Warren plane. Delta fillings at the Whittlesey level occur in this section, but are not found further eastward.

In this section a series of vigorous creeks flow to the northwest in parallel courses: Cazenovia creek at East Aurora, Buffalo creek at Wales and Elma, Little Buffalo creek at Marilla and Cayuga creek at Cowlesville. Standing waters were held by the ice barrier in each of these valleys and the inflowing streams dropped their detritus at varying levels, the larger delta plains ranging from somewhat above the Whittlesey level, or at about 920 feet, down below the Warren level, or to about 820 feet. (The Whittlesey shore at Elma Center station is 905 and the lower Warren 835 feet.)

There is an important difference between this section and those west of Hamburg. Here we do not find a steep rock slope from which the morainal drift has been swept, but we find instead a broad frontal moraine of usually sharp relief and dissected by numerous streams of the glacial drainage. On the meridian of Williston the moraine has a breadth of about 8 miles, from Wales Center to West Alden, and all the central part for a width of 5 miles is cut by conspicuous channels which carried the ponded waters westward from one valley to the next. The altitude of these stream channels declines, of course, along any meridian from south to north successively, although the difference between two successive cuts may not exceed 10 or 20 feet. The number and closeness of the channels are well seen on the four north and south roads from Marilla eastward.

Our interpretation of the moraines in this section is somewhat different from that given by Leverett [Monograph XLI, pl. XXV, p. 673-84]. He separates the moraines by broad belts of drainage into the Gowanda, Hamburg and Marilla moraines. The writer does not find such important concentration of the old drainage, but that on the contrary the channels are so numerous and widely distributed that the moraine can not justly be divided. For its entire width from East Aurora and Wales Center north to the Warren shore the moraine is essentially a unit.

Southeast of East Aurora nearly 3 miles are two scourways lying against morainal knolls at altitude of about 1140 to 1180 feet. Other westward outlets of the waters held in the Buffalo creek valley over Wales should occur at lower levels.

East Aurora lies on a broad delta filling built near the Whittlesey level. The head of the plain east of the village is about 925 feet. The Pennsylvania Railroad station is given as 921 feet. Downstream, or westward, the plain declines to under 900 feet. On the north of the village, between the delta plain and the south edge of the Hamburg moraine, is a channel some 60 rods wide with the

Plate 12

Bed and south bank of glacial river, $2\frac{1}{2}$ miles south of Orchard Park, near four corners. Looking eastward (upstream) from the north-and-south road. Continuation of channel shown in plate 13.

steep north bluff in till, 40 feet high. This channel would seem to be the latest and lowest, on this meridian, of the glacial drainage. It was the western extension of two glacial channels from the east. The higher of these forms a cut bluff at the three-corners on the Townline road, 2 miles northeast of East Aurora. Its westward continuation is seen leading southwest, south of the Marilla Street road, nearly to the village where it meets the present drainage. Another lower and broad channel crosses the Townline road a little distance north of the former, and south of the next three-corners, and leads west into the indefinite swampy tract a mile northeast of the village and which forms the head of the capacious channel north of the village.

Between the two old channels above noted lies a delta gravel plain which supports the Marilla Street road. This plain is much pitted along its northern margin, showing that it was deposited against the ice front; masses of the ice being buried in the gravel, their subsequent melting produced the basins or "kettles" in the plain.

East and northeast of East Elma, and curving around from north of Porterville to near Marilla, is another extensive and interesting delta plain. The northern margin certainly lay against the ice front, as is proven by the kettles or "pitted-plain" surface. At least nine glacial streams from the east share the responsibility for this deposit, the channels being distributed for 3 miles along the north and south road between Porterville and Marilla. The debouchure of the higher channels and their relation to the delta show clearly from the highway. The varying altitude of this multiple delta plain, 920 to 940, seems to correlate with the Whittlesey waters, which in this region had their greatest eastward extension with an altitude over 900 feet. This broad delta lies above and east of the hamlet of East Elma, and we will call it the East Elma delta.

The latest ice border drainage on this meridian has left two channels east and northeast of Marilla. The earlier of the two streams cut a conspicuous bluff back of the cemetery, southeast of the village, and also a channel about a mile southwest of the village, leading over to Buffalo creek at the Warren level. Marilla lies on a delta. The upper terrace, about 860 feet, may have been partially formed at the ice front in local waters connected with the glacial streams just noted, but as a plain of the ancient Little Buffalo creek the gravel terrace continues 1½ miles northwest into the Warren delta plain, capped with wave-built bars. The later of the glacial streams here seems to have dropped its detritus into the Warren flood.

In this region, therefore, we find the critical relation of the ice front to the changing lake levels; the lowering of the base level of drainage from the Whittlesey to the Warren waters, or from about 910 to about 860 feet. The Marilla delta is the most westerly delta built by glacial drainage close to the lake shore with a level below the Whittlesey plane.

The change in the level of the drainage is more abrupt than would be expected. It is not supposed that the broad Lake Whittlesey could fall suddenly to the Warren plane, but the ice front seems to have held so steadily here that the relation of lake level to inflowing streams changes abruptly, or within a short distance. Two miles southwest of Marilla the extended East Elma delta is over 900 feet altitude. At Marilla the delta is at the Warren level, 860 feet. The channels of ice border drainage 1 mile south of Marilla terminate at 900 to 940 feet. The channels at and southwest of Marilla are down to 860 feet. There seems no doubt that the higher channels debouched into Whittlesey waters; the lower into Warren waters.

An unusual display of ice border drainage is seen on the four north and south highways between the meridians of Marilla and Alden. On the road through Williston not less than nine channels are mapped, spaced through about 5 miles. The earliest and highest channel that has been noted on the Williston meridian is 3 miles south of Williston, leading over to Buffalo creek at Wales Center, with an altitude of 1100 feet. The lowest channel is at four-corners, 2 miles north of the village, where three primary channels lie athwart the north and south road and unite into one river course (the later of the two at Marilla) which carried the waters from the Cayuga creek valley (the Cowlesville lake) over to the Warren level at Marilla. The earliest flow through the upper course of this channel may have helped to cut the cemetery bluff at Marilla; and the later flow contributed to the lower delta terrace at Marilla in an embayment of Lake Warren.

The earliest and highest channels in the territory included in this chapter (between Buffalo and Cayuga creeks) lie east of the meridian of Cowlesville, since the Cayuga creek flows northwest. The highest channels actually seen and definitely mapped lie 1 mile north of North Sheldon corners at 1400 feet altitude. A still higher overflow should have occurred, somewhat under 1500 feet, and scourways will probably be found ¼ mile north of the corners.

Plate 13

South wall of glacial river channel, south of Long's Corners, 3 miles west of East Aurora. Looking west of south (downstream). The same channel at another place is shown in plate 12.

At Bennington corners and westward, and west of Folsomdale, the channels are excellently developed, specially the lower ones, leading toward Williston, which are cut in the rock.

Cowlesville to Attica and Batavia [pl. 5]. This section of country with its remarkable display of ice border channels lies between the Cayuga and Tonawanda valleys, a diagonal distance from Cowlesville to Batavia of 18 miles.

The highest known outlet is about 2 miles west of North Java, and carried the waters of the Varysburg-Johnsonburg lake over to the Java-Wales lake. This outlet channel heads where the railroad makes the upper crossing of the Tonawanda creek, 1½ miles west of North Java, and leads west and southwest through a moraine, 1¼ miles, over to a branch of Buffalo creek which flows south from Frink's Corners. The aneroid altitude is about 1500 feet. (Some higher stream work was seen in the village of North Java just south of the corners. This evidently carried the overflow of the North Weathersfield valley, a branch of the Tonawanda, westward past the ice front and built a delta close to the village on the southwest at over 1600 feet. This indicates that some temporary outlet for the North Java waters existed on the west at an elevation correlating with the delta, and superior to, and earlier in time than, the channel by the railroad.)

The next lower escape to the west was by the channels north of North Sheldon, already noted above. At this time a single body of water existed in both the Tonawanda and Cayuga valleys, since the broad swamp col at the head of Cayuga creek, near Perry's Crossing on the Buffalo, Attica & Arcade Railroad opens into the Tonawanda valley at about 1380 feet.

When the overflow was lowered to the channels at Bennington Corners, at and under 1360 feet, the Cayuga valley held a distinct lake, the Humphrey Hollow lake, and the Varysburg-Johnsonburg lake may have been tributary to it for a time by overflow through the Perry's Crossing col.

The Varysburg-Johnsonburg lake found direct escape past the ice border when ground was opened south of Bennington Center with altitude below 1380. These channels are sharp cuts across the north-south road, and terminate in conspicuous deltas southwest of Bennington, with altitude 1300 down to 1200 feet.

When the ice front had retired sufficiently a new channel was opened for the Tonawanda waters, the Kanawaugus valley, leading across south of Poland Hill through Bennington to the Cayuga valley east of Folsomdale. This is now a circuitous route and for a time the ice front held the river flow to a more direct westward course by cutting across the brow of the hill south of Bennington. Eventually the waters were ponded in the broader section of the Cayuga valley and an extensive delta was built above and below Cowlesville.

The subsequent and lower escape of the Tonawanda waters (Attica lake) over to the valley of Cayuga creek, and later directly into Lake Warren, has left striking records of river flow over a large area. This area is partly in the northern edge of Wyoming county but chiefly in the southern part of Genesee county [*see* pl. 6]. The Erie railroad follows one of the channels in the midst of the series, and the Delaware, Lackawanna & Western Railroad lies in a lower one at Ray station. The latest flow was along the lines of the Lehigh Valley and the New York Central Railroads. The entire area is covered by the Alden-Batavia moraine.

All the north and south roads between Alden and Darien show numerous waterways. The Countyline road, 1¼ miles east of Alden, shows several channels. These unite into two channels and debouch at Warren level near the village where they helped to form the extensive gravel plain, crowned with strong Warren bars. On the road passing through Darien Center 14 channels are found worthy of representation on the map; and an equal number lie on the next road to the east. The higher of these channels are 1200 feet.

The lower ice border drainage in this region poured into Lake Warren near Fargo station. The lowest lies along the south side of the Lackawanna Railroad east of Fargo station, with altitude about 900 feet. This channel terminates as a cut bank or bluff ½ mile south of the station, facing the delta, the broad smooth g avel plain that is bounded on the north by the railroad and on the west by the Countyline road. Two strong gravel bars built by Warren waves on the west margin of this delta lie across the north and south Countyline road, 1½ miles southwest of Fargo station, the north one supporting the cemetery. These channels lying along the Lackawanna Railroad have their heads north of Alexander and pass through or south of Ray station. One and one half miles west of Ray station and on the north side of the river channel is a broad gravel plain that was deposited as an outwash from the glacier, while the course of the glacial river which fed it is marked in the strong esker or sinuous gravel ridge which partly supports the crooked north and south road. The level of this plain, about

940 feet, was determined by the hight of the water in the Ray channel.

The latest glacial overflow from the Tonawanda valley was across from Batavia through the indefinite channels in the Batavia moraine now drained west by Murder creek. This overflow produced the broad delta plain northeast of Crittenden, which bears a series of Warren bars [*see* pl. 5]. All the region is half buried moraine. The contour lines of the Attica sheet show a vast number of morainic knolls with their bases buried in stream and lake deposits. The network of swamps and indefinite water courses attest the work of sluggish waters falling over into Lake Warren, the primitive shore line of which is buried in this region. The better defined stream channels are indicated on the map, plate 5. They lie south of Batavia and West Batavia and south of the New York Central Railroad to within 2 miles of Corfu, where they swing north of the railroad and village and as noted above terminate at the Crittenden delta, the south bank forming a bluff north of the highway.

The lowest overflow at Batavia has an altitude of about 900 feet. The gravelly plain in the southern part of the town is 10 to 20 feet lower, and may represent some combination of leveled kames, glacial outwash, stream delta and flood plain. The present Tonawanda creek meanders northward across this plain into the town, crossing the glacial stream courses, and then turns abruptly west. A mile from the turn its altitude is 880 feet and in 2 or 3 miles further it reaches the Warren plane. It seems certain that the west-flowing glacial waters would have followed the same course if it had been open to them. Evidently they did not, for the present stream winds sharply in a narrow channel among morainal knolls. Here seems to be a critical point in the relation of glacier and lakes. The ice front rested here on Batavia when the conditions that compelled westward flow of the glacial waters suddenly ended, and the glacial waters were sent eastward toward the Mohawk.

The large volume of water indicated by these capacious waterways seems beyond the possible supply of the Tonawanda valley alone, and suggests that other territory further east also sent its drainage westward through these channels; which suggestion is found to be the truth, as will be explained.

Channels conveying tributary water from Oatka and Genesee valleys

The territory covered in this chapter is not now a part of the Erie drainage area, but belongs to the Genesee river. During the time of the ice recession, however, an extensive region to the east, possibly including all the Finger Lakes district of central New York[1] was drained westward past the ice front until the latter had receded to Leroy and Batavia, at which time it appears that lower escape was opened to the east, through Syracuse, and the direction of the glacial drainage was reversed.

Plate 6 shows the channels between the Tonawanda, Oatka and Genesee valleys. The series of channels lying between the Tonawanda and Oatka are not excelled in their general character by any other series in the Erian drainage. The entire slope from the parallel of Linden to that of Batavia, 9 miles, is quite denuded of its drift, and the numerous strong channels are mostly in rock. They show the work of a large volume of water for a relatively short time.

The highest group of these channels lies south of the Erie Railroad at West Linden, at 1300 down to 1200 feet, and all in rock. The intermediate set of channels covers a breadth of $2\frac{1}{2}$ miles between the parallels of Bethany and East Bethany, the Lackawanna Railroad lying in the lowest member of the series, at 1000 feet.

On the north side of the Lackawanna channel at East Bethany is a fine example of a glacial outwash sand plain. The sinuous line of the ice contact shows conspicuously along the highway, on the northeast side, in the abrupt, irregular border of the plain and the accented morainal topography below the level of the sand plain. A strong esker, followed by the crooked road leading north, is the bed deposit of the feeding stream.

The lower series of channels are broad and somewhat indefinite scourways, from 1000 to 920 feet. They seem to be in drift, and were so low and nearly graded to their base level (either the shallow waters south of Batavia or the Warren lake at Corfu) that they were unable to deepen their beds. The later flow seems to have filled or leveled up whatever valley depression once existed at Batavia.

[1]At the time of this writing the full history of central New York drainage has not been deciphered. In a former writing [Geol. Soc. Am. Bul. 1899. 10:44] the idea was stated that Lake Newberry, which occupied the Seneca, Cayuga and Keuka valleys, was extinguished by westward escape into Lake Warren, near Canandaigua. This is now thought to be wrong, for it appears that Lake Warren did not enter central New York until subsequent to the time of all the ice border drainage in western New York. It now seems probable that the local waters adjacent to Seneca valley on the west were lowered into the Newberry lake, and that the latter finally found escape westward. If this is the correct interpretation then the Bethany-Batavia channels carried for a time the entire glacial drainage of all the territory as far east as Syracuse.

Between the Oatka and the Genesee valleys only two definite west-leading channels have been mapped. The higher is a deep, rock channel, at altitude of 1000 feet, with a northwest direction, opening into the Oatka valley at Pearl Creek. This is the eastern representative of the Linden and Bethany channels. The lower channel is 6 miles north and is utilized by the Lackawanna Railroad, with altitude of 940 feet. These two channels were the outlet of the seventh stage of the Genesee glacial lakes, which were named in a former publication the Warren Tributary lake.

The curving direction of these channels on the valley slope shows clearly the lobation of the ice front projecting up the low ground of the Genesee valley.

Here ends the too brief description of the Erian glacial drainage channels. But study of the region shows still other channels heading east of Leroy at 800 feet altitude, and northwest at 700 feet, which lead to the east. These are the beginning of a remarkable series of low level drainage channels extending east through Syracuse to the Mohawk valley. Those beyond Syracuse have already been described in former writings [*see* p. 7], and those between Leroy and Syracuse will form the subject of a future article.

Leroy and Batavia stand at the critical altitude between the two opposite directions of ice border drainage. During all the centuries while the ice front was melting back obliquely from the south slope of the Erie basin the ice border in central New York was also receding, so that low eastward escape was soon to occur through Syracuse. As long as the ice front, lying against high ground in the Syracuse district, shut out the central New York waters from a low eastward escape they all passed westward to Lakes Whittlesey and Warren, as described. But while the ice was resting over Batavia [*see* p. 31] the relations changed so as to permit lower eastward flow, even for the Oatka valley, and the direction of the ice border drainage was permanently reversed.

When the ice front passed north of Batavia the glacial waters on the east were down to perhaps near 800 feet, and the Tonawanda creek found a sinuous course through the moraine and entered Lake Warren as a land stream.

LOCAL GLACIAL LAKES

The drainage channels described in the preceding pages were the outlets for the glacier-dammed lakes held in the valley basins. It would be the more logical order to describe the lakes before describing their outlets; but the reverse order has been followed because the channels are existing features, and so much more abundant, widely distributed and conspicuous that they can be appreciated better than the other evidences of the extinct and now invisible lakes which produced them.

These glacial water bodies can be divided, somewhat arbitrarily, into two classes, according to the direction of overflow. (1) The earlier lakes which poured their outflow across the divide into drainage outside the Erie basin. This class of lakes produced the channels described briefly on pages 15-18. (2) The later local lakes which found escape for their surplus waters past the ice front and across the intervalley ridges, but wholly within the Erie basin. These lakes, which often constituted tributary series, made the hundreds of channels which have been briefly described in the preceding pages.

With outlets to southern drainage

All the larger lakes of this class existed in territory which has not yet been surveyed for the State topographic map; and as the study of lakes and water levels requires particularly a knowledge of altitudes which are now known in this territory only along a few lines of railroads, the investigation is made under a disadvantage. Without the topographic map the amount of labor required to secure full data is out of all proportion to the value of the results, and hence the subject is discussed here only in a general and provisional way, and subject to future correction and amplification, when the topographic sheets of Cattaraugus and Wyoming counties are available. The map, plate 1, will show the general course of the main water-parting between Erian and Alleganian waters, and the passes or cols across this line.

At the extreme west end of the State one or more small lakes may have been held in the north-sloping valleys with outlets across the divide to French Creek. Other examples of this class of lakes may be located on plates 2, 3, by the outlet channels across the main divide. The two larger ones occupied the highest portions of the Canadaway and Walnut valleys.

All the other notable lakes of this class lie in either Cattaraugus or Wyoming counties. The earliest primitive lakes must have been along the southern side of the Cattaraugus valley, in the heads of the valleys which incline northward. The lowest pass available for each valley was compelled to carry some overflow for a time, but possibly leaving little evidence of the flow. (The word "time" is used in a geologic sense and as relative, and may cover 10 years, or 100 years, or 500 years, or even more. We have no way of estimating the rate of recession of the ice front, which was doubtless very variable.) As the ice front retreated northward the smaller primitive lakes blended together and the higher passes of overflow were abandoned for lower, until finally only one channel persisted in each large basin. The early lakes in the eastern part of the Cattaraugus basin overflowed to the Genesee glacial waters, and finally out to either the Allegany or the Susquehanna drainage; while those in the south side of the basin all overflowed to the Allegany.

The main branch of the Cattaraugus rises in Wyoming county in the towns of Java, Arcade and Freedom and flows westward, being joined above Gowanda by the south branch. In the eastern part of the basin the lowest escape seems to have been at Machias, where a large stream-cut valley occurs at altitude of 1646 feet, by the Pennsylvania Railroad levels. The first of the larger lakes in the Cattaraugus basin, which we may call the Machias stage, overflowed for ages through this great outlet to Ischua creek and the Allegany river.

With further recession of the ice front a lower escape was uncovered a few miles south of Gowanda, by the south branch of the Cattaraugus, described as the Persia outlet on page 17. The opening of this outlet lowered the waters more than 300 feet and inaugurated the second Cattaraugus lake, which we will call the Persia stage. This level seems to have been held until lower escape was permitted on the slope west of Gowanda in the vicinity of Perrysburg, as described on page 22.

Throughout the Cattaraugus basin there will be found in the higher valleys many small stretches of level silts or sands which are delta fillings made by side streams pouring into the Cattaraugus lakes. These may lie at various levels, but the stronger or more extended fillings will be found to correlate with the Machias and Persia stages, as these were stable for longer time. These deltas should occur at about 1650 down to 1630 feet, and at about 1320 down to 1300 feet. Probably some of the villages in the basin have their sites determined by these level areas of gravel or sand, and these will most likely correspond to one or the other of the levels noted above. The lower water levels at Gowanda belong with the second class of glacial lakes [*see* p. 41].

Local lakes must have existed in the basins of the several parallel creeks lying in Erie and Wyoming counties north of the Cattaraugus basin, and now flowing northwest. We will not describe these lakes, but will simply name them in succession from west to east, as follows: In Erie county the New Oregon-Clarksburg lake occupied the valley of the south branch of Eighteenmile creek; the Boston lake, the main valley of Eighteenmile creek; the Glenwood-Colden lake, the valley of the west branch of Cazenovia creek; the Protection-Holland lake, the valley of the east branch of Cazenovia creek; the Java-Wales lake, the Buffalo creek valley.

In Wyoming county two valleys were occupied by high-level glacial waters; the Cayuga and the Tonawanda. The col at the head of the Cayuga valley leads over to the Tonawanda valley ½ mile north of Perry's Crossing, through a swamp, with altitude of about 1380 feet (aneroid)[1].

The upper sections of these two valleys were consequently flooded with a single lake, named the Varysburg-Johnsonburg lake after the two villages in the Tonawanda valley, and which had its outlet west of North Java leading over to the Java-Wales lake, already mentioned [*see* p. 29].

The details of the lake phenomena and history will be found an interesting study when the topographic maps are in hand.

With outlets past the ice front

The lakes of this class are the successors in each valley of those just discussed, but their direction of overflow was essentially different, and their distinct recognition is important to the full understanding of the history of the glacial waters. The existence of these lakes has frequently been mentioned or implied in the description of their outlet channels across the intervalley ridges.

As these lakes had a series of evanescent outlets across the declining ridges their levels were comparatively unstable, in which respect they are quite unlike their predecessors of the former group. Another difference is that these lakes were in series, one tributary to another, but always to the westward.

The highest outlets have not been noted in all cases, and have not been specially sought. They must always lie inferior to the head waters outlet of the earlier lake. When the topographic maps are at hand and altitudes are known it will be easy to locate the highest escape of each lake with considerable accuracy in advance of actual observation on the ground.

It is not now practicable to name all these lakes individually, since they fell continuously through hundreds of feet vertically and

[1]In a former publication *Glacial Waters in the Finger Lakes Region of New York* [Geol. Soc. Am. Bul. 10:33] this col was described as the early outlet of the Tonawanda valley waters. This was an error, due to misinformation. Having no reliable map the writer accepted the statement that the valley leading northeast from the swamp was the head of the Buffalo creek valley, whereas it is the head of the Cayuga valley and leads far northward.

contracted their areas until finally lost in either Whittlesey or Warren. They are properly named after the village or some other geographic feature in the lowest part of the lake bed.

Passing from the west the first lake of this class worthy of present mention is that which was held in the Canadaway valley, south of Fredonia, and already called the Shumla lake [p. 21]. This is a good type of this class of lakes, and its description will apply, in a general way, to all. The earlier lake had its outlet at the pass to southern drainage through the present Cassadaga lakes and Lilydale and Cassadaga villages. When the ice, resting against the slope south of Fredonia, was melted away from ground lower than the Cassadaga outlet, and which had opening freely to the west, the second lake was initiated. This highest channel to the west seems to have been at the three-corners, 3 miles west of Shumla and over ½ mile south of the mouth of the Wheelers Gulf canyon. The Cassadaga col is about 1320 feet altitude, and the westward escape is somewhat under 1300 feet.

This second Shumla lake was not long stationary for the withdrawal of the ice front on the sloping ground opened lower and still lower outlets, and the vigorous streams cut the series of bluffs and channels on the north-facing slope south of Fredonia. Not only was the lake surface lowered and the area contracted but as the ice barrier receded the lake followed. The lake thus migrated down the valley, diminishing in depth and area until finally it was lost in or blended with the invading Lake Whittlesey. The several channels serving as outlets of the Shumla lake with the correlating deltas have been described on pages 21, 22.

The next lake on the east was in the Walnut valley above Forestville. Probably some delta fillings may be found along the slopes which correlate with the stronger outlet channels across the slope to the westward. The village of Forestville lies on a delta built in the waning lake at its latest phase by the main creek, which had followed the lake as the lake had followed the ice.

The lake next eastward and the largest of all the lakes of this class in the Erie basin was the third phase of the Cattaraugus waters, determined in its several levels by the series of channels winding around the slope between Gowanda and Forestville. Two sets of terraces or water levels are found in the lower part of the valley, at Gowanda. The lower set was produced in the embayment of Lakes Whittlesey and Warren. The upper set correlates with the westward-leading channels. They are specially well developed at Gowanda village, and were briefly described in the former writing on this region.

The highest of the Gowanda levels is seen in a water-leveled plateau some distance southeast of the village, with altitude about 1210, or 100 feet lower than the Persia outlet (to Allegany flow for the second stage waters). Immediately south of the village is a high plateau terrace at 1032 feet, called the Studley level. The Broadway level is a strong terrace south of the village at 972 feet. Below the Broadway level is another terrace, named the John Brown level, at 883 feet, which corresponds precisely with the summit level of the broad Asylum plateau, northwest of the village and west of Collins. The high tower and water tank of the State Insane Asylum stands on the 883 feet level. Shoos corners, on the north side of the plateau, are on a broad terrace at 873 feet; while a lower plain at 857 to 852 feet forms the State farm and the site of Collins village. With the help of Mr B. W. Law these water planes were measured for altitude in 1900 without any knowledge of their correlation beyond the idea that the determining outlets were on the high ground to the west. During the summer of 1902 the slope between Perrysburg and Forestville was examined and the stream channels mapped entirely independently of any other features. Indeed the correlation of the channels with the Gowanda terraces was not made until the time of this writing. The relationship can now be expressed in the following table:

GOWANDA PLANES	OUTLETS
Highest plateau, 1210 feet	Highest well developed channels across high ground west of Perrysburg
	Minor scourways at various levels above and below 1100 feet
Studley plateau, 1032 feet	Strong channels at Smiths Mills station, and east, at 1020 feet
Broadway level, 972 feet	Strong cut terraces and bluffs north of West Perrysburg and around to Forestville, at 980 down to 920 ± feet
Asylum plateau, 883, 873 feet	Strong channels at Smiths Mills and east and west, at 900, 880 feet and lower
Collins plain, 855 feet	Lowest channels west of Smiths Mills and west of Forestville, at about 860 feet and declining
Fourmile level, 820 feet and declining west	Lake Whittlesey, 840 ± feet

The figures for the outlets are taken from the map contours and are not precise. Accurate measurements would probably show closer correspondence than this tabulation. When we realize the considerable variation in altitude of the water-leveled plains with reference to the water surface, and the fact that the lake waters were slowly drained down through all the levels from the highest to the lowest, the above correspondence is very striking and conclusive. It shows a harmony of facts indicating that the theory is sound.

Passing east from the Cattaraugus we shall find that the same series of parallel valleys which held lakes of the earlier class [*see* p. 35] also held lakes of this group, and with lowering surfaces as shown by the numerous channels already described as lying across the ground between the valleys. It seems unnecessary to recapitulate the lakes by the former names; and it is not desirable to give distinct names merely in recognition of changing outlets and different levels until we can describe them with greater detail and precision than is possible without the topographic sheets. In each valley a good observer can probably find sufficient lake and stream phenomena to yield an interesting history when translated by competent study and correlation.

In the Tonawanda valley the Attica lake was the successor of the Varysburg-Johnsonburg lake. The overflow channels of this water have already been described as the numerous strong channels lying in the broad belt north and south of Darien and Darien Center. Delta plains and terraces should occur along the sides of the valley at various levels. It would seem that they should be stronger at about 900 to 1050 feet, or correlating with the stronger overflow in the region of the Lackawanna and the Erie Railroads; but the conspicuous delta plain of the State Asylum farm at Varysburg, at 1200 feet, must correlate with some other outlet. The delta east of Alexander, at 950 to 920 feet, was built when the waters had outlet along the line of the Lackawanna Railroad. When the outflow was near Batavia the lake was too shallow and restricted to reach up the valley beyond Attica.

The theoretic succession of waters in the Tonawanda valley may be outlined as follows:

1 North Java lake. The outlet not determined, but at about 1600 feet.

2 Varysburg-Johnsonburg lake. Outlet west of North Java, 1510± feet.

3 Same lake, second stage. Flooding Humphrey Hollow (Cayuga valley). Outlet near North Sheldon, at 1500 to 1400.

4 Same lake, third stage. Outlet into Humphrey Hollow lake by the swamp col at Perry's Crossing station, 1380 ± feet.

5 Same lake, fourth stage. Direct outlet past the ice border south of Bennington, under 1380.

6 Attica waters, many stages. Outlets between Darien and Batavia.

In valleys east of the Tonawanda creek

The local lakes mentioned thus far were in valleys of the present Erie drainage. But during the glacial epoch and the episode which we are studying the valleys far to the eastward were tributary to the Erian waters, as already noted [p. 32].

The eastward extent of the territory which was drained by the Bethany-Batavia channels is not yet certain, but at its maximum it may have reached nearly to Syracuse. One determining element in the problem is the plane of the Newberry waters which had their outlet south, through Horseheads and Elmira, at the present altitude of 900 feet. The Newberry plane rises toward the north, like all of the glacial lake levels, and on the parallel of Batavia should have an altitude of about 975, or 100 feet over the Warren plane. With present partial knowledge of the trend of the ice front in the Finger Lakes district it seems probable that this front lay far enough to the north to allow free passage westward to the Newberry waters during the life of the Batavia channels. If this were the fact then the channels lying north of East Bethany, or from 975 to 950 feet, carried Newberry waters and diverted the flow from the south-leading Horseheads outlet, and all the territory as far east as Owasco and Skaneateles valleys was drained through the Batavia channels. Whether the above suggestion is true or not, it seems certain that the valleys of Oatka, Genesee, Conesus, Hemlock and Honeoye were tributary to Erian waters.

The Batavia channels might seem incapacious for the volume of water that would be contributed by so large a drainage area and from so long a frontage of melting glacier. But the scourways were not cut deep for the reason that they were already so low relative to their baselevel, the Warren plane. From Batavia to the Warren plane west of Corfu is about 12 miles, with a fall of about 30 feet. The Batavia plane and the buried moraine south and southwest show the effects of a large volume of water with a sluggish flow.

The earliest lake in the Oatka valley, called the Warsaw lake, had its outlet southward through Silver Springs at altitude of about 1400 feet. The channels above described, at Linden and the Bethanys, were the westward outlets of a lower lake, with levels falling from about 1300 feet down to 1000 feet, which we will call the Wyoming-Pavilion lake.

The full history of the waters in the Oatka and Genesee valleys belongs to another paper which should treat specially of the Genesee and central New York valleys.

GREATER GLACIAL LAKES

General statement

The evidences of standing water at high levels in the Huron-Erie basin were recognized in the early occupation of the territory, and many geologists have participated in the investigation, among whom should be mentioned N. H. Winchell, J. S. Newberry, G. K. Gilbert, J. W. Spencer, C. R. Dryer, and specially Frank Leverett and F. B. Taylor. The elaborate monograph by Leverett, already noted, is the latest comprehensive treatise on the subject, and its pages 711-55 give a good account of the lake history and records, with excellent maps. Recently Taylor has worked out in Michigan the history of the greater lakes in correlation with the different positions of the oscillating ice front.

For several years three vast glacial lakes, successively lower in altitude, have been recognized in the Huron-Erie basin. These have been named lakes Maumee, Whittlesey and Warren. Recently Taylor announces another lake level, "Arkona" representing a stage between the Maumee and the Whittlesey, but lower than the latter.

Lake Maumee

This earliest member of the series of great lakes in the Erie basin named by Dryer in 1888, did not extend into New York. It was initiated when the ice front retreated from the head of the Maumee valley at Fort Wayne, Ind., and the primitive and principal outlet was at Fort Wayne over to the Wabash-Mississippi. As the convex ice front receded northeastward the lake followed it until the southern branch of the lake, creeping along the glacier margin, reached as far as Girard, Pa. At the same time the western branch pushed along the ice margin in Michigan and found another and somewhat lower escape at Imlay across the "Thumb" of Michigan (the point of land between the south end of Lake Huron and Saginaw bay) over to the glacial lake Saginaw (occupying the Saginaw valley) which poured its waters into the glacial Lake Chicago (occupying the Michigan valley) with ultimate flow to the Mississippi.

Further recession of the ice front on the Michigan "Thumb" extinguished Lake Maumee, by opening an escape for the ice-imprisoned waters at a lower level. It has been supposed that the successor of Maumee was the next lower of the lakes which have left their shore inscriptions in the region, that is, Lake Whittlesey. But Taylor has recently found that the relation of shore lines and moraines indicates that the ice front receded from the Maumee level directly to a level below the Whittlesey and opened free passage for the waters to Lake Saginaw. This level of the waters in the Huron-Erie basin is thought to have persisted for a long time and to have formed the extensive beaches in Michigan and eastward, known as Arkona (named by Spencer).

At length a readvance of the ice in Michigan closed the Arkona outlet and forced the overflow to a higher level, farther south, on the thumb of Michigan, at Ubley. The beaches correlating with the Ubley outlet have long been known as the Belmore (named by N. H. Winchell from a town in Ohio) and the waters have been named by Taylor Lake Whittlesey.

The fall of the glacial waters from the Maumee down to the Arkona level with the subsequent rise to the Whittlesey level the writer believes to have occurred while these waters were yet excluded from New York. The facts and argument bearing on the above history will be found on pages 64-75. However, the continued recession of the Erian ice lobe during the life of Lake Whittlesey allowed these waters to push far into New York. In the State of New York we have, therefore, to deal only with Whittlesey and lower waters.

Lake Whittlesey

This water body, named by Taylor in 1897, was the successor to Lakes Maumee and Arkona in the Huron-Erie basin. Its outlet was at Ubley on the Michigan "Thumb," in a reentrant angle of the ice front. The overflow was contributed to the glacial lake Saginaw, in the valley of that name, which in turn had its outlet across Michigan by the Grand River valley to Lake Chicago. The strong shore line named by Winchell in 1872 the "Belmore," after the town in Ohio, is the beach of this lake. The Whittlesey beach extends into New York with strong development but weakens beyond Gowanda and disappears between East Aurora and Alden near the village of Marilla.

The Whittlesey shore has suffered deformation in common with all the beaches in the Erie basin, and rises from an altitude of 784 feet above ocean at State Line (taking the elevation of the track of the

Lake Shore & Michigan Southern Railroad at 787 feet) to 905 or 910 feet near Marilla.

The detailed description of this shore line will follow on later pages.

Lake Whittlesey came to its extinction by the recession of the ice front on the "Thumb" of Michigan which finally allowed the waters to fall to the level of, and to blend with, Lake Saginaw, the extended waters being called Lake Warren.

Lake Warren

This name is applied to the wide extended glacial waters that in the Huron-Erie-Ontario basin succeeded Lake Whittlesey, with its surface about 45 feet lower. While the ice margin was lying south of Alden, N. Y., its western continuation on the "Thumb" of Michigan receded from its position facing the Ubley channel, and the Whittlesey waters found lower escape and were finally blended with Lake Saginaw. Lake Warren was, therefore, only the far-extended Lake Saginaw, with outlet by the Grand River valley into the glacial Lake Chicago near Grand Rapids.

The Warren waters found their way eastward past the slowly receding ice front into central New York, and the great lake came to its extinction by the opening of new and lower outlets eastward to the Mohawk-Hudson in the region of Syracuse. The map in the 22d annual Report of the State Geologist, plate 1, shows the full extent of the Warren waters in New York. They formed only a narrow belt of open water south of the glacier margin, with numerous prolongations up the valleys of the Finger Lakes.

Unlike the Whittlesey shore, which is a unit and definite, the Warren shore phenomena about the Erie basin are complex, including usually a series of bars, ranging from 40 or 45 feet down to 70 feet below the Whittlesey. This multiplicity of the sand and gravel ridges has been regarded as the product of distinct levels of the lake waters, and in the writings of Leverett and Taylor the upper bars have been called Arkona, and the lower ones Forest (named by Spencer after a town in Ontario, Can.). The present writer has a different view as to the origin of the shore features, but the relationship and genesis of these beaches will be discussed later, after the detailed description.

Lake Dana

Lake Warren ended by the opening of channels of escape eastward to the Mohawk-Hudson. The falling waters with easterly outflow might be distinguished as sub-Warren or hypo-Warren, but since they were tending toward the Lake Iroquois level, having the outlet at Rome to the Mohawk valley, they have more properly been called hyper-Iroquois.

From the Warren to the Iroquois plane the lake waters fell through 440 feet of vertical distance (Warren level in central New York about 880, Iroquois about 440), and long pauses must have occurred during the lowering of the great volume of water and the cutting of the huge canyons and cataract cliffs in the Syracuse region which rival those of the present Niagara. Only one of these stages has been recognized, namely, that which produced the strong beach first discovered in the Seneca valley and named the Geneva beach, the producing waters being called Lake Dana.

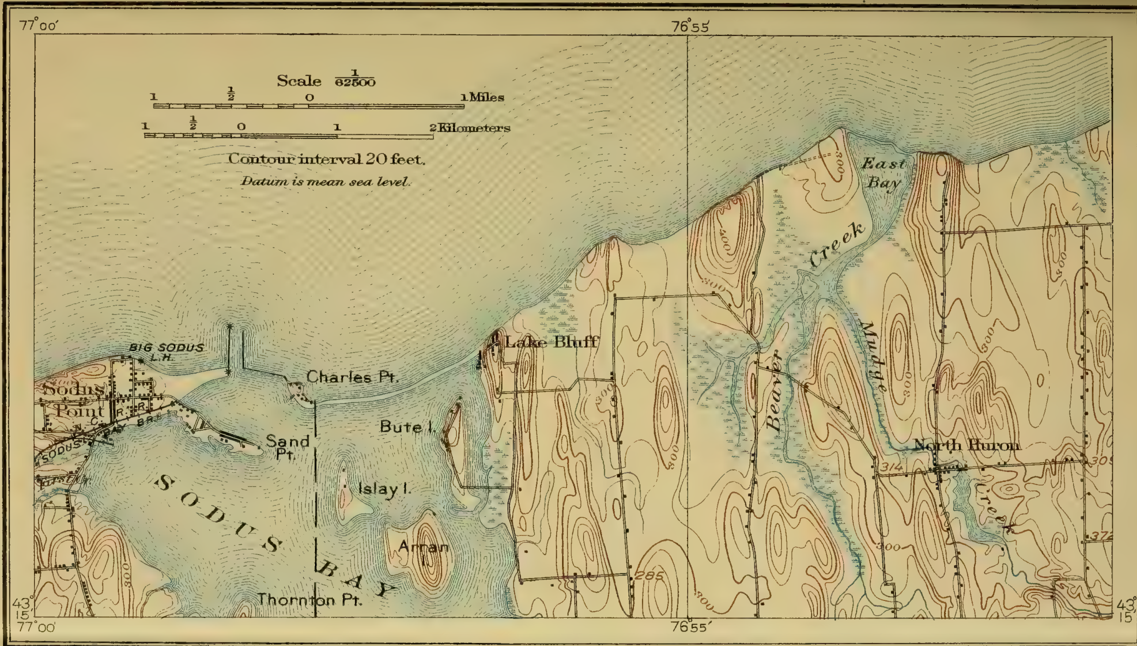
The altitude of Lake Dana is 700 feet, or 180 feet under the Warren plane. Its outlet is believed to have been the capacious channel leading east from Marcellus, as that is the only strong channel with the proper hight.

Numerous and indubitable evidences of this water surface have been found in wave-cut notches and spits of gravel on the hills as far west as Buffalo. Theoretically it should extend westward over the same general area as the Warren, and many evidences of standing water have been found in the Erie district at the Dana level, declining westward in accord with all the water planes, but no continuous beaches are found as the waters were too transient to do much work under unfavorable conditions. Lying 180 feet under the Warren plane the Dana plane passes under Lake Erie in the neighborhood of Westfield. Eastward, strong bars have been found at Fayette, between Seneca and Cayuga lakes.

SHORE LINES OF THE GREATER LAKES

General description of the beaches

The general relation of the ancient lake beaches to the present geography can be more clearly understood by examination of the maps than by verbal description alone. By reference to the maps [pl. 2-6] it will be seen that the several beaches lie in a belt which has, in general, a straight course across the entire area, with northeast by southwest direction from State Line to Indian Falls, a distance of nearly 90 miles. The chief exception to the above statement is the embayment at the Cattaraugus, which however affects only the higher beaches. It will also be seen that in the stretch from State Line to Silver Creek, about 38 miles, the beaches lie close together and parallel with each other and with the present shore of Lake Erie, which is only 1 to 3 miles away. At the embay-



WAVE-WORK OF LAKE ONTARIO

The primitive shoreline passed around all the bays. Wave-work has eaten back the headlands and constructed embankments across all the bays on the south shore of the lake. The bar connecting Lake Bluff with Charles Point is wholly built by the lake waters. Compare plates 15, 16. (These three illustrations from an existing lake show the formation of cliffs and bars on the ancient lake shores.)

ment or indentation in the higher ground forming the Cattaraugus valley the higher beaches swing landward, toward the southeast, nearly to Gowanda, or about 10 miles. Beyond this break, the belt of beaches continues its northeast course, but the beaches lose their continuity and parallelism. From the Cattaraugus to Eden Valley the higher beach, the Whittlesey, can be continuously traced by cliffs or bars, while the lower shore phenomena, the Warren, are discontinuous though strong, and distributed over a belt 2 or 3 miles wide. From Eden Valley to Indian Falls, on the contrary, the Warren beaches become more continuous and direct, while the Whittlesey beach, lying across ridges and valleys, is immature, broken and irregular and weakens and finally disappears near Marilla.

Throughout its whole extent in New York the Whittlesey beach is characterized by simplicity and unity. When marked by wave-built bars or embankments of sand and gravel it is single and definite and fairly strong excepting of course toward its extinction east of Buffalo. In this respect the Whittlesey and Warren are very different. The Warren shore phenomena are complex, being only exceptionally a single ridge of gravel. Usually the Warren forms several ridges, variable in strength and altitude. This complexity of the Warren shore will be discussed in a later chapter after the phenomena have been described in more detail.

In the Huron and western Erie basins the prevailing complexity of the Warren shore phenomena and frequent pronounced duplicity gave occasion for distinct names and for the belief in two distinct lake levels. The higher of the more persistent ridges was called "Arkona" and the lower "Forest," names given by J. W. Spencer to beaches in Ontario, Can. Throughout the district in New York described in this paper two bars or two series of bars may frequently be recognized, and the names Arkona and Forest have been used by Leverett in the description of this region. While convenient for use in study and discussion the names are inappropriate for final or permanent designation of the New York beaches since the types are far away in another province, implying two lake levels which are not yet proven, and are not descriptive or suggestive of the lake which produced them. The appropriate naming is to designate the beaches fractionally or locally by some geographic feature, usually a village on the bar, and to refer to the beaches in the comprehensive way as the higher or superior Warren and the lower or inferior Warren. These names will be noncommittal on the question of two distinct lake levels and can readily give way to any more distinctive names if needed in the future.

To the readers who are not familiar with shore phenomena a few words of description will be helpful, but observation in the field is the best teacher. The shore work done by lakes and seas is effected by the waves beating against the shore and by the currents running more or less parallel with it. The waves undercut the projecting points or saliences while the currents seize the resulting detritus and push it along the shore or into deeper water. The final result of this work is to pare away minor projections and to build ridges of sand or gravel across the narrower bays or reentrants, thus straightening or smoothing a shore line which primitively may have been very irregular. This geologic process is well illustrated along the shores of living waters and plates 14-16 clearly show the work on the Ontario shore at Sodus Bay.

When the work of waves and currents along a stretch of shore has accomplished all that is possible in the way of straightening the latter the beach is said to be "mature." Some geographers do not regard the shore as mature until all the lagoons behind the bars are filled by detritus from land wash or by vegetal accumulation, thus making a continuous mainland.

The shore of Lake Warren is comparatively straight and mature as far east as Crittenden, beyond which point the beaches indicate very much less work of the waters. The Whittlesey beach is fairly developed to the Cattaraugus embayment, beyond which the wave work diminishes.

Detailed description of Whittlesey and Warren beaches

As the direction of the beaches, highways and railroads are nearly northeast and southwest, parallel with the Erie shore, the constant reference to compass directions is verbally awkward. It will be more convenient in the description to speak of the directions alongshore as east and west, and the direction at right angles to this as lakeward and landward.

The figures given for altitude are usually by aneroid unless otherwise stated, but these are fairly reliable as the instrument was frequently checked by the railroad levels and all doubtful figures have been thrown out.

State Line to Westfield. At the New York-Pennsylvania boundary all the beaches lie below (or lakeward of) the railroads, in which respect the locality is unique in New York. At State Line station the Whittlesey (Belmore) beach is a ridge or terrace supporting

Plate 19

Edge of delta at brick church (West Portland), 3 miles northeast of Westfield. View from lowest Warren bar. Upper Warren bar is under the church.

the station of the Lake Shore and Michigan Southern Railway, which is given as 787 feet. The beach altitude is taken as three feet lower, or 784 feet. The conspicuous ridge east of the station, lying between the two railroads, which suggests a bar in form, is a morainal ridge and the west front of the Escarpment moraine. The Whittlesey waters laved the moraine in all this section.

West of the railroad station the Whittlesey beach swings over to the highway, carrying State Line village, and is followed by the

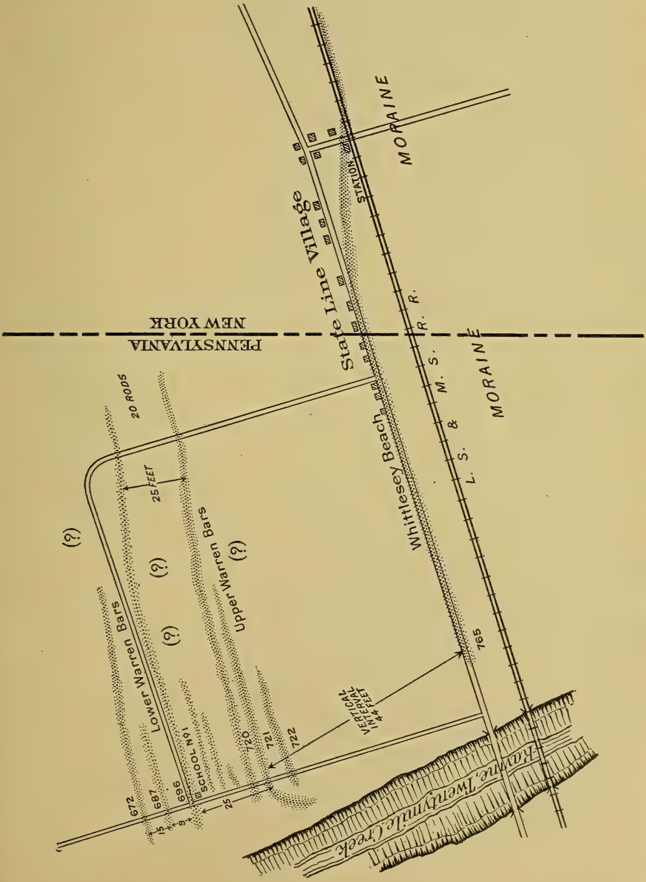


Fig. 2 Sketch of bars on delta of Twentymile creek at State Line

highway, into Pennsylvania. The relation of the geographic features is roughly indicated in the sketch, figure 2. We find here a characteristic development of wave-built bars on a delta, the delta of Twentymile creek. The horizontal spacing in the sketch is not accurate, being only estimated. The vertical spacing or altitudes are by aneroid and hand level and fairly reliable. The total vertical spacing of the Warren bars is about 50 feet. The interval of 45 feet between the Whittlesey and the upper Warren, and 25 feet between the upper and lower Warren is a fair example of the prevailing relation as far as the Whittlesey extends. The duality of the Warren series is unusually well expressed, and is possibly somewhat overemphasized in the sketch. On a strong delta bars may form rapidly, and the multiplicity of bars with some of inferior level, makes the delta bars, when taken alone, unsafe criteria for determination of the lake levels.

On the roads 1¼ miles eastward from State Line the Whittlesey bar lies between the railroads in excellent form at the altitude (aneroid) of 782 feet. The higher Warren carries the "Ridge Road" at 734 feet, while the lower Warren lies lakeward with altitude 715 feet. The highway follows the higher Warren east for ½ mile at which point the lower ridge unites with the higher, and on through Ripley village there is only one Warren beach, followed by the main street, with an altitude of 730 feet, and 60 to 70 feet under the Whittlesey. Southwest of Ripley 1½ miles the Whittlesey beach is crossed by the Chicago and St Louis (Nickel Plate) Railroad, and from this point eastward throughout its whole extent in New York it lies above or landward of the railroads. This is the only locality in New York where the traveler on the railroads is able to plainly see the Whittlesey beach, although a trained eye may detect the wave-cut slope between here and Brocton, lying above the Warren bars.

South of Ripley, lying under a highway, the Whittlesey beach is a broad, low ridge against the morainal slope. Nearer the village the beach falls below the road and farther east it carries the cemetery. The main street of Ripley at the east end of the village lies on the lower Warren, about 15 feet under the Lake Shore tracks, which are given as 749 feet, making the lower beach 734 feet. The Whittlesey lies about on the 800 contour of the topographic sheet. The railroads lie along the higher Warren which they have largely cut away.

In the stretch of 8 miles from Ripley to Westfield the Whittlesey beach lies against the steep morainal slope and is often weak and

Plate 16

Sodus Bay bar, Lake Ontario. View on the bar looking northeast toward Lake Bluff [compare pl. 14 and 15]. The crest of the ridge was built by the heaviest storms during highest water, and is about 5 feet over water in 1905.

discontinuous. In some places it has left no trace except a smoothing of the slope, one such point being on the road leading landward over a mile southwest of Forsyth. From Ripley to Forsyth it lies about $\frac{1}{4}$ to $\frac{1}{3}$ mile landward of the railroads.

The highway between Ripley and Forsyth follows the lower Warren, while the railroads occupy the position of the upper Warren which they have dissected or leveled. One mile east of Ripley the altitudes are: Whittlesey 796, higher Warren 761, lower Warren 730 feet. One half mile west of Forsyth the Warren is represented only by the lower bar, under the highway, 735 feet, while at the station this is distinct under the depot at 730, and the higher Warren lies above the railroad.

East of Forsyth the railroads lie lakeward of the beaches and thence eastward lie on the floor of the lakes while the highway follows the Warren beach. One half mile east of Forsyth the bars all have good development, specially the Whittlesey. On the road leading landward the following altitudes were taken: Whittlesey 792, higher Warren 760, lower Warren two bars 744, 730 feet.

East of Forsyth $1\frac{1}{2}$ miles and beyond four-corners only one ridge of Warren is shown. The Whittlesey is here a heavy bar of fine gravel and the interval between this and the Warren is 65 to 70 feet. About 2 miles southwest of Westfield a new road has been made, leading south, and on this road a small bar occurs intermediate between the Whittlesey and Warren. The intervals are about 25 and 16 feet, or 41 feet between Whittlesey and Warren.

About 1 mile west of Westfield, by the three corners, the Warren bars, all lying north of the highway, show fine development and multiplicity. There are four strong, close set ridges with vertical intervals in descending order of 11, 10 and 6 feet by hand level, giving a total range of 27 feet.

Approaching Westfield the beaches swing around up the creek, the upper Warren falling into line with the bold ridge of the Whittlesey. The inferior Warren is a weak bar $\frac{1}{2}$ mile north of the higher bar, and the beach altitudes here are 725, 745, 795 feet.

Westfield village lies on a delta of Chautauqua creek, bounded landward by the Whittlesey beach. The main street cuts through the higher Warren ridge, the break occurring at the high school. East of the school building and public square the superior Warren forms on the southeast side of the street, the strong ridge occupied by residences and the cemetery. The crest of this ridge is 5 feet over the United States Geological Survey bench mark (on the school building), making the altitude of the beach 753 (748 plus 5) feet. Several lower Warren ridges occur on the delta plain, as mapped in figure 3. The altitudes here are: Whittlesey 795, higher Warren (precise) 753, lower Warren 730, 725, and a still lower bar at 718 feet.

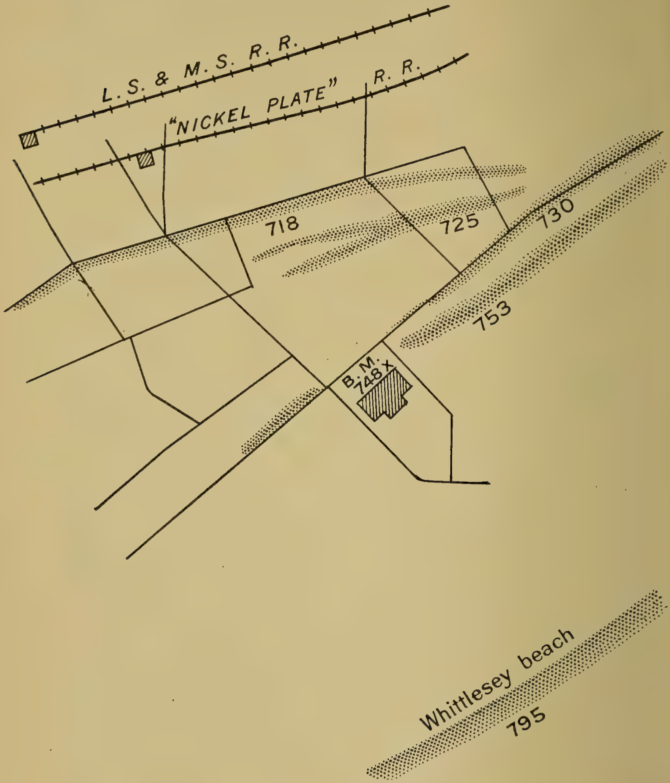


Fig. 3 Bars at Westfield

Westfield to Portland. In this stretch of 7 miles the two shore lines and the railroads hold a fair parallelism. The Warren bars lie along the highway about ½ mile from the railroads, while the Whittlesey lies about ¾ mile farther landward. South of Westfield and for 3 miles northeast the Whittlesey is a handsome ridge

Plate 17

Warren beach, 1 mile west of Ripley. Looking south from the lake bottom. The ridge carries a highway.

[*see* pl. 18] pursuing a direct course and presenting a bold lakeward slope. The 800 foot contour of the topographic sheet should lie along the face of this conspicuous ridge.

From Westfield to West Portland church, $3\frac{1}{2}$ miles, the highway is a direct line and lies on the lower Warren beaches. As seen from the road the beach is a broad, undulating ridge with a steep frontal or lakeward slope, facing the smooth plain of the ancient lake bottom. For 2 miles from Westfield the superior Warren is not prominent but represented by low, parallel bars somewhat higher than the highway. Gradually, however, the higher Warren strengthens and toward the West Portland corners it becomes a heavy gravel ridge about 38 feet higher than the lower Warren. This is an interesting locality for the study of these water levels. At the forks of the road the highway leading to Portland and Brocton rises quickly from the lower to the higher Warren ridge. The brick church stands on the upper Warren ridge, which beyond this point is a gravel plain nearly a mile wide, extending landward to the Whittlesey beach. Along the road the surface of the plain is a series of smooth ridges or swells, specially toward Portland and along the edge of the plain, the latter forming a steep cliff 35 to 40 feet high, and about $\frac{1}{4}$ mile from the highway. The lower Warren ridge lies below the cliff, which seems to have been eroded by the later Warren waves, as shown in plate 19. This broad gravel plain is the delta built in the Whittlesey and lowering waters from the detritus brought down by the glacial drainage channel south of Portland [*see* p. 21]. The large vertical interval between the Warren bars contrasts strongly with most other localities. On the north and south Townline road west of the brick church the lower Warren is about 25 feet under the upper Warren, and the Whittlesey is toward 50 feet higher. At the brick church the Whittlesey lies 40 to 45 feet over the upper Warren, which is 38 feet over the lower Warren, represented here by a single bar below the abrupt cliff.

On first sight the large interval between the Warren bars suggests two lake levels about 40 feet apart. But this relation is not confirmed at other localities. The relation here is exceptional and the product of special local conditions. The isolated lower bar may be regarded as inferior Warren, either an offshore construction or else built in the falling waters. It is comparable to the inferior bars often found on heavy deltas.

In the section of the West Portland corners and brick church the Whittlesey beach is a cliff for about $1\frac{1}{2}$ miles, but eastward it becomes a strong gravel ridge under the highway which utilizes the ridge for 9 miles, or to within 2 miles of Fredonia. Southeast and south of Portland the Whittlesey and its highway lie on the delta plain, but eastward the beach forms the north bank of the conspicuous river channel already described on pages 20, 21. This locality near Portland, with the glacial river channel, the delta plain with wave-built bars on top and its wave-eroded front, all lying at or just below the Whittlesey level, makes it one of great interest and critical importance.

Portland to Fredonia. From 2 miles southwest of Portland to 1½ miles southwest of Fredonia, a distance of at least 9 miles, the Whittlesey beach is followed by the "Ridge road," and is roughly parallel with the Warren shore and its highway. South of Brocton the two ridges are nearly a mile apart, while 2 miles east and southwest of Lamberton they are only ½ mile apart, these being the extremes of horizontal spacing in this section. The course of the Whittlesey shore is more indirect than that of the Warren as it bends to the irregularities of the higher ground, while the Warren lies on the Whittlesey bottom and delta fillings. In all its course from Portland to Fredonia the Whittlesey beach faces, or lies lakeward of stream-cut bluffs or river channels eroded by glacial drainage. For most of the distance it is a definite ridge of gravel, [*see* pl. 20], but in a few places it is a wave-cut cliff. One such cliff occurs south of Brocton, and others south of Lamberton.

The Warren shore is unusually varied in form and character between Portland and Fredonia. Portland lies on the higher and broader of several bars. Halfway between Portland and Brocton there are three bars with intervals, in descending order, of 35 and 20 feet. Brocton village lies below the Warren beach. One half mile east of the village the highway rises on to the beach, which for over a mile is a low bar facing a bold, wave-cut cliff cut in the delta front. Nearing Lamberton the beach is lost in an eroded embayment in the delta. For ½ mile east of Lamberton the road is on the single Warren ridge, but for the next 1½ miles the beach is a broad gravel plain, with several ridges, and an abrupt border ¼ mile north of the road as shown in plate 21. This plain is another delta plateau, leveled by Warren waves, but probably accumulated in Whittlesey waters from glacial drainage.

Toward Fredonia the road rises slightly above the Warren level, and is on till. The beach lies on an abrupt but eroded delta front ¼ to ⅓ mile lakeward of the road. No lower Warren bar is distinguished in this section unless it is represented by a short spit

Plate 18

Whittlesey beach, $1\frac{1}{2}$ miles east of Westfield. Looking southeast from the lake bottom.

close to the road on the south side of the creek. The several altitudes west of Fredonia are estimated as follows: Whittlesey 813, higher Warren 768, lower Warren 743, lake bottom 720 feet.

Fredonia to Walnut and Silver creeks. Along this stretch of 10 miles the shore features are excellently developed, continuous, straight, and for much of the distance the Warren beach is distinctly double. Not much verbal explanation is needed as the phenomena are clearly shown on the map. The road leading northeast from Fredonia lies on the higher Warren ridge for 3½ miles, then follows the lower bars for nearly 7 miles to Walnut creek. At the railroad station in Fredonia the higher Warren ridge is about 8 feet over the railroad station which is given as 762 feet. Using this as the datum the beaches near the village are: Whittlesey 820, higher Warren 770, lower Warren 750 feet. The cemetery is on the lower Warren.

Two miles east by north from Fredonia a conspicuous mound or cone of till stands in the Whittlesey beach and has been described on page 13.

Four miles from Fredonia the higher Warren loses its distinctive character and for a mile breaks up into low, disconnected bars, and afterward for 3 miles is practically unrepresented, the highway following the lower Warren all the way to Walnut creek. At Sheridan Station on the Erie Railroad the Warren consists of two low, broad sand bars between which lies the highway. Using the map figure of 758 feet for the west road crossing of the railroad as the datum, the altitudes at Sheridan are: Whittlesey bar 825, higher Warren (cemetery) 766, lower Warren (north of road) 755 feet. This gives vertical intervals of 59 and 11 feet. Former measurement made the intervals 60 and 10 feet. It will be found that 8 miles east the same intervals occur. Northeast of Sheridan for over a mile only the lower Warren ridge can be seen in the open ground, but at the south-leading road 2 miles from Sheridan the upper Warren reappears, and the altitudes are: Whittlesey 825, upper Warren 785, lower Warren 755, the vertical intervals being 40 and 30 feet. From this point to Walnut creek, 1¾ miles, the higher Warren is a conspicuous, strong ridge lying ¼ mile landward of the highway with a steady vertical interval of 30 feet above the lower Warren.

Approaching Walnut creek the Whittlesey beach, which all the way from Sheridan has been diverging from the Warren, acquires an east and west direction, and at the creek lies on the front of the Forestville delta, 2 miles south of the lower Warren, the latter keeping to its northeast course.

Hanover Center (Silver Creek) to Gowanda. In this section and the next one the Whittlesey beach swings far inland and all the phenomena are complicated.

On the meridian of Walnut and Silver creeks and Forestville the beaches lie on a delta, accumulated partly by glacial drainage and partly by the two existing creeks, in the successive lake waters. The Whittlesey beach retains its simplicity but the Warren bars are multiple. Between the two creeks the Whittlesey is a straight ridge 1½ miles long with northeast course. East of Silver creek for 3 miles it is mostly a cut cliff on the face of the moraine. From an angle of the Indian Reservation (1¾ miles northeast of Smiths Mills) it is followed by the highway, chiefly as a ridge, with a trend south of east for 2½ miles; then it leaves the road and swinging around to the southeast follows along the south side of the Cattaraugus valley, mainly as a gravel ridge, for a distance of about 5 miles, or to within 2 miles of Gowanda. Above Gowanda the narrow Cattaraugus valley is a postglacial ravine and the old valley is blocked with drift, whence it would seem that the Whittlesey waters did not reach beyond the village, although the level would today extend far up the gorge valley. The altitude of the beach south of the Cattaraugus creek is 840 feet, according to the map contours.

Between the Walnut and Silver creeks along the north and south road the Warren shore is represented by at least four ridges, of which the two extremes correspond to the two strong ridges west of Walnut creek. The vertical interval is 25 feet. At Hanover Center and eastward there are several bars, the village corners lying on the higher Warren, which is followed by the road northeast for 1½ miles. Farther east the road, about a mile long and connecting two roads, lies above fragmental bars of the higher Warren. North of the east terminus of this road and on the north and south road, in the reentrant right angle of the Indian Reservation are two clean-cut gravel ridges with smooth clay soil interspaces. These bars are beyond the limits of any delta, on a clay slope, about ¼ mile apart, and with vertical interval of about 13 feet.

Eastward from the point noted above the lower Warren beach lies along the top of the bluff, south of the Cattaraugus creek in the Indian Reservation; while the higher Warren bars lie at the angle of the road in the west limits of the Reservation and continue east along the 800 foot contour. The bars have not been continuously traced in the Reservation as the ground is in timber and with

Sodus Bay bar, Lake Ontario; view from Lake Bluff. Looking southwest [compare pl. 14 and 16].

few roads, but the higher Warren lies about halfway between the lower Warren, on the top of the river bluff, and the Whittlesey a mile south. On the north and south road west of Little Indian creek the altitudes are: Whittlesey 840, upper Warren 790, lower Warren 770 feet.

The village of Versailles stands on the Warren terraces and the shore line of Lake Warren crosses the Cattaraugus valley a short distance above the village.

Gowanda to North Collins. The Whittlesey shore line is somewhat irregular and broken throughout the rest of its course in New York, and fades out toward Marilla. The lake reached up the old Cattaraugus valley as far as Gowanda, and doubtless some remnants of its delta may be found about the village. The Erie Railroad station is given as 773 feet, or about 60 or 65 feet under the Whittlesey plane. The extensive sublacustrine delta plain, locally known as the "Four Mile level," will be described later under deltas. The super-Whittlesey levels about Gowanda, formed by the third stage of Cattaraugus waters, have been described under local glacial lakes [p. 38].

North of Gowanda the Whittlesey shore is a cut cliff along the west side of the State Asylum plateau, facing the Four Mile level which was the lake bottom. The shore line swings around the north point of the plateau and forms a bay north of Collins station. In the return curve it crosses the Collins-Lawtons road about 50 rods north of the residence of Mr B. W. Law, which stands on a broad spit lobe. The altitude here is 839 feet, taking Collins station as 861. After crossing to west of four-corners and then curving sharply up the valley of a branch of Clear creek the beach returns to the east side of the road leading to Lawtons, and for 3 miles it lies along the east side of the road in the form of weak bars and cliffs. At the Shirley road it makes a sharp curve to west of the corners around a point of delta and then runs parallel with the railroad through the east edge of North Collins.

Lying west of the stretch of Whittlesey shore described above is an outlier of rock 3 miles long and half as wide which formed an island in the lake. At the south end is a strong bar and spit on which stands the Indian Council House and village, $1\frac{1}{2}$ miles west of Lawtons. Strong cliffs or bars lie along the west side of the island, where the full force of the Whittlesey waves was felt. All about the north end of the island, which is 2 miles west of North Collins, the shore features are strong and conspicuous, forming a ridge under the road on the west side, and bars and cliffs just above the highways on the north and east sides.

The Warren shores extend up the Cattaraugus embayment as far as Versailles, as already stated. On the north side of the creek the shore has not been traced, but it appears west of Fenton and south of Brant in four broad sand bars running northeast and southwest across the highways at Brant. These are nearly of the same hight, the westerly one on the curving margin of the sand plain seeming the stronger, lying along the 760 contour of the map. These bars are lower Warren, and lie on the western edge of a great detrital plain which seems to have buried the morainal surface, since the lower ground contiguous on the west is a pronounced moraine [*see* p 13].

The beach crosses the east and west road at the creek, east of Brant, and extends northeast 3 miles to Pontiac. The higher Warren lies 1¾ miles east of Brant, on the east side of four-corners, and follows along the north and south road for a mile, then curves around to the east as a cliff in dark shale at the north end of the Whittlesey island described above. Farther to the southeast the lower Warren forms a bar at the four-corners 1 mile west of Collins, and near the Whittlesey shore. On the road leading north from this bar at the road corners are several bars at lower levels, the lowest along the south side of the east and west Townline road, and about 15 feet lower than the higher Warren.

The village of North Collins stands on a gravel plain some 20 or 25 feet under the Whittlesey level, which plain is probably a filling dropped in the lake by glacial drainage from the northeast past Eden; and the complex of bars westward as far as Brant is the work of waves on the extended and sloping delta plain. The altitudes at North Collins are generalized as follows: Whittlesey 850, higher Warren 800, lower Warren 780, using the railroad at the village as 830 feet. The locality is one of special interest as it has an unusual development of glacial lake features, which will repay careful study and precise measuring.

North Collins to Hamburg. From North Collins to a mile beyond Eden, a distance of 6 miles, the Whittlesey shore lies along the east side of the highway and railroad mainly as a cliff, although the cliffs may have been partly formed by glacial stream cutting. Beyond North Collins for 2 miles it exists as a bar, and shows well where it crosses the east and west road, 2 miles from the village.

Beyond Eden village the Whittlesey beach swings northeast, and east of the south branch of Eighteenmile creek it forms a bar along the crooked road 1½ miles southeast of Eden Valley, and as a cliff it curves around the high ground and crosses the roads lead-

Plate 20

Delta plain $2\frac{1}{2}$ miles southwest of Fredonia. Looking east across the plain to the Whittlesey beach in the background [compare pl. 21].

ing southeast and east. Northeast of Eden Valley 1½ miles the shore line lies around an island hill, with a spit on the southeast. On the east side of the middle branch of Eighteenmile creek the shore is a conspicuous cliff, curving in a half circle, convex to north, about the high ground on which lies the junction of three towns, and it ends as a bar spit northeast of four-corners, near the main creek.

The higher Warren carries the main highway all the way from North Collins to Hamburg, about 10 miles. A mile north of North Collins a good bar appears on the east side of the road, but from there to Eden, a stretch of 4 miles, the beach is chiefly a cliff in shale with a smooth slope on the west and no lower Warren level is represented. From Eden to Hamburg, through Eden Valley, the beach consists of heavy ridges or bars except where cut by streams.

The lower Warren features are represented on the plain west of Eden and Eden Valley by a complex of bars and sand knolls, some of the stronger bars being followed by the highways. The area is sandy and seems to have been spread with the finer detritus carried into Lake Whittlesey by the glacial drainage from the northeast. The bars and spits which have been noted from the roads are indicated on the map, plate 4. The road winding westward from Eden follows a series of overlapping bars which together form a broad low ridge. Taking the railroad at Eden at 788 feet the upper Warren level in the village is 802 feet. At Eden Valley a good bar close to the railroad station is 5 feet higher than the latter, or 783 feet, and is the lower Warren, while the upper Warren at the village east of the creek is about 800 feet. The bars and spits on the plain are at various low levels and decline westward. They were probably formed by the agitation of the waters offshore, and partly during the subsidence of the Warren waters at the extinction of the lake.

Hamburg stands on the western edge of a delta built in Whittlesey waters by glacial drainage from the northeast and later in Lake Warren by Eighteenmile creek. Running northeast and southwest across the plain is a frontal bar which supports the main streets. In the southwest part of the village the bar has an altitude of 807 feet, using the railroad as 789 feet. This is a precise elevation for the upper Warren.

Hamburg to Spring Brook (Cazenovia valley). In this section the Whittlesey shore line is discontinuous and the fragments are not wholly located. Up the valley of Eighteenmile creek the shore is a cliff north of North Boston along the east side of the highway.

Chiefly as a cliff it follows for about 3 miles along the roads leading north and then northeast. Newton cemetery is located on a gravel bar by a small creek. At the second three-corners the beach is a good bar with a stream-cut bank on the southeast.

At the four-corners, 1 mile south of Dewell's five-corners or 2 miles south of Orchard Park, the steep bluff shown in plate 12 was probably washed by Whittlesey waves, though primarily formed by river work. North of this bluff and south of the five-corners is a hill which was an island in the Whittlesey lake.

Leverett makes the Whittlesey beach cross the moraine at Orchard Park and follow along its north face [*see his* pl. XXV]. This is a mistake, for the Hamburg moraine was laved by Warren waters along its entire north face from Hamburg to Alden, and the moraine covers all the area between the Whittlesey and Warren shores. The Whittlesey beach is an irregular line winding through the moraine from 1 to 2 miles south of the Warren shore.

Orchard Park is below the Whittlesey, which is represented by bars at 880 feet, crowning the cemetery ridge east of the village and another ridge farther northeast.

Between here and Cazenovia creek no good features are noted, but the shore lies around the north face of a large hill west of the creek with the two ends of the half circle lying across the east and west "Mile Strip" road. On the east side of the creek the Whittlesey bars are more continuous, as will be noted in the next section.

Hamburg stands on the upper Warren bars with altitude of 807 feet. The lower Warren is conspicuous, forming heavy bars carrying ridge roads west and north of the village, and with altitudes 792, 789 feet and declining. The strong upper Warren bars are followed by the highway leading northeast to Abbotts Corners (Armor). At the four-corners south of the fair-grounds and 1½ miles northeast of the village the beach is a series of parallel bars which unite toward Armor.

The most extended and continuous ridge of the lower Warren series between Brant and Spring Brook is the bar called "Coopers ridge" which supports the road leading west from Hamburg to Lake Erie. The bar extends west about 4 miles, nearly to Wier's brick works, south of Wanakah station. The head of the ridge is about 790 feet, or 17 feet under the upper Warren, but the bar gradually declines westward until it is lost in the silt plain at about 750 feet altitude. Like the lower bars at Eden and Eden Valley this long bar projects away from the Warren shore out into the lake, with falling altitude.

Plate 21

West edge of delta plain built in Lake Whittlesey. View 2½ miles southwest of Fredonia. Looking southeast from Warren lake bottom.

Branching from the Cooper ridge near its head is a slightly higher bar, 793 feet, swinging northeast across the railroad to the north-leading road, and then lying parallel with the latter road. One half mile farther northwest, at three-corners, another good bar occurs across the road and carrying the ridge road which leads northwest, crossing the railroad and electric line. After supporting the road for a mile the bar swings away to the southeast and passes across the Erie county fair grounds. The east entrance to the enclosure of the fair grounds is on this lower Warren bar, which curving around to the northeast lies on the north-facing slope of the strong upper Warren and about 20 feet lower. This lower Warren is a well defined bar on the road leading northwest from Armor, only about 10 feet under the upper Warren at the corners. On the north road the lower Warren supports the village cemetery and then passes to the east side of the road and lies along the flank of the upper Warren, with a vertical interval of 10 to 15 feet. For $2\frac{1}{2}$ miles from here, to north of Orchard Park, the upper Warren is mainly an irregular wave-cut cliff in the north border of the moraine, while the lower Warren consists of broken ridges and spits. North of Orchard Park, toward Websters Corners, the highway lies between the Warren bars, the upper and double ridge on the east side being about 15 feet higher.

At Websters four-corners the lower Warren forms a great recurved hook, convex northwest, which crosses the east and west road $\frac{1}{2}$ mile west of the corners, and curving back towards the corners makes nearly a circle. Another bar lies farther west across the road, and another east of the corners on the north side of the road.

From Websters Corners to Spring Brook the Warren shore is irregular but fairly shown on the map with reference to the roads as broken and eroded bars and cliffs, along the face of the moraine. The Whittlesey lies landward in the moraine. The definite north edge of the moraine is an effect of the wave erosion.

Spring Brook to West Alden. In this section the Whittlesey shore line terminates.

On the east side of Cazenovia creek and south of Spring Brook the Whittlesey shore lies along the angling roads as distinct cliffs or bars, as shown in the map. They follow the 900 foot contour, lying at about 905 feet. A good display is found at the three-corners, 1 mile southeast of Spring Brook, where all three roads lie on the bars with a spit lobe forming the knoll on the northwest road. South of Elma Center station, $\frac{3}{4}$ mile, the shore lies around the north point of a hill, crossing the road under the houses of Henry

Klem and Mrs John Krohn. It is here 70 to 75 feet over the lower Warren at Elma Center station. Beyond an embayment on the east, reaching up the hollow followed by the Pennsylvania Railroad, it again forms a curve about the north side of another hill, and crosses the road north of three-corners, on the brow of the hill under the house of Mrs Clark. The beach altitude here is 905 feet, or 70 feet over the lower Warren bars at Steitz corners, 1 mile north. These latest formed fragments of the Whittlesey beach are inconspicuous bars and would not be seen without search, but they can be readily found by their relationship in altitude to the Warren.

It is an important and interesting fact that the vertical interval of about 70 feet between the lower Warren and the Whittlesey remains the same throughout the whole extent of the Whittlesey shore in New York.

These are the most easterly features which can with confidence be attributed to Whittlesey waters. A good example of a glacial outwash gravel plain 1 mile east of Marilla, at 915 feet is perhaps not too high for the Whittlesey plane. We here take our leave of the expiring Lake Whittlesey.

In this section the Warren shore features become strong and continuous. The village of Spring Brook lies on the Warren beach. About 1 mile east of Spring Brook the higher Warren holds the Tillou cemetery on the south side of the road, while on the north side the conspicuous inferior Warren is 12 feet lower. Eastward where the road crosses a creek the lower Warren is a strong bar 40 rods north of the road, while east of the gully the road is on the higher Warren. The two strong bars continue northeastward in excellent form to Elma Center Station, where they divide to make a close set series of gravel ridges, crosscut by the railroad. The station lies in the cut in the line of the lowest (north) bar, which is 835 feet altitude, taking the railroad as 824 feet. The highest bar of the series is only 8 to 10 feet higher, but a cliff shows higher wave-work.

Northeast, past the Lutheran church and cemetery, to Steitz corners (or Bullis corners), a distance of nearly 2 miles, the Warren beach is an excellent display of broad bars of fine gravel. At the church the beach includes four bars in a width of $\frac{1}{4}$ mile, and is essentially a gravel plain with rolling surface. At Steitz corners the series of several bars lie on the delta built in lake Warren by Buffalo creek. West of the corners the delta plain has an abrupt front 20 feet high, facing the low swampy lake bottom plain. The altitude of the lower Warren at Steitz corners is 835 feet.

South from Steitz Corners five higher bars appear, crossing the road, the highest lying about ½ mile south and 17 feet above the bar at the station, or 852 feet.

One half mile east of Steitz Corners, on the combined delta of Buffalo and Little Buffalo creeks, the upper Warren appears as a good gravel ridge lying across the road just east of the four-corners, on the west face of the moraine, with altitude of 846 feet. The lower Warren occurs as two bars obliquely crossing the north-leading road and with a pronounced hollow between them. East of Little Buffalo creek the several bars occur in strength, crossing the highways obliquely.

Northwest of Marilla on the north and south Townline road the beach is represented by four strong bars distributed through over a mile and vertically spaced through 20 to 25 feet. The Zion's church at the four-corners stands between the two middle bars. The two bars north of the corners are about 2 feet higher than the corners, or 832 feet. The highest bar is ½ mile south on the north bluff of the Little Buffalo creek, near three-corners, and has an altitude of about 855 feet.

On the road leading east from the four-corners at Zion's church the highest bar is contoured as 860 feet. The beach holds steadily the northeast direction all the way to West Alden but with variation in the number and strength of the bars. On the north and south road passing through Marilla three strong bars lie north of the four-corners, the lowest being at the angle of the road under a schoolhouse, with a low swamp lakeward, and with altitude by the contour of 840 feet. The middle bar is about 11 feet higher.

Continuing northeastward the bars cover another four-corners south of Cayuga creek, the highest bar passing to north of the east-leading road.

North of Cayuga creek, at West Alden and Alden, is an unusual display of bar ridges. On the West Alden section seven strong ridges are found, the lowest under three-corners at 830 feet, the highest over a mile landward at over 860 feet. The West Alden corners lie on the fourth ridge with altitude 845 feet.

West Alden to Fargo station; to Crittenden. At West Alden the Warren bars divide into two sets, the southerly and higher bars passing northeast through Alden and on toward Fargo station, terminating between the station and the Countyline road, while the lower series leads northward by Alden Center to Crittenden and continues as the Warren shore through central New York.

Alden lies on a delta built by glacial drainage from the east and four bars pass northeast through the village, the higher one being

860 feet. Two of these bars continue northeast nearly 3 miles and end ½ mile beyond the Countyline road, on the Fargo delta. These are broad ridges composed of the shale detritus supplied by the glacial drainage of the channels along the line of the Delaware, Lackawanna & Western Railroad. They are of nearly the same hight, 865 and 863 feet according to the map altitudes. The Countyline cemetery is located on the northern ridge.

The splitting of the Warren shore into two series of bars might suggest a dual lake history, or at least two stages of the Warren waters. The phenomena have the same origin and significance as the multiplicity and large vertical range of the bars on all the shore to the westward, considered along with the greater simplicity of the shore features from here eastward. The complex problem of the lake records and history will be considered later [*see* p. 64].

The difference in altitude between the Alden-Fargo and the Crittenden bars is very slight, though the northward uplift of the land surface should have some credit for the present equality in altitude. The Countyline cemetery bar is 863 feet, the Crittenden bars are 857-860 feet. In the 11.5 miles from Elma Center station to Crittenden the uplift is not over 25 feet, or a trifle over 2 feet a mile in the direction of the shore. Between the cemetery and Crittenden the uplift can not be over 6 feet, which makes an original difference of about 10 feet. It would seem that the element of altitude was not a strong factor in the case. The writer regards the separation of the beaches as largely an accident of the topography, along with some falling of lake level while the ice front was in this locality.

Another noteworthy feature connected with the strong bars all the way from Steitz corners to the end of the Alden series, about 9 miles, is the occurrence of pronounced swamp hollows lying between the bars. These sometimes resemble drainage channels and in a few cases are now occupied by brooks. Emphatic hollows between beach ridges are not uncommonly seen for short distances, but the writer has nowhere else found them so strong and persistent. The location of the hollows as between lower or higher bars is indifferent.

The northern series of bars swing northerly at West Alden and lie on the east side of the highway at Alden Center, where they are broad flat ridges of shale detritus on the banks of Ellicott creek. The bending road follows the bars to the West Alden station of the Lackawanna Railroad. At this point a moraine ridge stands inclosed in the shore deposits. North of the railroad and the moraine area four parallel bars lie oblique to the north and south road. The lowest, with altitude 847 feet, lies under the highway north of the overhead crossing of the Lehigh Valley Railroad and its north end swings around east as a recurved hook. The higher bar lies ½ mile east, and is occupied north of the Lehigh Railroad by the Crittenden highway. Its altitude at the Lehigh crossing is 857 feet. From this point north for about 2 miles the beach is a single heavy bar, supporting the village of Crittenden. North of the village the map gives the beach altitude as 860 feet.

A mile northeast of Crittenden the beach splits into a diverging or fan-shaped series of bars with nearly equal altitude, lying on the delta built in Lake Warren by the latest glacial drainage from the east, along the track of the present Murder creek. The southernmost bar lies along the north side of an east and west road; the most northern bar pursues a northeast course and supports a road for a mile, approaching Pembroke. The lakeward side of the shore in this stretch of 8 miles is a steep slope facing low, swampy ground.

The village of Pembroke lies on a shore or delta deposit of Murder creek. Northeast from Pembroke for 1½ miles the shore features are too weak to map, but a good bar occurs a mile northeast of Pembroke station under a north and south road, with its south end curving east. Northeast of this bar and at four-corners south of Indian Falls a bar is found supporting a cemetery, with elevation of 869 feet.

Up to Pembroke the Warren shore has been found in the form of heavy bars, with direct course, and for long stretches has developed to maturity. From Pembroke and Indian Falls eastward through central New York the bars are usually faint and the shore line is weak and very immature. The Warren shore west of Crittenden must have felt the wave work several times longer than the shoreline to the east of Indian Falls. The conclusion is that the glacier front rested for a long time on the high ground north and west of Batavia, and the Warren waters were then dammed off from the land to the east. Other glacial waters were, however, doing their work in that region. When the ice finally gave way and permitted the Warren waters to enter central New York, it was but a relatively short time before they were drained down by eastward escape and the Lake Warren extinguished.

From Indian Falls east to near Leroy the Warren shore lies along the brow of the scarp of Onondaga limestone which forms the high ground from northwest to northeast of Batavia. The scarp was probably the result of long eras of preglacial weathering with some modification by the ice rubbing. Through considerable stretches the Warren beach lies on the top of the ledges and is marked by the deposits of angular chert gravel, which the farmers call "chawed rock." Such is the case from Indian Falls eastward for 4 miles. In some stretches the shore is a limestone cliff, some striking examples of which are seen south of South Alabama (east and west of "Pond" survey station, northeast and east of Batavia, and west of Morganville).

In 1896 the Warren shore was traced in a general way, chiefly to prove its continuity and altitudes, from Crittenden around into the Genesee valley. The topographic maps were then not available and the plotting was done with reference to the roads. The bars are so weak and discontinuous that mapping is difficult and unsatisfactory even with the help of the topographic sheets.

As the province of this treatise is only the portion of the Erie basin lying in New York we will leave the Warren shore at its extreme north point, the limestone ledge at Pond station, 1 mile south of South Alabama, where its altitude is 887 feet.

Discussion of Whittlesey and Warren levels

The duality or multiplicity of the bars on the Warren shore, giving occasion for different names and the conception of two distinct lake levels, has been stated on page 45. Having now before the reader the detailed description of the shore features we are better prepared to discuss the causes and significance of their complexity and of the lake history.

The difference in complexity between the Whittlesey and Warren beaches is very marked. In all the Erie basin the Whittlesey beach is commonly a single ridge, which doubtless represents the wave-work at the surface and margin of the lake, while on the same slope the Warren shore, about 45 feet lower, has several ridges ranging through 10 to 30 feet vertically. However, the Warren shore is commonly more simple from Crittenden eastward, and the interesting problem discussed in this chapter is the cause of Warren complexity west of Crittenden as compared with the relative simplicity eastward.

The following table shows the vertical spacing of the bars, both Whittlesey and Warren, at many points along the shore. The figures are not precise, some being by aneroid, but all are carefully checked. Doubtful figures have been omitted from the table, and the errors are not greater than is the local variation in the individual bars. The tendency to read the aneroid in multiples of 5 feet is shown in the table, and the errors are certainly within that amount. A few accurate beach altitudes are included in the table.

TABLE OF VERTICAL SPACING BETWEEN WHITTLESEY AND WARREN BARS

LOCALITY	Interval in feet between Whittlesey bar and the highest strong Warren bar	Upper Warren altitudes	Interval in feet between higher and lower Warren bars	Lower Warren altitudes	Total range
State Line	44	....	25+24	....	69 +
2 m. w. of Ripley	48	....	19	....	67
Ripley	....	....	....	....	66?
1 m. e. of Ripley	35	....	31	....	66
½ m. e. of Forsyth	32	....	16+14	....	62
1½ m. e. of Forsyth	....	....	....	....	68
1 m. s.w. of Westfield	45	....	27	....	72
Westfield	42	753	28+7	....	70+
½ m. w. of West Portland	49	....	29	....	78
West Portland (brick church)	40	....	38	....	78
Brocton	45	....	....	....	....
2 m. e. of Lamberton	45	....	25	....	70
Fredonia	50	770	20	....	70
n.e. of Fredonia	45	....	25	....	70
2 m. n.e. of Fredonia	47	....	25	....	72
2½ m. n.e. of Fredonia	45	....	25	....	70
Sheridan	59	766	11	....	70
2 m. e. of Sheridan	40	....	30	....	70
South of Silver Creek	55	....	15+5	....	70+
Hanover Center	48	....	14+8	....	70
1½ m. n. e. of Hanover Center	50	....	? + ?=23	....	73
3 m. e by n. from Hanover Center	60	....	13	....	73
3½ m. e. of Hanover Center	50	....	20	....	70
North Collins	50	....	20	....	70
1 m. w. of North Collins	50	....	15	....	65
2 m. w. of North Collins	50	....	25	....	75
Eden	....	802	....	....	....
Eden Valley	....	....	16	784	....
Hamburg	....	807	17	790	....
2 m. n. e. of Hamburg (fair grounds)	....	....	20	....	....
Armor	....	....	15?	....	....
Websters Corners	....	....	15	....	....
Tillou Cemetery (1 m. n.e. of Spring Brook)	....	....	12	....	....
Elma Center station	....	....	....	835	70
Steitz corners	53	852	17	835	70
Zion's church (2 m. n.w. of Marilla)	....	860	....	832	....
West Alden	....	....	....	830	....
Alden	....	867	....	....	....
Countyline cemetery (2 m. n.e. of Alden)	....	865	....	....	....
Crittenden	....	....	....	858	....
Indian Falls	....	....	....	869	....
Pond station (s. of South Alabama)	....	....	....	887	....

The above table shows that the vertical interval between the Whittlesey beach and the highest Warren is commonly about 45 to 50 feet. The interval between the highest and the lowest Warren is relatively more variable, but the two intervals added together generally make a total range of about 70 feet between the Whittlesey and the lowest good Warren bar.

The vertical range of the Warren bars is thought to be greater than is usually possible for strong offshore or submerged bars in a body of fresh water having a steady surface or only a single level. That the higher and stronger bars represent a lake level of long endurance can not be doubted. They represent a water level, and the problem before us relates to a second or lower lake surface in explanation of the lower bars. The following suggestions are proposed.

1 The lower and multiple bars might be the effect of very slowly falling waters, with or without long pauses, produced by the down cutting of the lake outlet.

2 The vertical spacing might be due to progressive differential uplift or tilting of the land during the life of the lake.

3 The lower bars long ago suggested a second distinct lake level, and the names "Arkona" and "Forest" have been used by some authors for the upper and lower bars which in this writing are collectively called Warren.

4 The lower bars may, at least in part, represent the offshore, submerged sand ridges formed by the drag of heavy waves along with the transporting effect of shore currents.

In discussing the above explanations of the multiple bars the following facts should be considered:

a The practical absence of inferior or secondary bars of much strength along the Whittlesey shore. From the Whittlesey ridge down through the 40 to 50 feet to the upper Warren level, bar ridges are commonly wanting.

b The multiple Warren bars occur in strongest development on delta tracts or where abundant detrital material was available for ridge construction: for example, at State Line, Portland, Hanover Center, Brant, Eden, Hamburg, Elma and West Alden.

c Eastward from Crittenden or well beyond the Whittlesey area the Warren shore becomes simple and resembles the Whittlesey.

d In New York the Whittlesey was inaugurated as a primitive, invading lake, on the land surface abandoned by the ice sheet. The Warren water, on the other hand, was not inaugurated wholly by the invasion of a new body of water, but as far east as Marilla it was produced by the lowering of Lake Whittlesey or other waters.

e The complex Warren shore lies on a plain of slight incline and low relief which was the silted and filled lake bottom of the preceding Whittlesey, while the earlier and simple Whittlesey lies on the higher and steeper slope. From State Line to Silver Creek the land slope is uniform with no very heavy deltas or detrital fillings, and the Warren bars are close set and parallel. On the plains between Silver Creek and Hamburg, flat and silted, the bars are scattered. From Hamburg to Alden the bars are multiple but strong and compact. The divergence of the bars at West Alden into two sets seems to be an accident of the topography and the tributary ice border drainage. From Crittenden eastward the shore has more simplicity, as stated above.

f Multiple bars are regarded as the characteristic product of long-continued work of waves and shore currents in waters of comparatively steady or slowly falling level, and are consequently found in greater development along older and maturer shores. It is uncertain to what extent submerged bars can form in water which has very changeable or rising level, but such conditions are believed to be unfavorable.

g The depth of effective wave action in fresh waters has not been determined precisely, but it has been regarded as not over 30 feet. Supposing the Warren bars to represent a single level, the table of vertical spacing would indicate that the depth of bar construction could not commonly exceed 25 feet.

h A young outlet of insufficient capacity might involve considerable fluctuation of lake level by the damming of high waters. This would apply much more to Whittlesey than to Warren, because the Warren outlet had been previously the ultimate outlet (from Lake Saginaw) during all the life of Whittlesey.

With the above facts and principles before us we will now discuss the suggested explanations for the lower Warren bars.

1 The multiple Warren bars could not have been the product of lowering waters during the extinguishment of the lake or they would not be so uniformly limited to the belt covered by 70 feet under the Whittlesey plane, since the waters fell through the entire vertical distance to the present Erie. The bar phenomena which actually were produced by the subsiding or hypo-Warren waters are described below and we find that they are scattering and relatively few. Even those of the Dana level are disappointing, though generally recognizable.

A peculiarity of the strongest bars which belong to the phase of the falling waters is their direction transverse to the shore. Examples are Cooper ridge at Hamburg, the ridges at Eden and North Evans, as well as the Dana ridge at Evans. Instead of being parallel to the shore like normal shore bars they are directed into the lake, and decline in hight. The mechanics of the constructional operation is not clear, but the peculiar result in the bar form is evident.

It is again pertinent to repeat that the Whittlesey shore has practically no inferior bars, yet the lake was a large water body with twice the area of the present Erie, and the broad surface could not have lowered suddenly.

The objections to formation of bars at lower levels by falling waters does not apply with force to extremely slow subsidence, and it seems likely that such a series as the Warren bars, strong and irregularly spaced, might well be produced by the very slow falling of the surface due to the down cutting of the lake outlet, or to the extremely slow tilting of the land due to unequal uplift. This will be discussed later.

2 The splitting of the bars, with increasing vertical spacing, due to differential uplift or tilting of the land during the life of the lake is theoretically probable. The New York area lies north of the isobase or line of equal tilting drawn through the Warren outlet in Michigan, and any northward uplift or canting of the land during the existence of the lake should produce a separation of the beaches. With such origin the series of bars should manifest some divergence among themselves, or a range of vertical spacing increasing northward. Such is not readily apparent, for the vertical relation of the Whittlesey and Warren bars remains nearly the same through the 75 miles of shore line, though in that distance the whole double shore rises 122 feet. However, there are complexities in the study of shore deformation and bar divergence, and a small amount of divergence in spacing would be difficult to measure.

The diagram [fig. 4] is intended to indicate some of the difficulties in the study of deformation of shores formed in front of receding ice margins. Leverett has shown that west of New York the deformation of the shores is very slight. In New York there is an increasing deformation [*see* p. 77] as we pass northeastward, so that the uplift toward the termination of the Whittlesey beach at Marilla is 2 feet a mile. Taylor has concluded from a study of the features in the critical district of the Whittlesey outlet that the Whittlesey beach was produced in slowly rising waters. If this is the fact it would neutralize the effects of slight land warping.

West of the Marilla-Alden district the Warren bars were not formed at the ice front but were produced synchronously throughout the entire extent by the falling from the Whittlesey level. These bars should be continuous and should record among themselves all the divergence due to land tilting, but this effect is so small in the area of New York that it must be obscured by the constructional irregularity of the bars.

East of the Marilla district the Warren waters laved the ice front and from there eastward the bars should have the fragmental character due to a shore line extending toward receding ice while the land was tilting. But here the life of the lake was briefer and eastward the bars are not sufficiently developed to yield any reliable data.

The diagram shows that the bars formed in front of the receding ice margin are theoretically not continuous or in the same plane, but that they represent successively lower planes. Consequently our measure of deformation on such shores fails to show the full amount.

The above may give some idea of the quantitative difficulty in the study. The series of Whittlesey-Warren bars seem to retain a practically uniform relation and it seems quite certain that most of the land tilting which has occurred took place subsequent to Warren time. Nevertheless it seems probable that a small amount of deformation which may have taken place during Warren time helped to produce the multiplicity of bars and the large vertical spacing in New York.

3 The conception of a second water level was the very natural explanation of the considerable vertical range of the Warren bars, specially as in some localities only two conspicuous ridges are found. Objections to this explanation are the decided lack of uniformity in relative position of the lower bars, and the equally de-

Fig. 4 Diagram to illustrate theoretic tilting of shore lines

cided lack of horizontal uniformity and continuity. A lower water level should have been steadier than the superior or original level for the reason that the outlet was more mature and the lake larger in area. The lower Warren bars are sufficiently strong to have great continuity and uniformity of level if their formative conditions had favored it, but no separate or distinct water plane can be selected among the lower Warren bars.

4 The idea that the inferior Warren bars are chiefly the normal product of offshore waterwork in a lake of long life with very slowly falling surface would seem to harmonize the facts of variable altitude, horizontal discontinuity, generally finer material, and as a rule more rounded or flatter summits.

The incomplete data gathered in the table [p.65] indicate that a depth of 25 feet below the upper bar is the limit of effective bar construction. This figure may be reduced by whatever lowering of the surface level is to be allowed, and 5 feet may be taken out for the hight above the water surface of storm bars of coarse material.

The mechanics of the deeper work of the water is not well understood, but theoretically it would appear that the first offshore bar must lie below (in depth) and beyond (in horizontal distance) the zone of action occupied by the heavy waves which build the surface or marginal bar. The vertical distance between the marginal and the nearest submerged bar is greater (within limits) as the horizontal distance is less. It would appear, therefore, that normally a striking vertical interval might lie between a heavy marginal ridge and the first submerged bar, sometimes suggesting two distinct water planes.

It is apparent that the bar elements will vary with several factors: the topography and slope of the bottom, the volume and character of the detritus, the exposure to winds and depth of water, and the effectiveness of shore currents. It is not now possible to apply these principles to the case in hand. The factors in waterwork are so delicately adjusted and (to our sight) so capricious in their operation that they are elusive to study. It is very desirable that an examination of existing lakes and seas should be made with reference to the offshore constructive features. And we specially need criteria for distinguishing phenomena produced in slowly rising water from those produced in slowly falling water.

The absence of inferior bars along the Whittlesey shore may be due to the steeper slope, the more variable and perhaps rising water level, and the brevity of the life of the lake. The last factor is the probable explanation of the simplicity of the Warren shore east of Crittenden.

The multiple Warren bars probably represent only a single lake or a lacustrine unit with some change of level due to land warping and lowering of outlet, the lower bars having been formed as offshore ridges, in waters of long life, supplied with abundant detritus.

Since the above was written Mr Frank B. Taylor has announced the discovery of a complication in the glacial lake history, of which a brief statement has been inserted on page 42. Quoting his words from a letter: "The ice front on the "Thumb" of Michigan retreated in an oscillating manner with marked readvances covering a space of 20 to 25 miles in each readvance, and the Belmore (Whittlesey) and Upper Forest (Warren) beaches each records such a readvance, which raised the lake level."

Taylor's theory is that with the draining down of Lake Maumee the waters continued to fall to the Arkona level where they rested a long time, until a readvance of the ice front again closed the Arkona outlet and forced the lake waters up to the Whittlesey level. In other words, a lake (Arkona) approaching the Warren level existed in time between the Maumee and the Whittlesey, but lower than either.

The vertical intervals between these several lake beaches in Michigan are given by Taylor as follows: Between Whittlesey and upper Arkona, 30 to 31 feet; between upper and middle Arkona, 7 to 8 feet; between middle and lower Arkona, 8 feet, or a range of Arkona bars of 15 to 16 feet; between lower Arkona and Upper Forest, 14 to 17 feet. (It should be noted here that no such vertical relation occurs between any beaches in New York.)

The theory has been held by Taylor that the ice front in the Erie basin oscillated synchronously with that in Michigan, and that the retreat of the ice front was sufficient to allow Arkona waters to extend into central New York. In order to test this theory by the facts the following analysis is given.

Assuming Taylor's interpretation of the glacio-lacustrine history to involve the Erie basin, then one of the three following postulates or some combination of them must apply to the district between Cleveland and Crittenden.

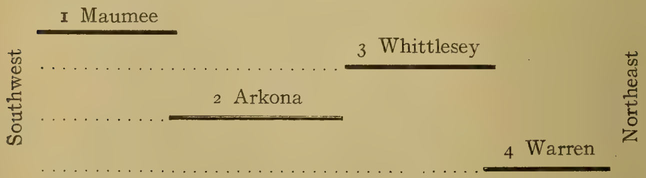
A The ice front stationary. Under this conception the waters of the three lakes, Maumee, Arkona and Whittlesey, would have the same limitation and the beaches would all terminate together at the moraine, and be wanting eastward. The channels of ice border drainage and their deltas would end at the Maumee level.

B The ice front oscillating synchronously with the oscillations on the "Thumb" of Michigan. The Arkona shore would form as far beyond (eastward of) the Maumee limit as the ice front receded in Arkona time. Then the readvance of the ice (oblique to the valley slope) would override and destroy a stretch of the Arkona beach. (If the ice reached the Maumee limit the features would simulate those in "*A*". The full-hight Whittlesey would extend eastward only up to the advanced moraine, or only as far as the undestroyed Arkona. In other words the Arkona and the Whittlesey would have the same eastward limitation. Both the Arkona and the Whittlesey would terminate against a moraine with full force instead of fading out. (Any recession of the ice during the Whittlesey episode would cause some fading of the shore line.)

The ice border drainage in the eastward stretch from the termination of the Maumee shore to the Whittlesey moraine would reach down to the Arkona level, except right at the moraine, where it would reach only to the Whittlesey level. Beyond the moraine, eastward, the glacial drainage would reach down to the Warren level. (There would be no glacial drainage, only land stream drainage, into the Whittlesey waters, except at the readvanced moraine.)

C The ice front continuously receding. The Maumee bars would fade out. The Arkona bars would extend farther eastward and also fade out, but would be modified by the subsequent submergence. The Whittlesey shore line would reach still farther east and fade out.

The ice border drainage in the Maumee territory would reach down only to the Maumee level. Eastward of the Maumee limit the glacial drainage would reach down to the Arkona level as far east as the Arkona shore extended. Farther eastward this drainage would reach down only to the Whittlesey level, as far as that shore extends, beyond which the drainage would reach down to the Warren level. This is expressed in the following diagram, in which heavy lines suggest the limits of glacial drainage.



The following important facts bearing on the three postulates may be restated.

1 Obliquity of ice front. The New York edge of the Erian ice lobe was oblique to the land slope, in consequence of which the

advance or retreat of the ice front involved oblique overriding or uncovering of the slope.

2 Shore lines. The Maumee shore line does not reach into New York, and is said to terminate near Girard, Pa. The Whittlesey beach is a definite and generally simple ridge extending east to near Marilla, or 100 miles farther than the Maumee. The Warren shore comprises a series of multiple ridges or bars as far east as Indian Falls, or 15 miles beyond the Whittlesey. From Indian Falls east it is weaker, broken and simple.

3 Possible Arkona. The only bars which can be regarded as Arkona are the higher ones of the Warren series. But these are not subdued by drowning; they are stronger than the Whittlesey; they are less interrupted and generally stronger than the lower bars; and they extend far beyond the limits of the Whittlesey.

4 Spacing of the beaches. The vertical distance between the Whittlesey and the highest Warren bars is commonly from 45 to 50 feet. The only instance of less spacing is southwest of Westfield, where five sections have given records of intervals 35-40 feet. The vertical intervals between the several Warren bars have no steadiness which would indicate distinct lake levels. The total range of the Warren bars is usually 20–25 feet, the greatest ranges being on deltas, and only two exceptional localities giving more than 25 feet. Some of the best sections, apart from deltas, give ranges of 11-15 feet, with interval between Whittlesey and upper Warren of 55-60 feet. The total range of the entire shore features is about 70-75 feet. The Belmore-Arkona interval in Michigan of 30-31 feet does not exist in New York.

5 Ice border drainage. The glacial drainage followed along the receding ice front, and clearly marks the successive positions of the latter. The streams debouched at the Whittlesey level as far east as the level extends. But beyond the Whittlesey limit, as at Alden, Crittenden, and Fargo, the ice border drainage clearly reached down to the Warren level.

Applying these facts to the three postulates of ice recession the conclusion is that (*A*) and (*B*) are emphatically ruled out, and that (*C*) applies to the New York area only subsequent to Arkona time. It is not doubted that the recession of the ice front may have been unsteady, even in New York, but the practically continuous recession in New York is in best accord with the discovered facts. The Arkona beach does not appear to be represented in New York. The channels and deltas of glacial drainage are clear, definite, unmistakable evidence of the ice limits and of the lake levels. As far east as Marilla the ice border drainage terminated at the Whittlesey level; eastward from this district the glacial drainage is down to the Warren level. It seems certain that the Whittlesey waters lay against the ice front while the latter receded from State Line to Marilla, a distance of 75 miles. The lake phenomena correlating with the ice front oscillation on the "Thumb" of Michigan should be found, if found at all, in the 30 miles of shore line between Girard, Pa. and State Line.

Theoretically it would seem improbable that a great stretch of glacier front, given great lobations by the land depressions, and with different conditions of latitude, climate, snow supply, direction and rate of flow and push or impulse should oscillate synchronously. There is evidence, which will be published in a later writing, that as between the Batavia and the Syracuse districts the motion of the ice front was a seesawing.

It is recognized that glacial and glacial lake history will be found increasingly complex as facts multiply and it is granted that some oscillation of the ice front was likely, but in the New York portion of the Erie basin the facts thus far favor the simpler history as outlined above. The records of ice border drainage and glacial lakes east of the Erie basin, the description of which does not belong in this discussion, seem to prove that no Huron-Erie waters earlier and higher than the lower Warren ever extended east of Crittenden.

Work of the subsiding waters: Lake Dana beaches

The general relation of the waters has already been given [p. 43], and some discussion of the phenomena. We will now briefly describe the features in order from west to east.

The time required for the lowering of the water surface from the Hamburg beach down to the Erie level, 235 feet, must be estimated in centuries if not in thousands of years, and we might expect to find some continuous beaches at intermediate levels. Although all the slopes are subdued and evidently subjected to water erosion and silting up of low places yet the phenomena as a whole are not striking. A few strong bars are found at different levels but no continuous shoreline.

Northwest of Westfield on the edge of the Chautauqua creek delta, at Barcelona, is a good bar on the cliff close to the Erie shore. Its height above the lake is 35 feet, making its altitude 607 feet.

At the north edge of the city of Dunkirk are a good bar on the lake cliff and a series of sand deposits which have been excavated. The bar is 22 feet over Erie, or 594 feet altitude.

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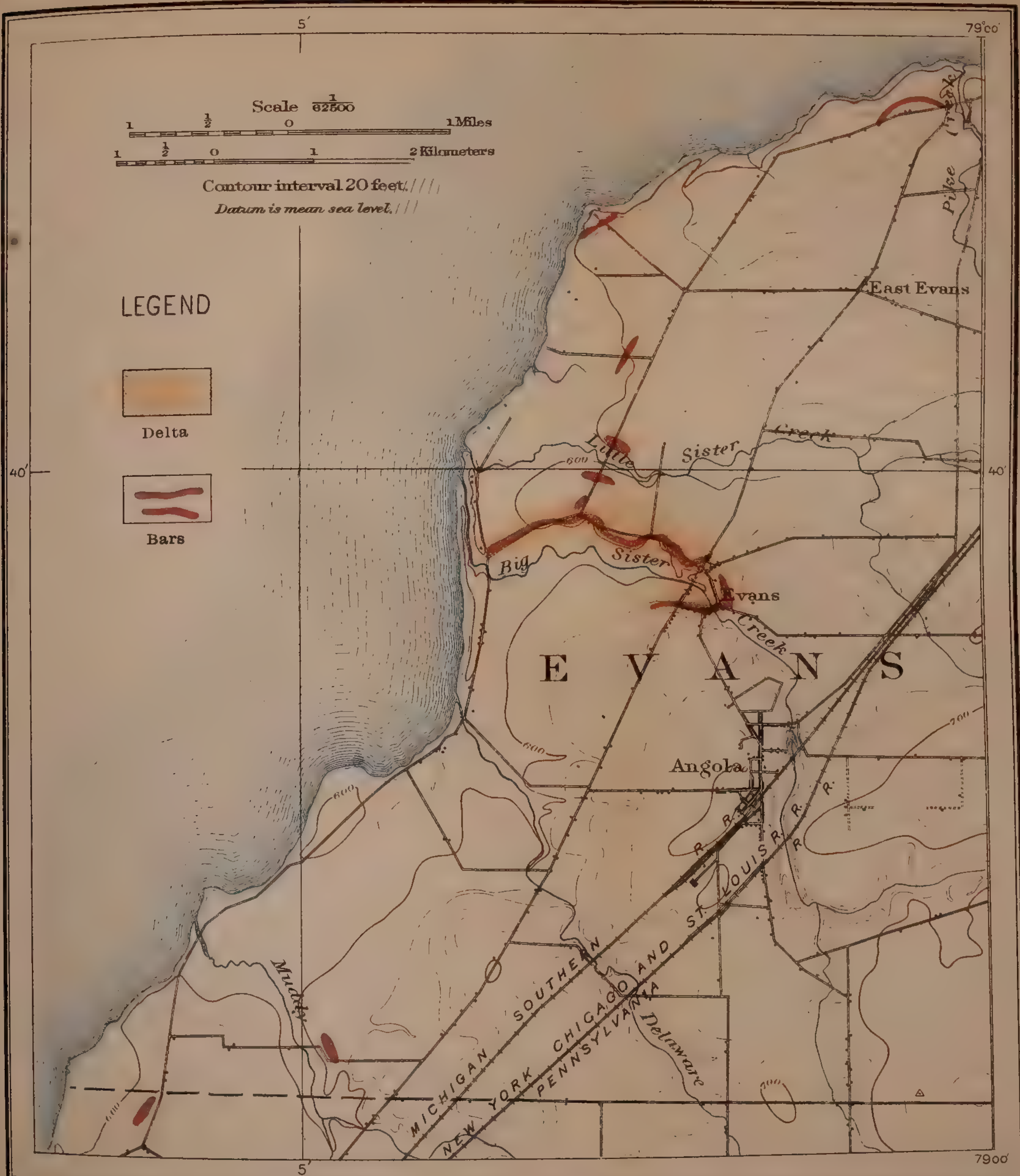

H. L. Fairchild 1905

LAKE DANA BARS IN EVANS

Several bars occur in the vicinity of Silver Creek. The strongest is over a mile southwest of the village on the 720 foot contour, crossing a north and south road. Other shore features lie east and northeast of the village, the highest being on the slope of the hill along the 700 foot contour. The lowest crosses the road leading to Irving at about the 600 foot contour.

North of Farnham 1½ miles a faint bar was seen on the east side of Muddy creek at the angles in the road, coincident with the 600 foot contour.

Conspicuous and extensive sand bars occur at Evans village, north of Angola, on the delta of Big Sister and Little Sister creeks [pl. 22]. The road from Evans to the lake along the north side of the creek lies on these bars for nearly 2 miles. The south street of the village is on a bar that passes west around the slope. In the village the bars are on the 620 foot contour and lower, while the ridge road is on the 600 foot contour. These beaches belong to the Dana level, and other correlating shore features occur northward on the 600–620 foot contours for 4 miles. A strong bar lies north of the road on the west side of Pike creek, near its mouth.

On the plain west of Eden and Eden Valley are extensive sand tracts and bars much below the Warren level. One leading west from Eden carries a curving road for 2 miles and resembles the Cooper ridge at Hamburg. Somewhat similar phenomena occur at Eden Valley Station, and in both cases they have lower Warren level at the eastern end but decline westward.

At North Evans there are strong bars on the delta of Eighteenmile creek, which seem to be over 700 feet altitude. The heaviest bar supports the road leading west from the corners, crossing the railroads and then turning south. Another bar lies north of the creek under the highway.

The strong bar called Cooper ridge, leading west from Hamburg for 4 miles, has been described on page 58. This declines from 790 feet altitude at Hamburg to toward 700 feet at the fading western end. It could not have been wholly formed during the life of Lake Warren at the full Warren level, but apparently represents continuous construction in the falling waters. The ridges at Eden and Eden Valley have similar relationship and genesis.

The east and west ridge at West Seneca, south of Buffalo, supposed by Leverett to be a beach [Monogr. XLI p. 772], is a morainal ridge of till with only a thin and patchy veneer of sand. The other ridges and knolls in the vicinity are also till, including the ridge at Ebenezer which is a continuation of the West Seneca Moraine ridge.

Some of the shore features mentioned above were first noted by

Leverett, who speaks of seeing other evidences of lake work at various levels from 30 to 60 feet over Erie. The writer also has observed many such features that are too faint or uncertain to map.

The most interesting of the hypo-Warren phenomena are those which belong to Lake Dana and which include several of the bars noted above. This lake had a level about 180 feet under Warren. Its shore features are usually weak in western New York, but can be found in favoring situations at the proper level.

At Pine Hill cemetery, in the northeast part of Buffalo, and northward near the city line, are well developed Dana bars, on or over the 700 foot contour [pl. 23]. Northeastward in the town of Alabama and specially in Elba there are spits on nearly all the drumlins which rise above 700 feet. These are often indicated by the numerous gravel pits, and are well displayed north of Elba village.

Through central New York the shore line retains the altitude of about 700 feet, and strong bars occur west of Geneva and at Fayette, east of Seneca lake.

The shore phenomena of Lake Dana should be found throughout the Erie basin at the following altitudes, which are determined by subtracting 180 feet from the Warren altitudes in the corresponding localities.

Altitudes of the Dana plane in the Erie basin

Northeast of Buffalo, at 680 to 690 feet altitude
Buffalo, 660 to 680 feet
South of Buffalo, 630 to 650 feet, or 60–80 feet over Erie
North Evans, 610 to 630 feet, or 40–60 feet over Erie
Evans, 600 to 620 feet, or 40–50 feet over Erie
Irving and Silver Creek, 590 to 610 feet, or 30–40 feet over Erie
Dunkirk, 575 to 595 feet, or up to 25 feet over Erie
Brocton, 575 to 585 feet, or up to 15 feet over Erie
Westfield, 575 feet and under, or at Erie level

By comparison with the above table it will be seen that the bars at North Evans are above the Dana plane, as are all the bars on the lake bottom plain between Hamburg and Brant. But the bars at Evans and north, the lower bars at Silver Creek, and the bars in the north edge of Dunkirk fall in the Dana plane. Many other correlating features will be found by any one who looks for them.

Deformation of the shore lines; land warping

The shore lines of the ancient lakes must have been originally horizontal, but they are not so now. In all the region of the present Great Lakes the northward rise of the beaches is evident

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BULLETIN 106 PLATE 23
PART OF BUFFALO QUADRANGLE

H. L. Fairchild 1905

LAKE DANA BARS NORTHEAST OF BUFFALO

proof of the recent tilting of the land surface. In other sections of the continent land warping may take place without any visible indication of the movement, but in this area of the Great Lakes the deserted shores of the "fossil lakes" supply a delicate test and measurement of the land deformation. The important element in the determination of the fact and of the amount of the deformation is the identity of the shore line or water level. In far separated localities this may be in doubt but in the region described in this writing the continuous tracing of the beaches leaves no uncertainty.

In calculating the amount of deformation in our district some care is necessary, for several reasons: first, because the amount of deformation is small; second, because the shore features are variable; third, possible discontinuity of the water planes [*see* p.70]; fourth, errors in railroad or other data. The best data for fixing the water levels are the crests of the wave-built gravel bars. Undoubtedly these are variable within narrow limits, some having been formed higher than the lake surface and some lower, or submerged. The higher and stronger and coarser of the marginal bars may be safely regarded as overtopping the water by a few (perhaps 5) feet. The lower bars in each cross-section were submerged an uncertain and variable depth and are not reliable data, at least for short distances. The stronger and higher marginal bars are more reliable criteria, and in long distances their variations may be neglected.

By using the Whittlesey and the stronger upper Warren bars in our calculations it is found that the average amount of differential uplift in our district is less than 2 feet a mile, but that the amount of tilting a mile increases as we pass to the northeast. The facts are given quantitatively in the following statement.

DEFORMATION IN NORTHEAST DIRECTION, USING WHITTLESEY BEACHES

From State Line to Marilla, 905—783 feet=122 feet, ÷ 74 miles=1.64 feet rise a mile
State Line to North Collins, 850—783=67 feet, ÷ 48 miles=1.4 feet a mile
State Line to Fredonia, 820—783=37 feet, ÷ 26 miles=1.4 feet a mile
Fredonia to North Collins, 850—820=30 feet, ÷ 22 miles=1.4 feet a mile
North Collins to Marilla, 905—850=55 feet, ÷ 26 miles=2.1 feet a mile

DEFORMATION IN NORTHEAST DIRECTION, USING WARREN BEACHES

State Line to "Pond" Survey station, 887—738=149 feet, ÷ 92.5 miles= 1.61 feet a mile
State Line to north of Marilla, 860—738=122 feet, ÷ 75 miles=1.63 feet a mile
Westfield to "Pond" Survey station, 887—753=134 feet, ÷ 81 miles=1.65 feet a mile
Westfield to Fredonia, 770—753=17 feet, ÷ 15 miles=1.1 feet a mile
Fredonia to Hamburg, 807—770=37 feet, ÷ 31 miles=1.2 feet a mile
Hamburg to Crittenden, 858—807=51 feet, ÷ 24 miles= 2.1 feet a mile
Crittenden to "Pond Survey" station, 887—858=29 feet, ÷ 11 miles=2.6 feet a mile

The increasing rate of uplift as we proceed northeast is clearly shown above, and is in entire harmony with facts in other portions of the basin of the Great Lakes. Leverett has shown [*loc. cit.* p. 755] that for 200 miles west from Ashtabula, O., the Whittlesey shore has practically no variation in altitudes, while east from Ashtabula to New York the uplift is a little less than one foot a mile. Farther northward in the Great Lakes basin the uplift is more rapid than any rate in our district, the gradient east of Lake Ontario being about 6 feet a mile. In the study of the beaches of Lake Iroquois along the north shore of Lake Ontario[1] Professor Coleman finds that the rate of deformation is greatest in a line 20° east of north, and that it increases northward, being 2 feet a mile from Hamilton to York, 3.4 feet a mile from York to near Port Hope, and 4.17 feet a mile from the latter point to West Huntington.

Using Professor Coleman's isobase of west 20° north by east 20° south we find that the Hamilton-York section of the Iroquois shore corresponds in position of deformation with our Crittenden-Pond section of the Warren shore, and that the gradients are 2 and 2.6 feet a mile. The correspondence is sufficiently close to indicate that a large area is involved in the same deformation.

The increase in elevation along these New York shore lines toward the northeast does not represent the full deformation of the area. The direction of greatest uplift of certain beaches about the upper Great Lakes has been found by Taylor to lie along a line 27° east of north, while in central New York it is believed that the line of maximum deformation is more nearly north and south or even west of north by east of south. As the direction of our shore line is about 45° east of north it follows that the maximum deformation of the region is somewhat greater than is indicated by the beaches.

The only north and south direction of any beaches in our district is the Whittlesey shore from Gowanda north to North Collins. In the 5.5 miles south from North Collins to the residence of Mr B. W. Law there is a fall of 11 feet, or at the rate of 2 feet a mile, while the gradient southwest from North Collins to near Smiths Mills is only 1.4 feet a mile. This comparison is only suggestive, as the distances are short and even a slight variation or error would make a disproportionately large difference in the result.

The general uniformity in vertical distance including the several bars of the two shores seems to prove that there was small deformation of tilting of the region during the life of the lakes [*see* p. 65].

[1] Coleman, A. P., The Iroquois Beach in Ontario. Geol. Soc. Am. Bul. 1904. 15: 347-68.

If such canting had been in rapid progress during the existence of the lakes the beaches should draw apart toward the northeast, or in other words the vertical spacing between the earlier and later beaches would increase to the northward. As there is an absence of apparent increase in the spacing the only conclusion is that the deformation of the region, or at least the tilting, has mostly occurred since the extinction of the lakes.

DELTAS AND LAKE PLAINS

These are features which mark the junction of stream and lake, the product of the reaction of the drainage and the standing waters. They are not so conspicuous locally as the beaches, but more widespread, and of great geographic and economic importance. The larger number of the villages of the district under description have had their locations determined by these detrital plains. Along the slopes nearer Lake Erie these gravel plains fronting the beaches are the favored ground for the grape industry which characterizes this part of the State. In the maps the deltas are not fully shown, because the determination of their limits would require careful survey and consume more time than was available.

Deltas of glacial drainage

It was inevitable that all drainage past the ice front should eventually reach standing water and deposit its burden of detritus. This fact explains the origin of a great number of areas of sand and gravel along the shore of the glacial lakes, some of them being of great extent. We will briefly note the more important of these deltas in order from west to east, or in the order of their formation. As far east as Hamburg or East Aurora the deltas of this class are related only to the Whittlesey waters, while from Marilla eastward they correlate only with the Warren waters.

The lake bars or ridges of sand and gravel which may or may not carry "Ridge roads" will be stronger and more developed every way in the localities where detritus from drainage was concentrated. From State Line to Westfield there was no very heavy accumulation of delta material, the largest being in the region of Forsyth, by the latest streams past the ice front from the eastward. All the earlier drainage past the ice escaped on the landward side of the Escarpment moraine and helped to build the delta plain west of State Line.

Westfield. Some part of the material forming the detrital plain on which the village stands must have been contributed by the drainage which cut the channels to the east and northeast.

Portland. We have here a clear example of a delta deposit wholly by glacial drainage. As no large land stream enters here the great detrital plain which is a mile wide at Portland and stretches southwest for 3 miles was entirely the work of glacial rivers, specially the great river which cut the remarkable channel, 8 miles long, heading at Wheelers Gulf 3 miles south of Fredonia.

Lamberton. The sand deposits south of the village and extending toward Brocton were partly built by the lower streams on the slope south of Fredonia.

Laona. The conspicuous terraces on the valley slope west of the village [see p. 21] are clearly the delta of the high-level rivers from the northeast.

Fredonia. The upper part of the valley filling, or south of the town, is partly the product of the later ice drainage on the lower slope east of the town.

Northeast of Fredonia for 3 miles the bars are heavy, the material being swept in by the later drainage on the slopes south of Sheridan.

Forestville. The village stands at the head of a delta which extends 5 miles north, to Silver Creek. The work of the ice drainage and of Walnut creek has been combined here. The capacious channels in the direction of Smiths Mills must have brought in a large volume of detritus, and the ancient valley north of Forestville may be deeply buried.

Gowanda. Some of the detrital filling in the Cattaraugus valley was contributed by the ice drainage on the slope east and south of North Collins.

Brant. The sand area at Brant is so extensive that it suggests a delta deposit, but it is so far removed from the area of drainage that its correlation is not clear. It may in part form an extension of the sand area west of North Collins, and be derived from the drainage past Eden.

Eden. The sand area west and northwest of Eden, and at Eden Valley, would appear to be a delta produced by the streams on the slope south of Hamburg.

Hamburg. The delta plain at Hamburg must have been partly the product of the glacial drainage on the northeast, or south of Orchard Park.

East Aurora. The plain on which the village stands was built in glacial waters, either Whittlesey or earlier local waters, by drainage from the northeast.

East Elma. The plain northeast of the village was built in the glacial waters by the several streams which cut across the moraine from the east. This plain may have been the latest delta filling that was built wholly in Whittlesey waters. Other fillings up the creek toward Porterville and Wales Center had similar origin.

Marilla. The valley filling at Marilla and farther up the valley of Little Buffalo creek were contributed by the glacial drainage from the east, but apparently at the Warren level. This would seem to have been the earliest of the glacial stream deltas to form at Warren level.

Cowlesville. The filling in Cayuga creek valley at and below Cowlesville was carried in by the glacial streams which cut across from the Attica (Tonawanda) valley on the east. This delta was probably at first in local waters held higher than the Warren.

West Alden and Alden. The extensive sand areas forming the bars at the Aldens were laid down in Lake Warren by the glacial overflow from the Tonawanda valley along the line of the Erie Railroad and past Darien.

Fargo. The extensive gravel plain south and southwest of Fargo station on the Delaware, Lackawanna & Western Railroad was wholly deposited by the glacial drainage from the east along the course of the railroad.

Batavia. The plain on which the village stands is a detrital filling and perhaps leveling of morainal gravels in shallow waters of the Tonawanda valley. The drainage was across from the Oatka valley, bringing the overflow of the Genesee valley and other eastern valleys [see p. 31].

Deltas of land-stream drainage; existing streams

The deltas of this class were formed at any or at all levels in the valleys in which were standing waters receiving contributions from land drainage. Theoretically this drainage had no relation to the ice front, and is in continued existence today. But practically the deposits contributed by these land streams can not be always discriminated from the same work in the same locality by the glacial drainage. The two classes of streams were at work together, and when a valley was receiving detritus from both glacial and land drainage we should expect that the bulk from the latter source would be dropped at the head of the bay, or wherever the land stream had its mouth. When the glacial drainage ceased, the land stream had no rival and was at liberty to spread its detritus over all the delta area. We should regard the land stream detritus as constituting the up valley portion and the superficial part of many deltas, with variations depending, however, on the local conditions.

In the Whittlesey territory no glacial drainage fell below the Whittlesey level; therefore all detrital plains below Whittlesey level in the Whittlesey area must correlate with land stream drainage. The same must be true of all deposits below the Warren level everywhere. But the materials of the lower land stream deposits were partly, in many cases, brought within the grasp of the land stream by the glacial drainage.

In most valleys of the region detrital filling occurred at various levels; in local glacial lakes, and at different hights; in Lake Whittlesey; in Lake Warren; and in hypo-Warren waters. We shall note only a few of the more important delta plains which have some relationship to the land stream drainage.

Westfield. The work of Chautauqua creek; in both Whittlesey and Warren waters, and lower

Fredonia. Work of Canadaway creek; in the Shumla lake, and in Whittlesey and Warren

Forestville. Work of Walnut creek; in local glacial lake, and in Whittlesey

Hanover Center. Work of Walnut and Silver creeks; in Lake Warren and lower

Gowanda. Work of Cattaraugus creek; the Fourmile level in Whittlesey, the Versailles in Warren

Pontiac. Work of Big Sister creek; in Warren and hypo-Warren

Evans. Work of Big Sister and Little Sister creeks; in Dana water

Eden Valley. Work of south fork of Eighteenmile creek; in Whittlesey and Warren waters

North Boston. Work of Eighteenmile creek; in Whittlesey water

Hamburg. Work of Eighteenmile creek; in Warren water

North Evans. Work of Eighteenmile creek; in hypo-Warren waters

East Aurora. Work of Cazenovia creek; in local glacial water and Whittlesey

Spring Brook. Work of Cazenovia creek; in Lake Warren

Wales Center. Work of Buffalo creek; in local glacial (Porterville) lake

Steitz Corners. Work of Buffalo creek; in Lake Warren

Marilla. Work of Little Buffalo creek; in Lake Warren

Cowlesville. Work of Cayuga creek; in local glacial lake

West Alden. Work of Cayuga and Ellicott creeks; in Lake Warren

Alden. Work of Ellicott creek; in Lake Warren

Attica. Work of Tonawanda creek; in local glacial (Attica) lake

Batavia. Work of Tonawanda creek; in local glacial waters

Indian Falls. Work of Tonawanda creek; in Lake Warren

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New York State Education Department

New York State Museum

JOHN M. CLARKE, Director

PUBLICATIONS

Packages will be sent prepaid except when distance or weight renders the same impracticable. On 10 or more copies of any one publication 20% discount will be given. Editions printed are only large enough to meet special claims and probable sales. When the sale copies are exhausted, the price for the few reserve copies is advanced to that charged by second-hand booksellers, in order to limit their distribution to cases of special need. Such prices are inclosed in [ ]. All publications are in paper covers, unless binding is specified.

Museum annual reports 1847–date. *All in print to 1892, 50c a volume, 75c in cloth; 1892–date, 75c, cloth.*

These reports are made up of the reports of the Director, Geologist, Paleontologist, Botanist and Entomologist, and museum bulletins and memoirs, issued as advance sections of the reports.

Director's annual reports 1904–date.

These reports cover the reports of the State Geologist and of the State Paleontologist. Bound also with the museum reports of which they form a part.

Report for 1904. 138p. *20c.* Report for 1905. 102p. 23pl. *30c.*

Geologist's annual reports 1881–date. Rep'ts 1, 3–13, 17–date, O; 2, 14–16, Q.

In 1898 the paleontologic work of the State was made distinct from the geologic and was reported separately from 1899–1903. The two departments were reunited in 1904, and are now reported in the Director's report.

The annual reports of the original Natural History Survey, 1837–41, are out of print.

Reports 1–4, 1881–84, were published only in separate form. Of the 5th report 4 pages were reprinted in the 39th museum report, and a supplement to the 6th report was included in the 40th museum report. The 7th and subsequent reports are included in the 41st and following museum reports, except that certain lithographic plates in the 11th report (1891) and 13th (1893) are omitted from the 45th and 47th museum reports.

Separate volumes of the following only are available.

Report	*Price*	*Report*	*Price*	*Report*	*Price*
12 (1892)	$.50	17	$.75	21	$.40
14	.75	18	.75	22	.40
15, 2v.	2	19	.40	23	.45
16	1	20	.50	[*See* Director's annual reports]	

Paleontologist's annual reports 1899–date.

See first note under Geologist's annual reports.

Bound also with museum reports of which they form a part. Reports for 1899 and 1900 may be had for 20c each. Those for 1901–3 were issued as bulletins. In 1904 combined with the Director's report.

Entomologist's annual reports on the injurious and other insects of the State of New York 1882–date.

Reports 3–20 bound also with museum reports 40–46, 48–58 of which they form a part. Since 1898 these reports have been issued as bulletins. Reports 3–4, 17 are out of print, other reports with prices are:

Report	*Price*	*Report*	*Price*	*Report*	*Price*
1	$.50	9	$.25	15 (En 9)	$.15
2	.30	10	.35	16 (" 10)	.25
5	.25	11	.25	17 (" 14)	.30
6	.15	12	.25	18 (" 17)	.20
7	.20	13	.10	19 (" 21)	.15
8	.25	14 (En 5)	.20	20 (" 24)	.40
				21 (" 26)	.25

Reports 2, 8–12 may also be obtained bound separately in cloth at 25c in addition to the price given above.

Botanist's annual reports 1867–date.

Bound also with museum reports 21–date of which they form a part; the first Botanist's report appeared in the 21st museum report and is numbered 21. Reports 21–24, 29, 31–41 were not published separately.

Separate reports for 1871–74, 1876, 1888–96 and 1898 (Botany 3) are out of print. Report for 1897 may be had for 40c; 1899 for 20c; 1900 for 50c. Since 1901 these reports have been issued as bulletins [*see* Bo 5–9].

Descriptions and illustrations of edible, poisonous and unwholesome fungi of New York have also been published in volumes 1 and 3 of the 48th (1894) museum report and in volume 1 of the 49th (1895), 51st (1897), 52d (1898), 54th (1900), 55th (1901), 56th (1902), 57th (1903) and 58th (1904) reports. The descriptions and illustrations of edible and unwholesome species contained in the 49th, 51st and 52d reports have been revised and rearranged, and, combined with others more recently prepared, constitute Museum memoir 4.

Museum bulletins 1887-date. O. *To advance subscribers, $2 a year or $1 a year for division* (1) *geology, economic geology, paleontology, mineralogy; 50c each for divisions* (2) *general zoology, archeology and miscellaneous,* (3) *botany,* (4) *entomology.*

Bulletins are also found with the annual reports of the museum as follows:

Bulletin	*Report*	*Bulletin*	*Report*	*Bulletin*	*Report*	*Bulletin*	*Report*
G 1	48, v.1	Pa 2,3	54, v.3	En 11	54, v.3	Ar 3	52, v.1
2	51, v.1	4	" v.4	12, 13	" v.4	4	54, v.1
3	52, v.1	5, 6	55, v.1	14	55, v.1	5	" v.3
4	54, v.4	7–9	56, v.2	15–18	56, v.3	6	55, v.1
5	56, v.1	10	57, v.1	19	57, v.1, pt 2	7	56, v.4
6	57, v.1	Z 3	53, v.1	20	" v.1 "	8	57, v.2
Eg 5, 6	48, v.1	4	54, v.1	21	" v.1 "	9	" v.2
7	50, v.1	5–7	" v.3	22	" v.1 "	Ms 1, 2	56, v.4
8	53, v.1	8	55, v.1	Bo 3	52, v.1		
9	54, v.2	9	56, v.3	4	53, v.1	*Memoir*	
10	" v.3	10	57, v.1	5	55, v.1	2	49, v.3
11	56, v.1	En 3	48, v.1	6	56, v.4	3, 4	53, v.2
M 2	" v.1	4–6	52, v.1	7	57, v.2	5, 6	57, v.3
3	57, v.1	7–9	53, v.1	Ar 1	50, v.1	7	" v.4
Pa 1	54, v.1	10	54, v.2	2	51, v.1		

The figures in parenthesis in the following list indicate the bulletin's number as a New York State Museum bulletin.

Geology. G1 (14) Kemp, J. F. Geology of Moriah and Westport Townships, Essex Co. N. Y., with notes on the iron mines. 38p. 7pl. 2 maps. Sep. 1895. *10c.*

G2 (19) Merrill, F. J. H. Guide to the Study of the Geological Collections of the New York State Museum. 162p. 119pl. map. Nov. 1898. [*50c*]

G3 (21) Kemp, J. F. Geology of the Lake Placid Region. 24p. 1pl. map. Sep. 1898. *5c.*

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PLATE 1

General map showing ancient lake shores and abandoned stream channels in the New York part of the Erie basin

PLATE 2

Effects of glacial waters, State Line to Sheridan

PLATE 3

Effects of glacial waters, Sheridan to Gowanda

PLATE 4

Effects of glacial waters, Gowanda to Orchard Park

PLATE 5

Work of glacial waters, Orchard Park to Batavia

PLATE 6

Glacial stream channels, Attica to Genesee Valley

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Part of Clinton county. State geol. rep't 19. 1901.

Oyster Bay and Hempstead quadrangles on Long Island. Mus. bul. 48. 1901.

Portions of Clinton and Essex counties. Mus. bul. 52. 1902.

Part of town of Northumberland, Saratoga co. State geol. rep't 21. 1903.

Union Springs, Cayuga county and vicinity. Mus. bul. 69. 1903.

*Olean quadrangle. Mus. bul. 69. 1903. *10c.*

*Becraft Mt with 2 sheets of sections. (Scale 1 in. = ½ m.) Mus. bul. 69. 1903. *20c.*

*Canandaigua-Naples quadrangles. Mus. bul. 63. 1904. *20c.*

*Little Falls quadrangle. Mus. bul. 77. 1905. *15c.*

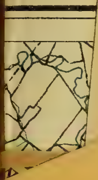
*Watkins-Elmira quadrangles. Mus. bul. 81. 1905. *20c.*

*Tully quadrangle. Mus. bul. 82. 1905. *10c.*

*Salamanca quadrangle. Mus. bul. 80. 1905. *10c.*

*Buffalo quadrangle. Mus. bul. 99. 1906. *10c.*

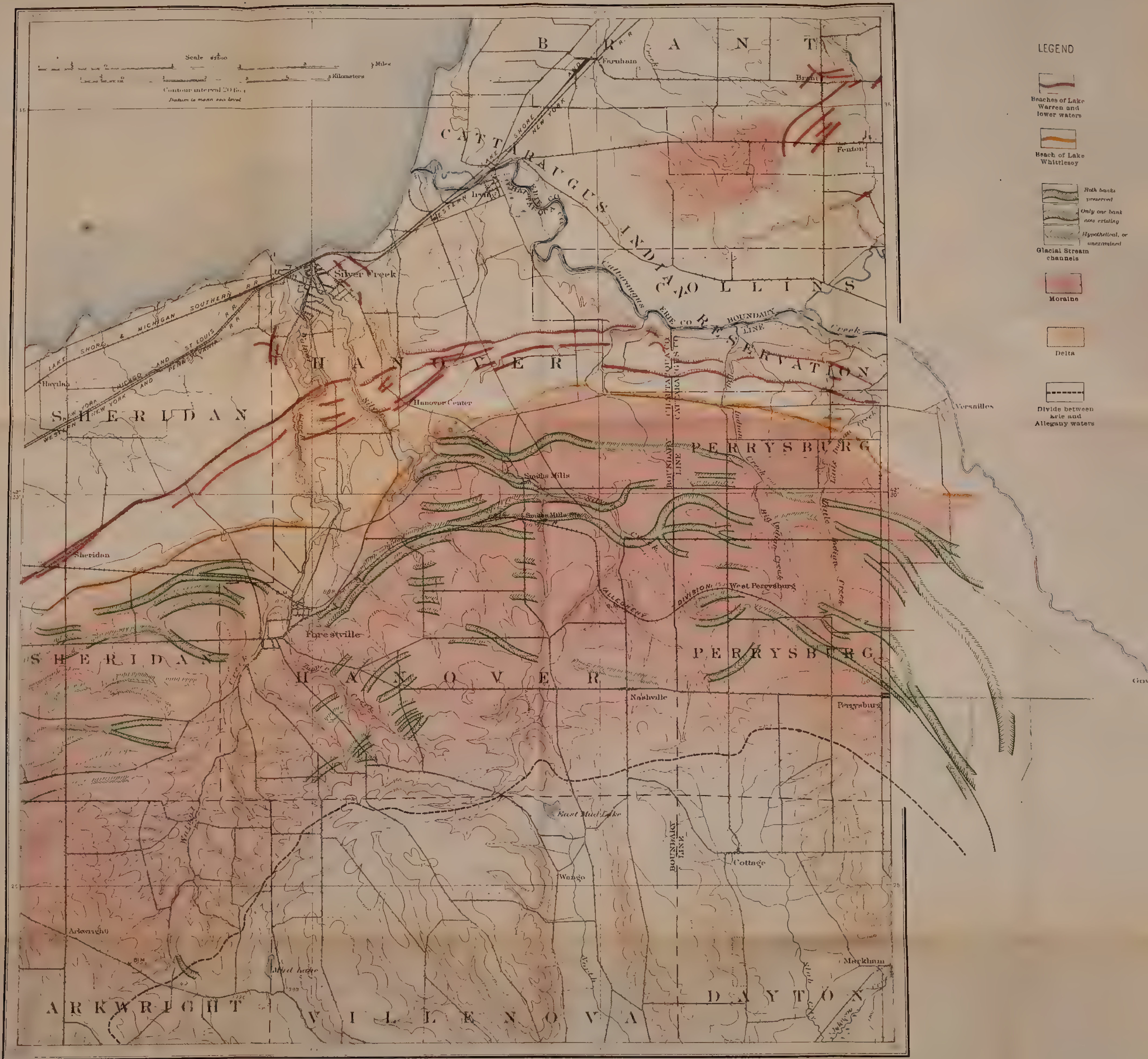
*Penn Yan–Hammondsport quadrangles. Mus. bul. 101. 1906. *20c.*



GENERAL MAP SHOWING ANCIENT LAKE SHORES AND ABANDONED STREAM CHANNELS IN THE NEW YORK PART OF THE ERIE BASIN

H. L. Fairchild 1905

EFFECTS OF GLACIAL WATERS, STATE LINE TO SHERIDAN

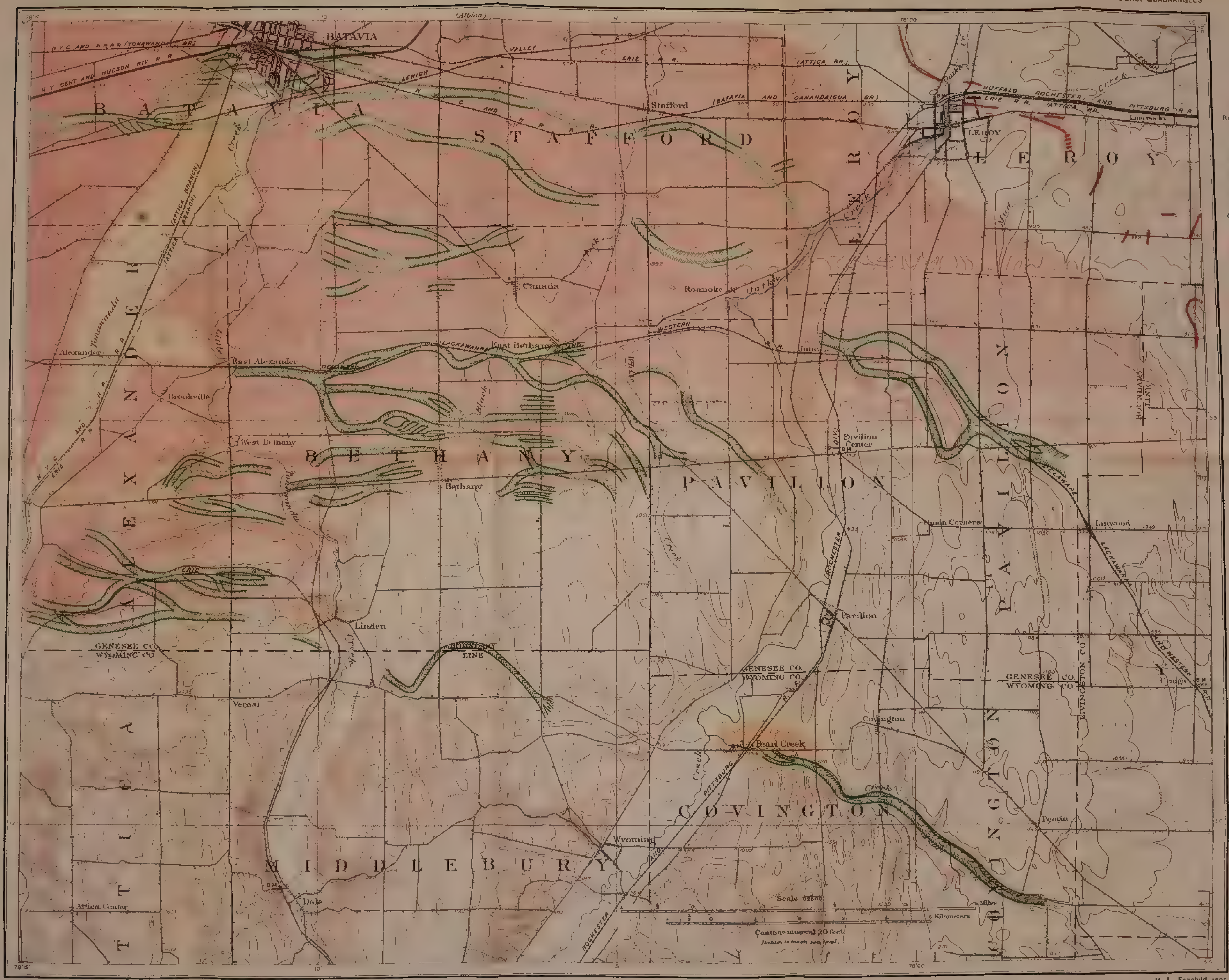


EFFECTS OF GLACIAL WATERS,
SHERIDAN TO GOWANDA

EFFECTS OF GLACIAL WATERS, GOWANDA TO ORCHARD PARK

WORK OF GLACIAL WATERS, ORCHARD PARK
TO BATAVIA

H. L. Fairchild 1905



GLACIAL STREAM CHANNELS, ATTICA TO GENESEE VALLEY