CORRELATION OF BEACHES WITH MORAINES IN THE HURON AND ERIE BASINS.

FRANK LEVERETT.

ABSTRACT. This paper attempts to bring down to date the knowledge concerning the beaches and correlative moraines of the Huron and Erie basins in Ontario as well as in Michigan, Ohio, Pennsylvania and New York. It also calls attention to errors that appear in earlier papers and reports on this subject. It covers the entire series of beaches from the Maumee down to the Algonquin. The latter is not included since Lake Algonquin extended over the Lake Superior and Lake Michigan basins as well as the Lake Huron basin. This is a companion paper to one by the late Frank B. Taylor "Correlatives of the Port Huron morainic system of Michigan in Ontario and western New York," unpublished at the time of his death. Both papers in essentially this form were presented at the Annual Meeting of the Michigan Academy of Sciences in March, 1933.

INTRODUCTORY STATEMENT.

THE first paper by the writer on the subject of correlation of moraines with beaches was read before the Wisconsin Academy of Sciences in December 1891, and pertained to the moraines and beaches on the south side of the Lake Erie basin. The paper and accompanying map appeared in This Journal, April 1892. A second paper in the same Journal in July 1895 extended the correlation eastward into western New York. A few years later, in 1902, the subject was more clearly treated in a monograph on the "Glacial Formations and Drainage Features of the Erie and Ohio Basins."[1] The correlative moraines of beaches found in Ohio and northwestern Pennsylvania there received the name "The Lake Escarpment Morainic System." It was shown that the Maumee beaches dwindle in strength from Cleveland, Ohio, eastward in passing from the outer to the inner members of the morainic system. It was also shown that the Whittlesey beach dwindles from Dunkirk, New York, eastward in passing from the outer to the inner members of a later series of moraines, the Gowanda, Hamburg and Marilla

[1] Monograph XLI, U. S. Geological Survey. Especially pp. 651-652, 726-740, and Pls. xviii and xix.

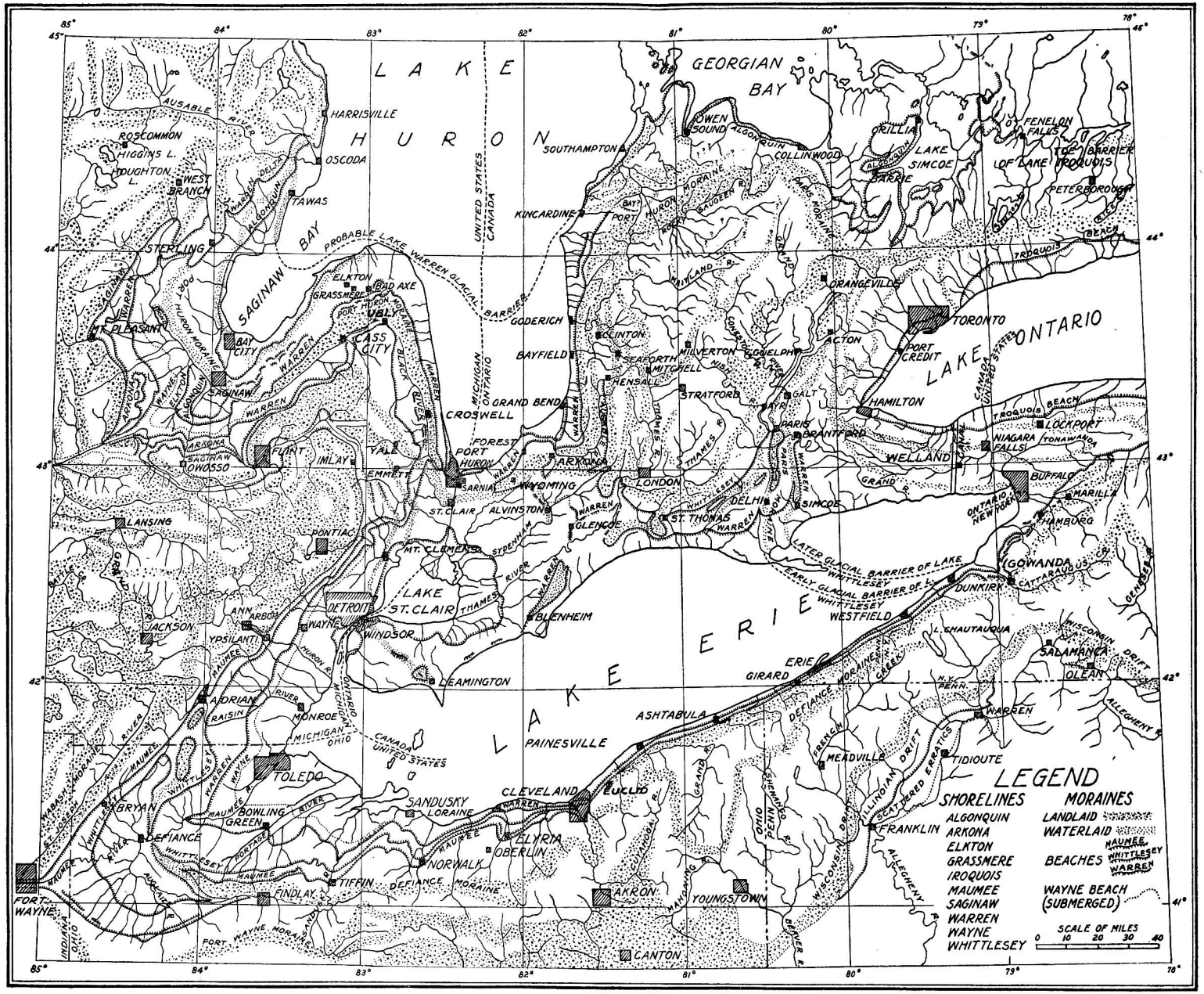

Fig. 1. Pleistocene Beaches and Moraines in the Huron, Erie and western Ontario Basins, by Frank Leverett.

moraines. The upper Warren beach was found to correlate with the Alden and Batavia moraines west of the Genesee valley in New York, while the lower Warren found its ice barrier east of that valley. The field work on which that report was based was completed in 1895.

Five years later systematic field work on the beaches and correlative moraines of southeastern Michigan was taken up. In this study the late Frank B. Taylor was an associate. It was he who worked out an interesting relation of the Port Huron morainic system and its attendant water body, Lake Whittlesey, to the outlying Arkona beaches. The Arkona beaches were found to antedate the higher-lying Whittlesey beach, and to have been washed down and rendered obscure by the waters as they rose to the higher level, except in a protected situation just outside the Port Huron morainic belt, in a bay of Lake Whittlesey in St. Clair and Sanilac counties, Michigan.

Maumee beaches were found to be present in weak development on the Goodland, Berville, or Mount Clemens, moraines in St. Clair County, showing that they were formed near the end of that lake stage. The next later moraines, Emmett and Yale, seem to have been formed as the lake was being drained down to the Arkona level, as no Maumee beach has been found on them. These results were obtained by 1903, but it was 30 years later before the writer had opportunity to identify the correlative moraine of Lake Maumee on the east side of the Lake Huron basin, in Ontario. It was also determined about 1903 that Lake Warren extended into southeastern Alcona County, Michigan, on the west side of the Huron basin, and correlates there with the Tawas moraine. But the extent of Lake Warren and its correlative moraine east of the Huron basin was not determined until 30 years later.

Some field work was carried on by Taylor in the part of Ontario between the Erie and Huron basins in 1908 and 1909, chiefly on the distribution of the morainic systems, with only incidental attention to the correlative beaches. He also made a special investigation of the district around Niagara Falls, the results of which are presented in the Niagara Folio,[2] while the results of the study of moraines are presented in the Transactions of the Canadian Institute.[3] An interpretation as to the ice barrier of Lake Whittlesey presented in the Niagara

[2]Folio 190, U. S. Geological Survey. Published in 1913.

[3]"Moraine systems of southwestern Ontario." Trans. Canadian Inst., Vol. 10, pp. 57-79, with map. Published in 1913.

Folio was later recognized by him to be incorrect, and his revised interpretation, presented in a paper before the Michigan Academy of Sciences in 1933[4] now appears with the present paper.

During the past five years the present writer has accompanied Prof. Donald C. MacLachlan of Wayne University, Detroit, as an adviser in his studies of glacial features and tilting of shore lines of southwestern Ontario and southeastern Michigan, the results of which are the basis for a thesis submitted by MacLachlan as a candidate for the degree of doctor of philosophy from the University of Michigan. This has given the present writer opportunity to obtain the data necessary to make the correlations of moraines with the several shore lines of glacial lakes in Ontario which are here discussed. These interpretations only touch in a minor way on the comprehensive study of remarkable variations in trend of tilt lines that forms the basis of MacLachlan's thesis. The writer takes this occasion to express his appreciation of the advantages derived from this association with Professor MacLachlan in rounding out the subject embraced in the present paper.

BEACHES OF LAKE MAUMEE.

In the Erie basin there are three members, known as the upper, middle, and lower Maumee beaches. On the south side of the basin the upper beach has been found only where it lies outside the Defiance moraine, from Findley, Ohio, westward to the Fort Wayne outlet. Its highest altitude, 790 feet, is only 10-15 feet above that of the middle beach. A different condition is found on the west side of the basin. There the upper beach is present the entire distance of 165 miles from the Fort Wayne outlet to the Imlay outlet. It is present on the inner as well as the outer slope of the Defiance moraine, and also on the inner slope of the Birmingham moraine. In the first 35 miles northeastward from the Fort Wayne outlet the interval between the upper and middle beaches increases about ten feet, and the upper one reaches the 800-foot contour about six miles southwest of Bryan, Ohio. It is generally between 800 and 805 feet from there to Birmingham, Michigan. The altitude of the middle beach is between 765 and 780 feet from the Fort Wayne outlet clear to Birmingham. The upper beach

[4] "Correlatives of the Port Huron morainic system of Michigan in Ontario and western New York."

rises from 805 feet at Birmingham to about 850 feet at the head of the Imlay outlet, while the middle beach rises from 780 feet to 820 feet, thus nearly paralleling the upper beach in this tilted portion. There is less increase in the interval between these beaches in the 130 miles from Bryan, Ohio, to Imlay, Michigan, than in the first 35 miles from the Fort Wayne outlet. The lowest Maumee is generally 20 feet lower than the middle beach and weaker.

Eastward from Findlay, Ohio, to the vicinity of Cleveland there are two beaches, the middle and lower Maumee. The higher and stronger one is generally between 770 and 780 feet, and the lower one between 750 and 760 feet. From Cleveland eastward the higher one becomes weak, and seems to be exposed no farther than the west end of the Euclid moraine, ten miles east of Cleveland. The lower one is traceable to the vicinity of Girard, Pennsylvania, in rather weak form. It is present on the inner slope of each of the several members of the Lake Escarpment morainic system, as shown on Plate xviii on Monograph 41, U. S. Geological Survey. This morainic system thus correlates with the closing part of Glacial Lake Maumee, as previously noted. The lower beach shows a slight rise eastward from near Ashtabula, Ohio, and is between 770 and 780 feet near its terminus. The rate of tilting is similar to that of the Whittlesey beach, and the interval between them about 20 feet, as it is in the untilted part to the west.[5]

In Michigan the moraines that correlate with the middle and lower Maumee beaches lie east of the head of the Imlay outlet, and circle around on the east, north and west borders of the outlet channel. As indicated in Fig. 6, Monograph 53, U. S. Geological Survey, the Imlay moraine seems to correlate with the upper beach of Lake Maumee. The Goodland Mount Clemens and Emmett moraines appear to be the correlatives of the middle and lower Maumee beaches, and the Yale moraine the ice barrier at the end of Lake Maumee. On the west slope of the "Thumb"[6] the Flint moraine may correlate with the Imlay, for

[5] As indicated in some of my earlier publications, certain features in southeastern Michigan suggest an early Lower Maumee stage preceding the Middle Maumee stage, which theoretically found an outlet across the "Thumb" north of the Imlay outlet. A readvance of the ice sheet then completely concealed it. Outflow through the Imlay outlet was reestablished, probably at the level of the Middle Maumee beach. The channel was then cut down about to the level of the Lower Maumee. Probably it was this revived Lower Maumee stage that extended to Girard, Pennsylvania.

[6] The peninsula between the Saginaw and Huron basins.

it was formed long before the Imlay outlet ceased operation. With the retreat of the ice barrier from this moraine the course of the Imlay outlet shifted from a position outside the Flint moraine to a northwest course through the moraine into Lake Saginaw. It built a conspicuous delta there which may correlate with the middle and lower beaches of Lake Maumee. The Goodland and Mount Clemens moraines, which lie east of the Imlay moraine, have the middle Maumee beach in weak form on their crests, and are thus rather close correlatives of that beach. Before the end of Lake Maumee the ice barrier had receded far enough north on the east side of the "Thumb" to bring a tributary outlet into operation that comes into the Imlay channel from the east at North Branch. It is probable that this correlates with the lower beach. The bed of the main channel at its head near Imlay is also low enough to have served as a line of discharge down to the end of Lake Maumee. The bed of the outlet there is about 790 feet, at the bottom of the peat that now covers it. The lower Maumee beach, being about 20 feet below the middle beach, its level should be 795-800 feet at the head of the Imlay outlet. It is not a strong beach anywhere in its entire course in Ohio and Michigan, and apparently was a rather short-lived lake stage.

It now seems probable that the ice sheet had shrunk at least to the position of the Emmett moraine, and possibly to the Yale moraine at the end of Lake Maumee. The Emmett moraine is distinctly traceable to the north side of Lake St. Clair at New Baltimore, Michigan, and may embrace the ridge on the west side of the lake in Grosse Pointe. It does not seem to be definitely developed on the east side of Lake St. Clair. The Yale moraine is strongly developed as far south as Avoca, in St. Clair County, and then continues in a southeast course to the head of Pine River, and there passes under the Port Huron moraine. That moraine seems to have covered it south from there in Michigan, and also for many miles in the adjacent part of Ontario. Its first appearance outside the Port Huron morainic system in Ontario is near Clinton. It was noted there by Taylor, and called the Clinton moraine.[7] It is only exposed for a few miles there, and passes under the Port Huron again a few miles north.

That the Clinton moraine is the ice barrier of Lake Maumee is inferred from the presence of a beach just outside of it at

[7] Trans. Canadian Inst., Vol. X, p. 12, and map, 1913.

Hensall, Ontario. This is much too high to be referred to Lake Whittlesey, and seems to be the product of a bay of Lake Maumee that occupied the Au Sable Valley, here called Au Sable Bay. The altitude of the beach is 910 feet. It is about 85 feet higher than the Whittlesey beach directly opposite Hensall. These beaches show a similar interval in St. Clair County, Michigan.

Lake Maumee appears to have covered the Thames valley and border districts to within a few miles of London, and to have covered extensive areas southeast of that city. The elevated moraine southeast of St. Thomas probably stood above it, but no attempt has been made to determine the extent of Lake Maumee in Ontario.

THE LAKE WHITTLESEY BEACH.

Three beaches on the south shore of Lake Erie near Cleveland, Ohio, brought to notice by Col. Charles Whittlesey a century ago,[8] seem to have been the middle Maumee, Whittlesey, and Warren beaches. At a similar date the Whittlesey beach had been traced by Bela Hubbard for 60 miles in southeastern Michigan, and its position in Wayne County shown on a map.[9] The following year Hubbard mapped its course across Macomb into St. Clair County. He also noted the beach of Lake Wayne at Wayne village.

In 1872, N. H. Winchell gave the beach of Lake Whittlesey the name "Belmore Ridge," from a small village in northwestern Ohio.[10] This was the name commonly applied to it for a quarter century. But in 1897 Taylor suggested the name Whittlesey for the lake and its beach.[11] Since then the name Belmore has dropped out of use.

It was known for at least a quarter century that the level of Lake Whittlesey was below that of the Fort Wayne outlet of Lake Maumee, before Taylor found the place of its discharge at Ubly, Michigan, and brought it to notice in Vol. 8 of the Bulletin of the Geological Society of America. In the same paper Taylor outlined the course of the Whittlesey beach northward from the previous limit of mapping, in St. Clair County,

[8] Second Ann. Rept. Geol. Survey of Ohio, p. 55, 1838.

[9] Third Ann. Rept. to Douglas Houghton. House Doc. No. 8, pp. 102-111, 1840.

[10] Proc. Am. Assn. for Adv. of Science.

[11] Bull. Geol. Soc. America, Vol. 8, 1897.

across Sanilac County to the Ubly outlet, in southern Huron County, Michigan.

The present writer's work on the Whittlesey beach has been chiefly on the part east of Elyria, Ohio, mostly in the 1890's, and published in 1902. But the Berea and Cleveland quadrangles were reviewed in 1920, and results published in 1933.[12] In Monograph XLI, published in 1902, it was noted that the Whittlesey beach begins to dwindle near Dunkirk, New York, near the western terminus of the Gowanda moraine, but appears in weak form on the inner slope of two later moraines, the Hamburg and Marilla.[13] These moraines are interpreted to be the correlatives of Lake Whittlesey. But in Monograph LIII, of which the writer was joint author with F. B. Taylor, there appears a very different interpretation of the ice barrier of Lake Whittlesey, written by Taylor, which escaped our attention when reading the proof. He put the ice barrier near the position it held at the time of Lake Warren, and interpreted the upper Warren beach to be the beach of Lake Arkona (See pp. 373-376). Having later recognized the error of this interpretation, he prepared the paper "Correlatives of the Port Huron morainic system in Michigan in Ontario and New York" that is presented here as a companion paper.

On the south shore of Lake Erie, the Whittlesey beach begins to rise in northeastern Ohio. It is between 735 and 745 in the untilted part in northern Ohio and southeastern Michigan. The tilt starts near Birmingham, Michigan. There is a rise of 25 feet between Birmingham and Avoca, or to 765 feet, in a distance of 40 miles, and 35 feet to the Ubly outlet in a distance of 50 miles in a nearly due north course. The course from Birmingham to Avoca is northeastward. In northeastern Ohio the beach rises to 750 feet at the line of Ohio and Pennsylvania. It rises steadily from there northeastward to 900 feet at its terminus near Marilla, New York, a rise of 150 feet in a distance of 120 miles. On the north side of Lake Erie the beach reaches an altitude between 875 and 900 feet near Paris, Ontario. It is about 40 feet higher in its most northern exposures near Paris than at its southernmost exposures near Delhi and Simcoe. As indicated in Taylor's paper, Whittlesey waters were up to 820 feet in Au Sable Bay where the border drainage of the Port Huron morainic system reached the lake.

[12] Bull. 818, U. S. Geol. Survey, 1933.

[13] See pp. 651-652, 726-740, and Plates xviii and xix.

THE ARKONA BEACHES.

Although the Arkona beaches have a lower altitude than the Whittlesey beach they were formed by a lake that antedated Lake Whittlesey. The lake was also more extensive than Lake Whittlesey, for it occupied the Saginaw basin and southern part of the Huron basin, and probably extended farther east in the Erie basin than Lake Whittlesey. Its extent seems to have been as great as that of Lake Warren, in which case it extended into the western part of the Lake Ontario basin. The position of its ice barrier is not definitely known, for it was within the limits of the Whittlesey ice barrier.

The readvance of the ice border to the limits of the Whittlesey ice barrier on the "Thumb" of Michigan initiated a higher lake in the district to the east, with a level about 30 feet above Lake Arkona, but did not affect the level of the part of Lake Arkona in the Saginaw basin. This higher body of water, Lake Whittlesey, discharged through the Ubly outlet and down Cass River to the smaller Lake Arkona at Cass City, Michigan, and built a conspicuous delta at that place. The outlet of Lake Arkona, both at its greatest extent and its later reduced area, was through Grand River to Lake Chicago, in the Lake Michigan basin. The outlet was cut down about 15 feet by the discharge from Lake Arkona. This led to the development of three beaches, separated by intervals of less than ten feet. In the untilted area the upper one is about 710 feet, the middle one between 700 and 705 feet, and the lower one about 695 feet.

The name Arkona was applied to the lake by Taylor,[14] on the supposition that it formed the beach at Arkona, Ontario, previously brought to notice by J. W. Spencer. That beach at 785 feet is now known to be the beach of Lake Whittlesey. The beach of Lake Arkona, at 750 feet, comes within about two miles of Arkona, and is well preserved there, just outside of the Port Huron moraine. This fact, and there being no other village than Arkona so near it, makes it seem unnecessary to find a different name for the lake.

In the paper just noted, Taylor presented the interesting evidence that the Arkona beaches suffered little or no modification by the waters of Lake Whittlesey where they are close to the Port Huron moraine in St. Clair and Sanilac Counties, but are washed down and made obscure as they pass away from

[14] Taylor, F. B.: Relation of Lake Whittlesey to the Arkona beaches: Seventh Ann. Rept. Mich. Acad. Sci., pp. 30-36, 1905.

the border of the moraine, wave action there having been more effective. The same condition of preservation is exhibited near Arkona, Ontario. The relation of the Arkona beaches of the Port Huron morainic system in St. Clair and Sanilac Counties, Michigan, and the narrowness of the body of water in the bay west of the morainic belt is set forth on a map forming Fig. 5 of Monograph LIII, U. S. Geological Survey. The map shows the weak, or interrupted, character of the Whittlesey beach in this bay. There was also a narrow bay near Arkona, between the Port Huron morainic system and the Seaforth moraine, in which the Arkona and the Whittlesey beaches are present.

The Arkona beaches in Michigan are so fully described by Taylor in Monograph LIII (pp. 362-373) that only a few lines seem necessary to bring the subject up to the present state of knowledge. The recent topographic maps with five-foot contours that embrace the part near the outlet, serve to show the amount of tilting the shore lines have experienced. The highest Arkona beach is 725 to 728 feet, or 15 to 18 feet higher than in the untilted part. An earlier beach in the Saginaw basin, that of the Early Lake Saginaw, is 735 to 740 feet. As indicated above, the Imlay outlet of Lake Maumee formed a large delta in this lake a few miles northwest of Flint. The uplift of this beach probably is fully as much as that of the highest Arkona beach. Altitudes given by Taylor near Croswell (p. 375) based on aneroid readings, have been confirmed by levels run by MacLachlan, the highest beach of Lake Arkona being 753 feet, and the second beach 737-741 feet in the two to three miles south from Croswell. The tilting here is about 40 feet in a distance of 60 miles from Birmingham, where the tilting begins.

As indicated in the discussion of the Whittlesey beach, the interpretation of the Arkona beach in Ontario and New York presented by Taylor in Monograph LIII was recognized by him some years ago to be erroneous. On Plate xviii, the profile carries the name "Arkona beaches" where it should be "Upper Warren beach" from near the State Line of Pennsylvania and New York eastward to Alden, New York. The errors are chiefly on pages 373-376. That the beach there classed as Arkona is the Upper Warren beach has been maintained by Fairchild in several of his papers. The present writer also made the same interpretation in Monograph XLI, published in 1902. A recent paper by Fairchild, entitled "Closing stage of New York glacial history," while correct as to the "First

Lake Warren," brings in a complicated history between it and the "Second Warren" for which there seems no necessity; the two beaches are accounted for by the deepening of the Grand River outlet in Michigan, through which the lake had its discharge, and the "Second Warren" is a close successor of the "First Warren."[15] There was no shifting of the outlet.

THE LAKE WARREN BEACHES.

The beaches of Lake Warren stand next below those of Lake Arkona, but it followed Lake Wayne, which stood about 20 feet lower than the upper Warren beach, and had an eastward discharge to the Mohawk-Hudson valley and Atlantic ocean. A readvance of the Ontario ice lobe blocked this eastward line of discharge, and reestablished a westward discharge through the Grand River outlet in Michigan to Glacial Lake, Chicago, and thence to the Gulf of Mexico. Lake Warren covered the basin of Lake Erie, a large part of Lake Huron, including Saginaw Bay, and much of the lowland which lies between Lake Huron and Lake Erie. It also included a small part of the Ontario basin, outside the present lake, and had eastward extension beyond the Genesee River in New York.

At the Cleveland meeting of the American Association for Advancement of Science in 1888, J. W. Spencer gave a paper "Notes on the Origin and History of the Great Lakes of North America" in which he made "Warren Water" cover the whole Great Lakes region, but regarded it as marine. In 1897, Taylor, in a paper "Correlation of Erie-Huron Beaches with Outlets and Moraines of Southeastern Michigan."[16] suggested the present more restricted use of the name, and classed it as a glacial lake.

The upper and main Warren beach was recognized as a "lake ridge" at an early day along the south shore of Lake Erie, and was known as the "North Ridge." It constitutes a part of Gilbert's fourth beach in northwestern Ohio, a sandy belt with very little gravel, which runs thence to a large sandy delta of the Raisin River in eastern Lenawee County, Michigan. It varies greatly in strength in southeastern Michigan, being weak where there were wide shallows in front of it. It has strong development as a gravel ridge on the inner slope of the Port

[15] Bull. Geol. Soc. America, Vol. 43, pp. 603-626, especially 607-612, 1932.

[16] Bull. Geol. Soc. America, Vol. 8, pp. 56-57, 1897.

Huron morainic system northward from Port Huron, and continues strong on that slope as the morainic belt curves around into the Saginaw basin about to Vassar, Michigan. It then becomes sandy around the west end of the Saginaw basin, and in much of its course northward on the west border of the basin. It is distinctly traceable to a large delta of Au Sable River in northeastern Iosco County, Michigan. It there lies just outside the Tawas moraine, which is interpreted to mark the correlative ice barrier. Possibly the Bay City moraine also correlates with this lake stage.

On the east side of Lake Huron the Warren beach extends north a little beyond Kincardine, and there finds its correlative ice barrier in what Taylor termed the "Kincardine moraine strands."[17] On that side of Lake Huron the lower Warren beach is present clear up to the ice barrier, and is better developed on the whole than on the west side of the basin, but is much weaker than the upper Warren beach. The interval between the beaches is usually less than 20 feet. They lie on the inner slope of the Port Huron morainic system from near their north end down to the place where the morainic belt becomes waterlaid, near Wyoming, Ontario. They cross there to the outer slope and run eastward a few miles before resuming a southward course. Near Walnut the Seaforth moraine is crossed, but a conspicuous bar follows the crest of the moraine southward to Alvinston. A bay east of the moraine extended several miles up Sydenham valley. The shore then leads away from the valley to Aplin as a definite gravel ridge, but is ill-defined between Aplin and Thames River. A delta on the river below Delaware has an altitude above 725 feet. A sandy strip extends from Aplin to Glencoe, connecting there with a strong gravel bar that runs south nearly to Thames River.

South of Thames River the beach is well-defined on the inner slope of the St. Thomas moraine from Dutton eastward to Kettle Creek near St. Thomas, and also around the prominent part of the St. Thomas moraine southeast of the city. Eastward from there to Simcoe the Warren shore is in a sandy strip without definite shore features.

From Simcoe northward the beach is finely developed on the inner border of the Galt moraine, past Waterford, Brantford and St. George, to Sheffield, five miles southeast of Galt. From there the course is eastward to a moraine on the Niagara

[17] Trans. Canadian Inst., Vol. X, p. 13, 1913.

Escarpment near Carlisle which appears to mark the ice barrier of the lake. This ice barrier overlapped the escarpment and covered the site of Niagara Falls, from Copetown, Ontario, eastward far into New York. As determined by Fairchild, some 40 or more years ago, Lake Warren had an extension eastward as a narrow strip of water south of this ice barrier to points a few miles beyond the Genesee valley.[18]

South of the Thames valley there were two prominent islands in Lake Warren. One about 25 miles long and less than five miles in average width, starts near the south bluff of the river opposite Bothwell and runs in a course west of south past Ridgetown and Blenheim to the Lake Erie shore. This ridge may be a continuation of the Seaforth moraine, and also an interlobate formed by the union of the Huron and Erie lobes. In his paper in the Transactions of the Canadian Institute Taylor applied the name Blenheim to it (pp. 13-14, and map). The other island covers a few square miles northwest of Leamington, Ontario, Taylor suggested that this may correlate with the Blenheim moraine, the gap between them having been cut away by the encroachment of Lake Erie on the part of its north shore between them. The Huron lobe evidently reached this island of Lake Warren near Leamington, and the Erie lobe was here united with the Huron lobe to form what has been termed the "Detroit Interlobate" moraine, that runs northwest from Leamington to Detroit. The glacial striae near the southwest border of the moraine in the Sibley quarries have a bearing to the northwest showing clearly that they are the product of the Erie lobe, while moraines coming down to Detroit from the north, the Mt. Clemens and the Emmett, were clearly the product of the Huron ice lobe.

As Lake Warren extended much farther north on the east side of the Huron basin than was assumed at the time Monograph LIII was published it becomes necessary to call attention to errors in Fig. 6, p. 370, in the placing of ice barriers in the Huron basin. The ice barrier of Lake Warren was probably about in the place assigned to the ice barrier of Lake Lundy. The Bay City moraine seems to have run northward to the point of the "Thumb" and thus reached about the position there which the Lundy barrier is given in Fig. 6.

There is a very prominent mass of gravelly drift, called Font Hill, located 12-15 miles west of Niagara Falls, with points

[18] Bull. Geol. Soc. America, Vol. 8, pp. 274-277, 1897.

above the 875-foot contour, or fully 200 feet above the surrounding country. The Warren beach is well defined on its south side at about 825 feet, with a wave-washed slope below it. The beach is not so well defined on the north slope. This may be due to the persistence of the ice barrier there during the development of the beach. The ice barrier certainly was near by, and was likely to have prevented any effective wave work there.

The upper Warren beach maintains an altitude of 675-680 feet in the untilted part of its course from near Birmingham, Michigan, southward and eastward into the northeast part of Ohio. The lower Warren in this part is generally a slight notch cut into the inner slope of the upper Warren and so is not differentiated from it. In Cleveland, however, both beaches have long been recognized, the upper Warren being known as the Woodland Avenue beach, while the lower Warren is known as Euclid Avenue beach. The Woodland Avenue beach is about 680 feet, and the Euclid Avenue beach is ten to twelve feet lower, one bench mark on it being 668 feet.

The Warren beaches where tilted are closely parallel to the Whittlesey, the interval between the upper Warren and Whittlesey being about 50 feet in Ontario and in western New York. The upper Warren terminates near Alden, New York, and is slightly above 860 feet there. The lower Warren is 848 at Crittenden, near the same isobase. The lower Warren reaches an altitude of 920-925 feet on Baker Hill in the south part of the Fairport, New York quadrangle, in southeastern Monroe County, the easternmost point the beach has been recognized. This is about 50 miles, nearly due east from Crittenden. As the tilt line here has a NNE trend, this difference of about 75 feet falls far below the full amount of uplift. The trend of the Warren beaches from northeastern Ohio to Alden and Crittenden, New York, is about northeast, thus approaching the trend of the tilt line. The rise of 180 feet is made in a distance of about 150 miles.[19]

On the north side of Lake Erie the Warren beaches on the island near Leamington show no tilting, the upper beach being 675-680 feet. But there is a rise to 700 feet at the south end of the long island at Blenheim. The lower beach there is

[19] A detailed discussion of the beaches of western New York by Fairchild is given in Bulletin 106 of the New York State Museum, published in 1907. His latest paper is found in the Bulletin of the Geological Society of America, Vol. 43, published in 1932.

about 680 feet. It is a cut bluff on the west side of the island from Blenheim northward past Ridgetown, but is a gravelly beach on the east side, facing Lake Erie. The upper beach also is gravelly. At the north end of the island the upper beach reaches 725 feet in a few places. The bar near Glencoe, on the north side of the Thames valley is about 730 feet, and the bar at Alvinston has nearly the same altitude, for the trend of the isobase in that district is about NNW. The lower Warren is finely developed near Alvinston, and is above the 700-foot contour. The upper Warren beach is only 700 feet where it crosses over the Port Huron morainic belt near Wyoming. It reaches 725 feet near Forest, and rises with quite irregular rate northward from there to its terminus, where its altitude is 880 feet.

The description in the preceding paragraph pertains to the beaches as developed within the district covered by the Huron ice lobe. The Erie lobe, however, may have reached the eastern and southern sides of the islands south of the Thames valley, as suggested above. The upper Warren beach at the crossing of the St. Thomas moraine near Dutton is about 725 feet. It rises to about 750 feet near Simcoe, to 800 feet near Brantford, and to a little above 850 feet at the northeast end, by the glacial barrier. For some miles outside the glacial barrier the lake waters swept the till deposits away and exposed the limestone ledges on all the prominent places, but without forming a definite beach on their borders. But from near St. George southward a definite beach of sandy and gravelly material is generally present. Note has already been made of the definite beach and wave-washed slope on the south side of Font Hill, near Niagara Falls. The beach there is about 25 feet lower than at the terminus by the ice barrier northwest of Hamilton, Ontario. Perhaps it is the lower Warren beach.

In Michigan the untilted upper Warren beach ranges from 675 to 685 feet. Its crest in the Ann Arbor quadrangle is very close to the 680-foot contour. Near the Clinton River the upper and lower Warren beaches are finely developed, and show a difference of about 15 feet in altitude. The tilting sets in near Utica, on the east side of Clinton River. Near Lenox the two ridges have altitudes of 700 and 690 feet. At Goodells the upper beach is 707 feet, and near Abbottsford 708 feet. On the inner slope of the Port Huron moraine the altitude is 709 feet on the Pere Marquette Railway east of Atkins. MacLachlan's levels on the upper Warren north from here show

considerable irregularity in the rate of rise. The upper Warren reaches 765 to 770 feet at its northernmost points on the "Thumb," near Bad Axe, Michigan. It decreases in altitude southwest from there and crosses over the Port Huron moraine at Vassar at about 700 feet. Outside this moraine in Tuscola and northwestern Genesee counties the Warren beaches are generally sandy, with dunes on them, making it difficult to determine their exact altitude. On entering southern Saginaw County definite gravel beaches appear which are traceable westward to the head of the Grand River outlet, near Maple Rapids. This part shows two and in places three Warren beaches, the highest being near the 690-foot contour, and the lowest about 675 feet, with a middle one at 680-685 feet. The bed of the outlet was cut down to about 660 feet, by the time the Lake Warren waters ceased flowing through it, as shown by the contours of the Elsie, Michigan, topographic map. The Perrinton map shows the beaches where they turn into the Grand River outlet. The advance sheet of the Merrill quadrangle shows the Warren beach to be generally below the 690-foot contour as far north as Merrill, but is above that contour in the northwest part of the map. In the Shepherd quadrangle it is in a sandy tract as far north as Salt River, and complicated with dunes. But north of Salt River it catches the 695 and 700-foot contours. There are two ridges less than a mile apart, each 695-700 feet.

Lake Warren extended up the Tittabawassee valley a few miles beyond Lat. 44° on the outer side of the Port Huron morainic belt. Its west shore passed near Beaverton, at about 710 feet. The shore doubled back a few miles on the outer slope of the morainic belt, and then crossed over it near Rhodes. Its altitude there is about 730 feet. It is between 730 and 740 feet in the northwest township of Bay County, and 745 feet at Sterling, on the Michigan Central Railway. The altitude increases about 50 feet in the 35-40 miles northeastward to the edge of the great delta on the Au Sable River. This delta spread out to a width of 15 miles on the borders of Lake Warren. The lake extended only a few miles beyond it into southeastern Alcona County. Its altitude there probably is slightly above 800 feet. The 800-foot isobase runs ESE from here to Goderich, Ontario, on the east side of Lake Huron. The tilt line thus has a NNE trend in harmony with what was anticipated before the shore had been completely mapped on the east side of Lake Huron.

THE WAYNE BEACH.

The Wayne beach is below the level of the Warren beaches, but it seems to antedate them, as it shows clear evidence of submergence and modification by the Warren waters. Its outlet has not been certainly fixed by continuous tracing, but it seems to have led eastward through some of the channels south of Syracuse, New York, into the Mohawk Valley. It is a little too low to have drained through the Grand River outlet its beach being 655-660 feet, though that outlet was cut down later about to its level by the waters of Lake Warren. As previously stated, the Wayne beach is named from the village in Wayne County where it was noted by Bela Hubbard about a century ago. The position of its ice barrier seems to have been along the south side of the Ontario basin, but a readvance of the Ontario ice lobe has concealed any moraine formed by it.

The Wayne beach is prevailingly of sandy character throughout its course from the Maumee River in Ohio northward across Monroe, Wayne and southeastern Oakland counties in Michigan. In places, as at Wayne and Royal Oak, there are three constituent ridges, all at the same altitude, occupying a strip from one-half mile to a mile in width, that stand three to five feet above the ground between them. The sandy belt in which the beach was developed is in places three to five miles or more in width. The beach is generally near its outer border, and the sand extends down to lower levels on the lakeward side. After passing Clinton River in western Macomb County the sandy belt becomes less conspicuous and constant. The beach also becomes more difficult to trace. So far as identified, it maintains an altitude about 20 feet below the upper Warren beach, and is within ten feet of the level of the lower Warren. On slopes as steep as prevail on the inner border of the Port Huron morainic belt in St. Clair, Sanilac, Huron and Tuscola counties it can scarcely be separated from the lower Warren beach. In the Saginaw basin south and west of Cass and Tittabawassee rivers the surface is prevailingly sandy at the level of the Wayne beach, and it is complicated with ridges due to wind action, and difficult to identify. On the inner slope of the Port Huron morainic belt in Bay, Arenac and Iosco counties the surface is prevailingly sandy at the level of this beach. No continuous tracing was attempted in the Saginaw basin.

No systematic tracing of the Wayne beach was attempted on the south side of the Erie basin in Ohio and States farther east. Nor was a tracing attempted in Ontario.

BEACHES BELOW THE WAYNE BEACH.

There are two beaches in Michigan between the Wayne and the Algonquin known as the Grassmere and Elkton beaches which evidently were formed by a lake that had eastward discharge similar to that of Lake Wayne. They are both weak, and difficulty has been found in identifying them in parts of their course in spite of the fact that their altitudes are known where not affected by tilting. The Grassmere stands about 640 feet and the Elkton 620 feet above sea level. They are thus about 40 and 60 feet respectively below the upper Warren beach. Their tilting begins near the line at which the higher beaches begin to rise, or not far from Birmingham, Michigan. But the rate of rise compared with that of the Warren beach has not been accurately determined. Continuous tracing of these beaches has not been attempted, either on the north or the south side of the Erie basin, or on the east side of the Huron basin. It can be inferred that tilting in the Erie basin is restricted to the east part, the part in which the higher beaches have been tilted.

In the discussion of these beaches by Taylor in Monograph LIII, U. S. Geological Survey, the name Glacial Lake Lundy was applied to the body of water which formed them, that name being taken because Spencer had noted a beach at Lundy's Lane near Niagara Falls at an early date. He considered this beach the same as the Geneva or Lake Dana beach brought to notice later by Fairchild, who traced its course much farther in New York than Spencer had done with the Lundy beach. Fairchild estimated the Lake Dana plane to be about 180 feet below the Lake Warren plane. The beach at Lundy's Lane is 150 feet below the Warren beach on Font Hill. Fairchild noted that gravelly bars are found at widely different levels in western New York between the Warren beaches and the shore of Lake Erie, but no continuous shore line. He discusses them as "Work of subsiding waters."[20] One of the best defined bars runs west for two miles from Elma on the north side of Buffalo Creek, and continues nearly a mile farther on the south side. Its altitude is above the 760-foot contour, with a 767 bench mark north of Elma. This is 60 feet below the Warren beach at Elma Center, thus showing the same interval as the Elkton beach in Michigan. It is fully 80 feet above the Lundy beach of Spencer near Niagara Falls (678 feet), and the Dana beach

[20] Bull. 106, New York State Museum, pp. 74-76, pls. 22 and 23, 1907.

of Fairchild at Pine Hill Cemetery in the northeast part of the city of Buffalo about 680 feet. The present writer is inclined to question the correlation of the Lundy-Dana beach with the Grassmere or the Elkton beach. This doubt is strengthened by the fact that the best defined beach below the Warren on the east side of Lake Huron runs parallel with it. From Bayfield, Ontario, northward to the north side of the Lucknow topographic map, about 30 miles, an interval of 85 feet is maintained, with a rise of 65 feet in both beaches. From this it is inferred that the main part of the tilting came after the lower beach was formed. In the case of the Grassmere and Elkton beaches, Taylor was of the opinion that they exhibit some splitting near the north end of the "Thumb," that called for uplift during their development.

In view of the great distance between the Michigan and the New York districts, and the weak and discontinuous condition of the beaches that lie between the Warren beach and the present lakes, it seems hazardous to attempt definite correlations.

DEVELOPMENT OF THE ST. CLAIR VALLEY

An interesting record of the transition from a strait to a well established river at the south end of the Huron basin was presented by Taylor in Monograph LIII, U. S. Geological Survey, pages 472-484, Figs. 10-12. When the ice withdrew from the Port Huron moraine, ponded waters in front of it covered a wide space, from Port Huron eastward to Wyoming, Ontario, in their passage southward into the St. Clair and Erie basins, with but little effect on the part of the moraine thus submerged. But eventually as the waters lowered to the stage marked by the Elkton beach they began to cut channels or creases across the moraine, as shown in Fig. 10 of that publication. The advance sheets of maps under preparation by the U. S. Geological Survey from Lake St. Clair northward to Latitude 43° show the drains that run in these channels, and give data for the interpretation that they cut the moraine to within 35 feet of the level of Lake Huron in the ones nearest to St. Clair River, or 615 feet above sea level. The beds are thus about five feet below the level of the Elkton beach. The St. Clair River seems to have become the single line of discharge with a bed at about this level. In its passage through the moraine the river swept its channel clear of gravel bars. But on passing into the plain outside, at the site of St. Clair village, the stream spread more

widely and deposited gravelly bars. The bars in and near St. Clair village are about 605 feet. The thickest deposit noted is six feet, and some bars have but three feet. They show a slight descent down the valley to 600 feet near Robert's Landing. These deposits are correctly shown in Fig. 10 as "Gravel bars," north from Belle River, but are incorrectly classed as "St. Clair esker" farther south. The bars are in harmony with the level of Lake St. Clair at its highest stage, 595-600 feet. They probably are referable to the Early Lake Algonquin, as depicted in Plate XXI of the monograph. The swampy channels south from St. Clair village seem referable to the time following the Kirkfield stage of Lake Algonquin when the waters of Lake Algonquin were returned to the St. Clair outlet. Their volume probably was much greater than that from the Early Lake Algonquin. They evidently were abandoned before the Nipissing Great Lakes stage for they are higher than the Nipissing beach.

BORDER DRAINAGE.

Incidental reference has been made to lines of border drainage, such as the Imlay and Ubly outlets, in which the ice sheet formed one bank and outlying land the other. Such border drainage channels are conspicuous features in western New York, as noted by Fairchild in several of his papers. They there generally have a definite bluff on the landward side where they cut into and truncate prominent projecting points. In Ontario and Michigan, owing to the gentler slopes which prevail, the bluffs are seldom conspicuous features. The streams which formed these border channels generally had a more or less rapid descent, but in places, as in Kersley Lake near Flint, Michigan, they are expanded into narrow lakes with static water, with a weak beach on the landward border. The channels in New York often had expansions at the valleys crossed by them, that held static water.

DRAINAGE AS AFFECTED BY STAGNANT ICE.

Another kind of glacial drainage characterized some of the valleys south of the Erie Basin in Pennsylvania and Ohio that are tributary to the Ohio River. As suggested by the present writer in Monograph XLI in 1902, in his report on the Erie and Ohio basins (pp. 391-392), lobes of ice that were nearly or quite stagnant probably persisted in the deep valleys after the ice sheet had melted from the ridges between them, the condition

being similar to what Goldthwait has brought to notice in New England and discussed in the November 1938 issue of This Journal. In these Ohio River tributaries drift knolls appear at lower levels in the valley bottoms than the terraces on their borders. These terraces have a down-stream slope, and seem to mark lines of drainage in operation while ice still persisted in the axis of the valleys. The valley of Lake Fork of Mohican River was used in that report as an illustration of these features.

A few years later, in 1914, Prof. George D. Hubbard presented a paper in This Journal in which he announced that a glacial lake in this valley, called Lake Creigton, had tilted shore lines, with a southward slope of four feet per mile. As this valley is outside the tilted portion of the Erie basin, and as the rate of tilting announced there is far greater than had been noted in any of the shore lines in that basin, the present writer presented a criticism of Hubbard's paper in the same Journal in 1914, and called attention to his own interpretation, which does not demand tilting. The bordering waters in the valley, making their way down it among the stagnant masses of ice, may easily have descended at a rate of four feet per mile, and thus would account for the slope of their deposits. It is surprising, therefore, to find that Hubbard still clings to the idea of great tilting in that valley, as shown by his communication in the December 30, 1938, issue of Science, for he cites no evidence in support of his view, and ignores the alternative interpretation that had been brought to his attention in 1914.

ANN ARBOR, MICH.